On Decision Making Ability of Subjects with Long-term Intoxicant Consumption Using Single Trial Visual Evoked Potential Signals

Ramaswamy Palaniappan, Danilo P. Mandic and Dragan Obradovic

Abstract — **We investigate the decision making ability of subjects with a history of long-term intoxicant (alcohol) consumption in relation to short-term visual memory using P3 amplitudes obtained from single trial visual evoked potential (VEP) signals. This is made possible by means of digital filtering and principal component analysis (PCA). The results show a significantly lower P3 amplitude for these subjects as compared to controls. This electroencephalogram based analysis conforms with the common knowledge that long-term alcohol use causes permanent and negative residual effects on decision making ability related to short-term visual memory.**

Keywords — **Alcoholics, Electroencephalogram, PCA, P3, Visual Evoked Potential.**

I. INTRODUCTION

THE abuse of intoxicants, especially alcohol, is a major cause of concern, however, only in the recent years, we have seen studies focusing on the ill-effects caused by long-term use of alcohol. But there is still much that has yet to be discovered on the effect of the residual effects of excessive and long-term use of alcohol on mental activities. The nature of certain jobs (like drivers requiring to decide an action based on immediately seen road signs) makes it important to study the effects of alcohol on short-term visual memory.

Visual Evoked Potential (VEP) is the electrical potential recorded at the scalp using electrodes when the subject is evoked by an external visual stimulus. The use of VEPs in neuropsychological studies is a common practice due to their non-invasive nature [1]. One of the important applications of VEP has been in the diagnosis of various health problems related to the brain like epilepsy, depression and sleep disorders. In relation to alcoholism, VEPs have been used in analysing the electrophysiological differences in subjects with a history of long-term alcohol consumption and controls (non-alcoholics) [2, 3, 4]. These studies have used parameters like c240 and c320, P3 and N4 obtained from averaged VEP signals to study the

electrophysiological differences in these 'alcoholics' and non-alcoholics. In another study [5], the authors have used high frequency VEP signals to classify alcoholics and non-alcoholics.

The most common artifact that corrupts and makes processing of VEP signals difficult is the background or ongoing electroencephalogram (EEG). The brain is constantly engaged in other activities even while during external visual perception and this causes the ongoing EEG. In terms of signal processing, EEG signals are much higher in amplitude than VEP signals and in some cases share the same spectral bandwidth with VEP signals. Furthermore, EEG signals are highly variable. All these cause difficulty in VEP analysis. To reduce the effects of the ongoing EEG from VEP, ensemble averaging is a de facto standard in the pre-processing stage [6]. Although averaging helps to decrease the noise variance [7], it also has the unwanted effect of smoothing out the responses from multi-trial VEP signals, which are not strictly time-locked.

Here, the well known P3 component of VEP is analysed. The P3 (or P300) component is the third positive component within VEP, which normally occurs at between 300 and 600 ms after the stimulus, and reaches its maximum value in the midline parietal area of the brain [2,3]. This component is evoked in a variety of decision-making tasks, and in particular when a stimulus is recognised.

The most common method to evoke P3 responses is through 'oddball' experimental paradigm [3, 8]. Using this method, some studies have reported lower P3 amplitudes for alcoholics as compared to non-alcoholics [2, 3]. The study by Zhang *et al* [4] has shown that no significant difference exist between alcoholics and non-alcoholics using c320 (similar to P3) responses in the parietal region (like Pz). This study used modified delayed "matching-to-sample" paradigm to invoke short-term visual memory.

Therefore, this work here is novel as previous studies involving decision making ability in alcoholics used parameters from averaged VEP signals, where the specific study by Zhang *et al* [4] showed no significant difference in decision making ability related to short-term visual memory.

As such, our objective here is to show that significant difference does exist in P3 responses (specifically from the Pz channel). To achieve this, single trial analysis is adopted rather than the usual ensemble averaging. Since invoking short-term visual memory involves recognition, we set out to analyse single trial P3 amplitudes. We

R. Palaniappan is with the Dept. of Computer Science, University of Essex, Colchester, CO4 3SQ, United Kingdom. (tel: +44(0)-1206-872773; fax: +44(0)-1206-872788; e-mail: rpalan@essex.ac.uk, palani@iee.org).

D. P. Mandic is with the Dept. of Electrical and Electronic Engineering, Imperial College of Science, Technology and Medicine, London, United Kingdom. (email. d.mandic@imperial.co.uk).

D. Obradovic is with the Siemens Corporate Technology, CT IC 4, Otto-Hahn-Ring 6, 81739 Munich, Germany. (e-mail: dragan.obradovic@siemens.com).

followed the approach from Zhang *et al* [4] and focused on VEP signals extracted from object recognition recordings while performing a modified delayed "matching-to-sample" paradigm. Using the proposed single trial approach, we provide statistical evidence of significant differences in the P3 amplitudes between alcoholics and non-alcoholics.

II. METHOD

The data set from Zhang *et al* [4] were used, where 20 subjects (10 alcoholics and 10 controls) were considered. The alcoholics were significantly older than the control subjects [t(118.9)=12.64, p=0.0001]. The mean age for the control group was MA=25.81 years (SD=3.38) ranging from 19.4 to 38.6 years of age. The mean age of alcoholic group was MA=35.83 (SD=5.33), ranging from 22.3 to 49.8 years. The alcoholics tested had been abstinent for a minimum period of one month (through closed ward detention). Most of the alcoholics had been previously drinking heavily for a minimum of 15 years. The diagnosis of alcohol abuse was made by the intake psychiatrist of the Addictive Disease Hospital in Brooklyn according to DSM-III criteria. The control subjects were matched for age to the alcoholics as much as possible, and were not alcohol or drug consumers. The two groups were also matched for socioeconomic status.

In this study, P3 responses were obtained while subjects performed an object recognition task for three types of visual stimuli: i) a single stimulus (S1); ii) S1 followed by a second matching stimulus (S2M); iii) S1 followed by a second non-matching stimulus (S2N). This added to the complexity of the mental task, which involves not only stimulus recognition, but also short-term memory encode/access, and decision making. The objects presented to the subjects were chosen from the Snodgrass and Vanderwart standardised picture set [9].

A. The experiment setup

During the experiment, the subjects were seated in a reclining chair located in an RF shielded soundproof room. Measurements were taken from 64 EEG channels that were sampled at 256 Hz, from electrodes placed on the scalp of a subject. The electrode positions were chosen according to an extension of the Standard Electrode Position Nomenclature, as recommended by the American Encephalographic Association. The visual stimuli were shown on a computer display unit located 1 meter away from the subject. The duration of each visual stimulus was 300 ms, with the inter-stimulus interval of 1.6 s and the inter-trial interval of 3.2 s. Presentations of matching and non-matching objects were random. The subjects were asked to decide whether the second picture (S2) was from the same group the first one (S1). After the presentation of S2, the subjects were instructed to click a mouse key in one hand if S2 matched S1 and to press a mouse key in the other hand if S2 was different from S1.

B. The mental task

The VEP signals were recorded while the subjects were presented with two consecutive visual stimuli, which were pictures of objects from the Snodgrass-Vanderwart picture set [9]. These pictures represent various objects, which can be straightforwardly named, that is they are associated with definite verbal labels. This fact is important as some amnesics may perform differently on recognition tasks using complex (abstract) pictures [10]. In order to preserve the consistency of the representation and to suit the mental task under investigation, the pictures were grouped into different categories based on their relevance to the memory and cognitive processing within the brain.

The first visual stimulus (S1) shown to subjects was a randomly chosen picture from the modified database, as explained above. The second stimulus shown was chosen according either to the matching (S2M) or non-matching (S2N) rule, relative to the initial stimulus (S1). To reduce the possible ambiguity, S2N was chosen to be different from S1 not only in its visual appearance but also in terms of the semantics. For example, if a picture of an elephant is shown for S1, then S2N will not be a picture from the animal category. One-second EEG measurements after each stimulus presentation were recorded. Figure 1 shows a stimulus presentation for the case of S2N.
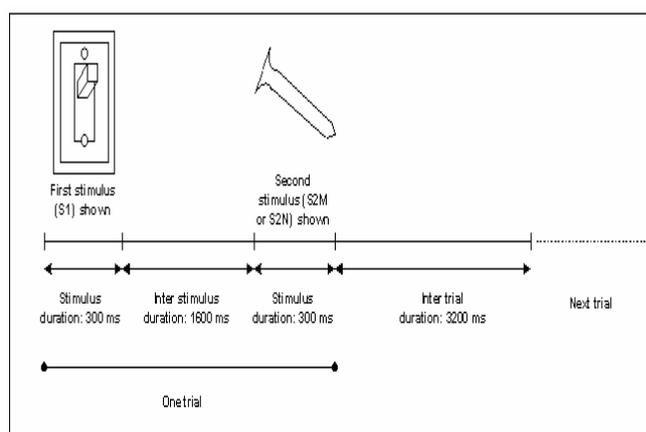

Fig. 1. Example of stimulus presentation for the case of S2N.

C. Signal Conditioning

Following the approach by Lange and Inbar [11], a combination of frequency selective digital filtering and statistical subspace decomposition was used to reduce EEG artifacts from VEP signals. This was achieved through low pass digital filtering and Principal Component Analysis (PCA). Figure 2 shows a block diagram of the whole single trial P3 analysis procedure. The signals in the data set were hardware bandpass filtered between 0.02 and 50 Hz, a commonplace in practical EEG data manipulation. The nose electrode was used as reference. The eye-blink artifact contaminated VEP signals were removed from the records, and were detected based on amplitude discrimination (the threshold value of 100 μV was used since blinking typically produces potential of 100-200 μV lasting for 250 ms [12]. For every subject, a total of 40 S1, 20 S2M and 20 S2N artifact-free trials were used in the analysis.
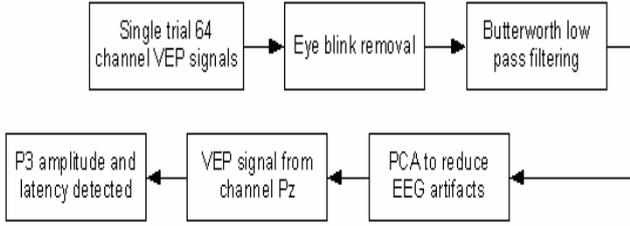
Fig. 2. Block diagram of the proposed single trial P3 amplitude and latency analysis.

Following the approach from by Begleiter *et al* [3], where P3 responses were shown to be band-limited to 8 Hz, the extracted VEP signals from S1, S2M and S2N were lowpass filtered using a combination of a 9th order forward and 9th order reverse Butterworth digital filter with a cutoff frequency at 8 Hz. This way, a minimum attenuation of 30 dB was achieved in the stop band, with the transition band being between 8 and 12 Hz.

D. Reducing EEG from single trial VEP

To reduce EEG artifacts, PCA was applied to the 64-channel VEP data, and a total of 400 single trials of S1, 200 single trials of S2M, and 200 single trials of S2N were analysed for both alcoholics and non-alcoholics.

Let matrix $\mathbf{z}$ denote the extracted signal, and let $\mathbf{R}$ be the covariance of $\mathbf{z}$, given by

$$\mathbf{R} = \mathbf{E}(\mathbf{z}\mathbf{z}^{\mathbf{T}}) \qquad (1)$$

where $\mathbf{E}(\cdot)$ denotes the statistical expectation operator. Let $\mathbf{F}$ be the orthogonal matrix of eigenvectors of $\mathbf{R}$, and $\mathbf{D}$ the diagonal matrix of eigenvalues of $\mathbf{F}$, that is, $\mathbf{D} = diag(d_1,....,d_n)$. Principal components (PCs) can now be computed as

$$\mathbf{y} = \mathbf{F}^{\mathbf{T}}\mathbf{z}^{\mathbf{T}}. \qquad (2)$$

Next, the VEPs with reduced noise (i.e. background EEG) were reconstructed using

$$\tilde{\mathbf{z}} = \tilde{\mathbf{F}}\hat{\mathbf{y}}, \qquad (3)$$

where $\tilde{\mathbf{F}}$ and $\hat{\mathbf{y}}$ denote respectively the eigenvectors and PCs which correspond to eigenvalues whose values are greater than unity.

Using PCA, vector space projections are performed along the directions of the components that describe most of the signal variance (power). Based on this principle, Lange and Inbar [11] have shown that the first few PCs account for a large proportion of the VEP variance, while the rest can be attributed to the background EEG noise. In this work, to select the number of PCs to be used, Kaiser's rule [13] was applied. This way, PCs for which the eigenvalues are greater than unity were considered to be part of the VEP subspace.

III. EXPERIMENTAL RESULTS

Single trials of VEPs from the Pz channel were analysed, because the P3 response reaches its maximum in the middle parietal area [2, 3, 8]. The amplitude of P3 responses was identified as the largest positive peak in the period of 300-600 ms after the stimulus onset. The t-test was used to establish a statistical difference in P3

amplitudes between alcoholics and non-alcoholics. This choice was based on the assumption of normal distribution of the P3 responses, because the number of trials were much higher than 30 (rule-of-thumb limit for using t-test). The significance level of the t-test was 0.05.

Our aim is to show that the amplitudes of VEP responses are affected by long term alcohol abuse, and hence the decision making based on visual stimuli.

Table 1 gives the results of t-test analyses for single trial amplitudes of P3 responses. The term condition in the table refers to the tested hypothesis. For example, S1<S2M means that the tested hypothesis is that S1 amplitudes are lower than S2M amplitudes. For alcoholics, these tests showed that P3 amplitude responses for S1 were smaller in magnitude than those for S2M and S2N. However, there was no significant difference between P3 amplitudes for S2M and S2N. For non-alcoholics, the t-test showed that P3 responses for S1 were smaller in magnitude than those for S2M and S2N, which is similar to the result for alcoholics. However, the P3 responses for S2M were larger in magnitude than those for S2N.

Next, the hypothesis that the amplitudes of P3 responses for alcoholics are lower than those for non-alcoholics was tested. The results of the statistical test are given in Table 2. From the Table, it can be seen that the P3 responses were greater in magnitude for alcoholics as compared to non-alcoholics for S1, S2M and S2N, with the significance of differences in descending order.

TABLE 1: T-TEST RESULTS FOR SINGLE TRIAL P3 AMPLITUDES

Subject	Condition	Result
Alcoholics	S1<S2M	t(394)=-1.92,p=0.028
	S1<S2N	t(276)=-1.25, p=0.11
	S2M>S2N	t(332)=0.08, p=0.47
Non-alcoholics	S1< S2M	t(436)=-1.55, p=0.061
	S1<S2N	t(410)=-0.81, p=0.79
	S2M>S2N	t(396)=2.08, p=0.019

TABLE II: T-TEST RESULTS FOR SINGLE TRIAL P3 AMPLITUDES WITH ALCOHOLICS<NON-ALCOHOLICS ALTERNATIVE HYPOTHESIS

Stimulus	Results
S1	t(725)=-6.87, p=7 x 10^{-12}
S2M	t(381)=-5.23, p=1 x 10^{-7}
S2N	t(384)=-2.25, p=0.013

IV. DISCUSSION

To analyse the electrophysiological differences in mental tasks between alcoholics and non-alcoholics, we have analysed P3 responses from single trial VEP signals. The data collected by Zhang *et al* [4] were used, where no significant difference in the quality of processing of mental tasks was reported between alcoholics and non-alcoholics. This was achieved using the c320 (similar to P3) responses. In that work, ensemble averaging method was used to reduce EEG artifacts from VEP signals. It has been elsewhere reported that alcoholics exhibit lower P3 amplitudes [2, 3] and longer latencies [1], as compared to non-alcoholics.

In this paper, as an alternative to the ensemble averaging approach, single trial responses have been analysed. These were obtained using digital filtering methods together with PCA.

The P3 response is commonly associated with the decision-making process. The amplitude response results conform to the analysis of Bentin and McCarthy [14], where it was shown that matching repeated stimuli (like S2M) results in a higher amplitude of P3 response as compared to a single (such as S1) or non-matching stimulus (such as S2N). The non-alcoholics exhibit this behaviour but for the alcoholics, this is the case only partially, that is, S2M amplitude > S1 amplitude but not S2M amplitude > S2N amplitude. This indicates that alcoholics might have difficulty when deciding whether the second stimulus was matched or non-matched to the first one.

Non-alcoholics have also been found to be able to make more confident decisions, as represented by the P3 amplitudes being higher as compared to the ones for alcoholics. However, this difference is emphasised only for simpler tasks like S1 and S2M, while for S2N, this difference is marginal.

The results from the analyses indicate that the differences of P3 amplitudes between alcoholics and non-alcoholics are significant for stimuli S1, S2M and S2N, in a decreasing order. In conclusion, the proposed single trial P3 analyses have provided strong evidence that significant electrophysiological differences for the delayed matching-to-sample paradigm experiment do exist between alcoholics and non-alcoholics. This conforms to existing studies on the permanent and damaging residual effect of long-term alcohol use.

REFERENCES

[1] Misulis K.E., *Spehlmann's Evoked Potential Primer: Visual, Auditory and Somatosensory Evoked Potentials in Clinical Diagnosis,* Butterworth-Heinemann, 1994.

[2] Almasy, L., Porjesz, B., Blangeo, J., Goate, A., Edenberg, H.J., Chorlian, D.B., Kuperman, S., O'Connor, S.J., Rohrbaugh, J., Bauer, L.O., Foroud, T., Rice, J.P., and Reich, T., "Genetics of Event-Related Brain Potentials in response to a Semantic Priming Paradigm in Families with a History of Alcoholism," *American Journal of Human Genetics*, vol. 68, pp. 128-135, 2001.

[3] Begleiter, H., Projesz, B., Reich, T., Edenberg, H.J., Goate, A., Blangero, J., Almasy, L., Foroud, T., Eerdewegh, P.V., Polich, J., Rohrbaugh, J., Kuperman, S., Bauer, L.O., O'Connor, S.J., Chorlian, D.B., Li, T.K., Conneally, P.M., Hesselbrock, V., Rice, J.P, Schuckit, M.A., Cloninger, R., Nurnberger Jr., J., Crowe, R. and Bloom, F.E., "Quantitative Trait Loci Analysis of Human Event-related Brain Potentials," *Electroencephalography and Clinical Neurophysiology,* vol. 108, 244-250, 1998.

[4] Zhang, X.L., Begleiter, H., Porjesz, B., and Litke, A., "Electrophysical Evidence of Memory Impairment in Alcoholic Patients," *Biological Psychiatry*, vol. 42, pp. 1157-1171, 1997.

[5] Palaniappan, R., Raveendran, P and Omatu, S., "VEP Optimal Channel Selection for Neural Network Classification of Alcoholics," *IEEE Transactions on Neural Networks*, vol. 13, no.2, pp. 486-491, March 2002.

[6] Aunon, J.I., McGillem, C.D., and Childers, D.G., Signal Processing in Event Potential Research: Averaging and Modelling, *CRC Critical Review Bioengineering*, 5, pp. 323-367, 1981.

[7] Kay, S., *Fundamentals of Statistical Signal Processing: Estimation Theory,* Prentice Hall, 1994.

[8] Polich, J., "P300 in Clinical Applications: Meaning, Method and Measurement," *American Journal of EEG Technology,* vol. 31, pp. 201-231, 1991.

[9] Snodgrass, J.G. and Vanderwart, M., "A Standardized Set of 260 Pictures: Norms for Name Agreement, Image Agreement, Familiarity, and Visual Complexity," *Journal of Experimental Psychology: Human Learning and Memory*, vol. 6, no. 2, pp. 174-215, 1980.

[10] Starr, A., and Philips, L., "Verbal and motor memory in the amnesic syndrome," *Neuropsychologia*, vol. 8, pp.75-88, 1970.

[11] Lange, D.H. and Inbar, G.F., Variable Single-Trial Evoked Potential Estimation Via Principal Component Identification," *Proceedings of the 18th Annual International Conference of the IEEE EMBS*, pp. 954-955, 1996.

[12] Kriss, A., Recording Technique, In: Halliday, A.M. (ed), *Evoked Potentials in Clinical Testing,* Churchill Livingstone, 1993.

[13] Jolliffe, I.T., *Principal Component Analysis,* Springer-Verlag, 1986.

[14] Bentin, S. and McCarthy, G., "The Effects of Immediate Stimulus Repetition on Reaction Time and Event-Related Potentials in Tasks of Different Complexity," *Journal of Experimental Psychology: Learning, Memory and Cognition*, vol. 20, no. 1, pp. 130-149, 1994.