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TWO LEVEL PCA TO REDUCE NOISE AND EEG FROM EVOKED POTENTIAL SIGNALS

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ABSTRACT

Two common artifacts that corrupt evoked responses are noise and background electroencephalogram (EEG). In this paper, a two-level principal component analysis (PCA) is used to reduce these artifacts from single trial evoked responses. The first level PCA is applied to reduce noise from these VEP signals while the second level PCA reduces EEG. The method is used to analyse the object recognition and decision-making capability during visual responses. The analysis is extended to study the differences in visual response between alcoholics and non-alcoholics using single trial P3 visual evoked potential (VEP) signals. The analysis shows that alcoholics respond slower and weaker to visual stimulus as compared to non-alcoholics.

1. INTRODUCTION

Evoked Potential (EP) is typically generated by the nervous system in response to external stimulus [8]. In recent years, EP analysis has become very useful for neuropsychological studies and clinical purposes [1-4, 8, 13, 14]. Specifically, the effects of alcohol on short-term visual memory in humans have been studied using evoked responses [13]. Evoked response has also been used to determine the genetic predisposition towards alcoholism [3].

The EP signal is embedded in the ongoing EEG with additive noise causing difficulty in detection and analysis of this signal. The traditional technique of solving this problem is to use ensemble averaging. However, this approach requires many trials and the averaged signal might tend to smooth out inter-trial information, thereby distorting the analysis. In addition, information available from single trials is lost.

In this paper, we propose a two-level PCA method to reduce noise and EEG effects from EP signals. Although single level PCA has been commonly used to reduce noise artifacts from biomedical signals [9], the application of PCA consecutively for two times is novel. The first level PCA reduces noise, while the second level PCA reduces EEG contamination. In addition, this proposed method enables single trial analysis of EP signals. The second level PCA is similar to the method proposed by Lange and Inbar [7]. In this paper, both the noise and EEG are assumed to be ergodic processes.

The method is applied to Visual EP (VEP) signals to analyse the object recognition and decision-making capability exhibited during visual responses. These VEP signals are extracted during the presentation of different visual stimuli. P3 or P300 responses (commonly associated with stimulus recognition and decision-making capability) of VEP signals are used in the analysis. The analysis is extended to study the differences in VEP responses between alcoholics and non-alcoholics.

2. VEP DATA PRE-PROCESSING

Twenty subjects participated in the experimental study consisting of 10 alcoholics and 10 non-alcoholics. The alcoholics are non-amnesic and have been abstinent for a minimum period of one month (through closed ward hospitalisation) and are also off all medications for the same period of time. Most alcoholics had been drinking heavily for a minimum of 15 years and started drinking at approximately 20 years of age. The non-alcoholic subjects are not alcohol or substance abusers. The subjects are seated in a reclining chair located in a sound attenuated RF shielded room. Measurements are taken from 61 channels placed on the subject's scalp, which are sampled at 256 Hz. The electrode positions (as

shown in Figure 1) are located at standard sites using extension of Standard Electrode Position Nomenclature, American Encephalographic Association. The signals are hardware band-pass filtered between 0.02 and 50 Hz. Nose electrode is used as reference.

2.1 Snodgrass And Vanderwart Picture Stimuli

The VEP signals are recorded from subjects while being exposed to two stimuli, which are pictures of objects chosen from Snodgrass and Vanderwart picture set [12]. These pictures are common black and white line drawings like an airplane, a banana, a ball, etc. executed according to a set of rules that provide consistency of pictorial representation. The pictures have been standardised on variables of central relevance to memory and cognitive processing. These pictures represent different concrete objects, which are easily named i.e. they have definite verbal labels. Figure 2 shows some of these pictures.

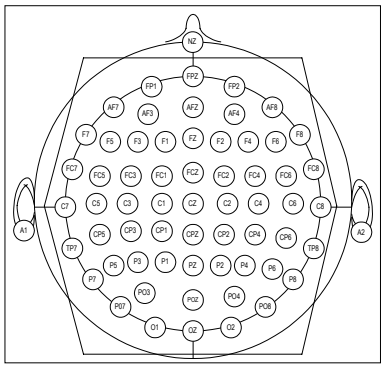

Figure 1: Electrode positions

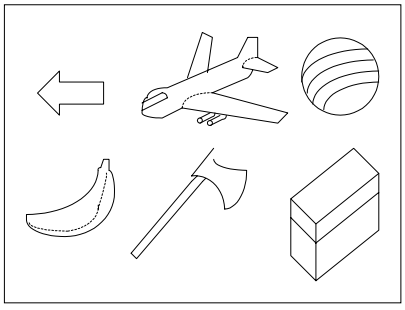

Figure 2: Some objects from Snodgrass and Vanderwart picture set

The second stimulus is shown in either matching (S2M) or non-matching (S2N) condition to the first sample stimulus (S1). Care is taken to ensure that the S2N is different from S1 not only in visual form but also in terms of semantic. Stimulus duration of each picture is 300 ms and inter-stimulus interval is 1.6 s with an inter-trial interval of 3.2 s. The presentations of matching and non-matching trials are random. The stimuli are shown using a computer display unit located 1 meter away from the subject's eyes. The subjects are asked to decide whether the second picture (S2) is the same as the first (S1). They are asked to press a mouse key in one hand if S2 matched S1 and to press a mouse key in the other hand if S2 differed from S1, after the presentation of S2 on each trial. The designation of the hand indicating match or non-match is alternated across subjects. Response accuracy and speed are stressed equally. One-second measurements after each stimulus onset are stored. Figure 3 shows an illustrative example of the stimulus presentation for the case of S2N. For further details of the data collection process, refer to [13, 14].

2.2 Eye Blink Artifact Removal

In this study, VEP signals with eye blink artifact contamination are removed using a computer program written to detect VEP signals with magnitudes above 100 μV. These detected VEP signals with eye blinks are then discarded from the experimental study and additional trials are conducted as replacements. The threshold value of 100 μV is used since blinking produces 100-200 μV potential lasting 250 milliseconds [6].

2.3 Digital Filtering

The extracted VEP signals are low pass filtered since P3 responses mainly consist of low frequency components. Almasy et. al. [1] and Begleiter et.al. [3] have used cut-off frequency of 8 Hz while Polich [10] suggested a cut-off frequency of 30 Hz. In this paper, we have used a 9^{th} order forward and 9^{th} order reverse Butterworth digital filter with a 3-dB cutoff frequency at 8 Hz. Order 9 is used since it is sufficient to give a minimum attenuation of 30 dB in the stop band with a transition band from 8 to 12 Hz. Forward and reverse filtering are performed to achieve zero phase response i.e. to avoid any phase distortion.

2.4 Setting The Prestimulus Baseline To Zero

In general, peak P3 amplitudes of the VEP signals are measured relative to the pre-stimulus baseline, i.e. the

mean of EEG prior to stimulus onset [1-3, 13, 14]. However, in our analysis, the pre-stimulus EEG is not available. Therefore, the pre-stimulus baseline is set approximately to zero by removing the mean from the post-stimulus data. This is possible since the post-stimulus single trial data (before averaging or applying PCA) consists mainly of EEG since the EEG/VEP ratio is very high. Therefore, the mean of the extracted signal after stimulus onset can be assumed to approximate the mean of EEG before stimulus onset. Removing the mean from the extracted post-stimulus signal denotes that the pre-stimulus baseline is set to zero. The P3 amplitude measurements obtained now will be similar to baseline-to-peak measurements.

3. METHODOLOGY

In the experimental study, a total of 40 S1, 20 S2M and 20 S2N artifact free trials are used in the analysis for each subject, giving an overall total of 400 S1, 200 S2M and 200 S2N trials for alcoholics and likewise for non-alcoholics. These trials are from the correctly elicited responses only.

PCA is applied to the single trial 61-channel VEP data to reduce noise artifacts. The PCA method is as follows. Assuming matrix $\mathbf{z}$ to represent the extracted 61 VEP channels, the covariance of matrix $\mathbf{z}$ is computed using:

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

Next we compute, $\mathbf{E}$ and $\mathbf{D}$, where $\mathbf{E}$ is the orthogonal matrix of eigenvectors of $\mathbf{R}$ and $\mathbf{D}$ is the diagonal matrix of its eigenvalues, $\mathbf{D} = diag(d_1,....,d_n)$. The principal components (PCs) can now be computed using

$$\mathbf{y} = \mathbf{E}^{\mathbf{T}}\mathbf{z}^{\mathbf{T}} . \quad (2)$$

The first few PCs account for a large proportion of VEP while the rest represents noise. This is since VEP signals have a higher degree of correlation between the channels as compared to noise, which is random (i.e. no or little correlation between channels). As such, the PCs that represent VEP have much higher eigenvalues than the PCs that represent noise.

In our work, Kaiser's rule [5] is used to select the number of PCs to be used. Using this method, PCs with eigenvalue more than 1.0 are considered to be part of the VEP subspace. The VEP (without noise) can now be reconstructed from the selected PCs using

$$\tilde{\mathbf{z}} = \hat{\mathbf{E}}\hat{\mathbf{y}} , \quad (3)$$

where $\hat{\mathbf{E}}$ and $\hat{\mathbf{y}}$ are the eigenvectors and PCs corresponding to eigenvalues more than 1.0. Note that the dimension of $\tilde{\mathbf{z}}$ is still the same as $\mathbf{z}$.

Noise reduced VEP signals from channel Pz are stored for analysis. Pz is chosen in particular since most researchers state that P3 response is maximal in midline parietal [1, 3, 8].

The second level PCA analysis is applied to the noise removed VEP signals (from channel Pz). This second level PCA functions similar to the first level PCA except that the PCA is applied across trials and not across channels in a trial as in the first level PCA. In other words, EEG in the second level PCA replaces noise in the first level PCA. The second level PCA is applied to the multi-trials of channel Pz VEP signals, while in the first level, PCA is applied to multi-channel single trial VEP signals. This procedure is illustrated in Figure 4 (note that after first level PCA, only channel Pz is stored).

P3 amplitude and latency (from the noise and EEG reduced channel Pz) are detected via an automated procedure. This P3 component is identified as the most positive peak during the period of 300-600 ms after stimulus onset. This time window period is chosen based on studies by Almasy et. al. [1] and Begleiter et. al. [3]. T-Tests are conducted to analyse the differences in the visual response of alcoholics and non-alcoholics.

4. RESULTS AND DISCUSSION

Table 1 gives the results of t-Test analyses of latencies of P3 responses. All the discussion here is based on significance level of 95%. The t-Test shows that the P3 responses for S1 are faster than S2M and S2N. However, there is no significant difference between P3 response time for S2M and S2N. These t-Test results are true for both alcoholics and non-alcoholics.

In Table 2, the results of t-Test comparison between P3 latencies between alcoholics and non-alcoholics are tabulated. The alternative hypothesis tested is that the alcoholics' latencies are greater than the non-alcoholics' latencies. From this table, it can be seen that P3 responses are slower for alcoholics as compared to non-alcoholics for S1 and S2M, with the difference for S1 being significantly different. The difference is marginal for S2N. Therefore, the significance of difference of P3

latencies between alcoholics and non-alcoholics are higher for S1, followed by S2M and S2N.

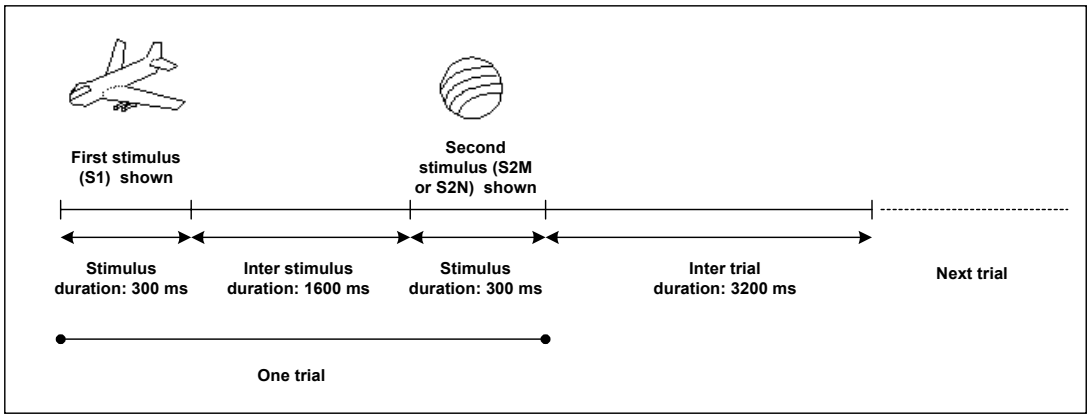

Figure 3: Example of stimulus presentation for the case of S2N

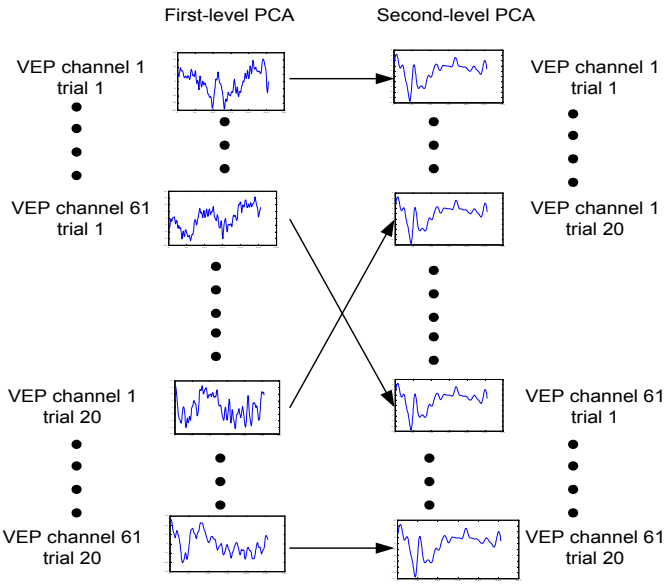

Figure 4: First-level and second-level PCA (for S2N and S2M stimuli)

Table 1: t-Test results of P3 latencies

Subject	Condition	Result
Alcoholics	S1 < S2M	t(388)=-2.28, p=0.012
	S1< S2N	t(377)=-1.85, p=0.033
	S2M<S2N	t(397)=0.33, p=0.63
Non-alcoholics	S1 < S2M	t(486)=-2.30, p=0.011
	S1< S2N	t(454)=-2.59, p=0.0049
	S2M<S2N	t(395)=-0.38, p=0.35

Table 2: t-Test results of single trial P3 amplitudes with alcoholics>non-alcoholics alternative hypothesis

Stimulus	Results
S1	t(796)=2.53, p=0.0058
S2M	t(381)=2.17, p=0.015
S2N	t(387)=1.38, p=0.084

Table 3 gives the results t-Test analyses of amplitudes of P3 responses. The t-Test for alcoholics shows that the P3 amplitude responses for S1 are lower than S2M and slightly lower than S2N. However, there is no significant difference between P3 amplitudes for S2M and S2N. The t-Test for non- alcoholics shows that the P3 amplitudes for S1 are lower than S2M and S2N, which is similar to alcoholics. But the amplitudes for S2M are higher than S2N, which is not the same as the case of alcoholics where there is no significant difference.

Table 3: t-Test results of 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

The results of t-Test comparison between P3 amplitudes between alcoholics and non-alcoholics are given in Table 4. The alternative hypothesis tested is that the alcoholics' amplitudes are lower than the non-alcoholics' amplitudes. From this table, it can be seen that the P3 responses are higher for alcoholics as compared to non-alcoholics for S1, S2M and S2N, with the significance of differences in descending order.

Table 4: t-Test results of single trial P3 amplitudes with alcoholics<non-alcoholics alternative hypothesis

Stimulus	Results
S1	t(725)=-6.87, p=6.72e-12
S2M	t(381)=-5.23, p=1.37e-7
S2N	t(384)=-2.25, p=0.013

5. CONCLUSION

In this paper, a two level PCA method is used to reduce noise and EEG from VEP signals. The method is applied to analyse the object recognition and decision-making capability using P3 responses from single trials of VEP signals. The analysis is extended to study the electrophysiological differences between alcoholics and non-alcoholics.

It has been reported that alcoholics exhibit lower P3 amplitude [1,3] and longer latency [8], in comparison to non-alcoholics. Our results show that the P3 response time for S1 is faster than S2M and S2N for both alcoholics and non-alcoholics. P3 is commonly associated with decision-making process. Because S1 does not require any decision-making, the response time is lower than S2M and S2N, where a decision has to be made on the similarity/non-similarity of the second stimulus. There is no significant difference in P3 response time between S2M and S2N for both alcoholics and non-alcoholics, which indicates that the decision making process between S2M and S2N takes similar amount of time for each individual.

P3 response times are slower in alcoholics. However, this difference is clearly indicated by S1, followed by S2M and S2N. This shows that the slowing of P3 response for alcoholics is more clearly indicated by simpler tasks (S1 and S2M) rather than complex ones (like S2N).

It has shown by Bentin and McCarthy [4] that matching i.e. repeated stimuli (like S2M) have a higher P3 amplitude response as compared to new (like S1) or non-matching stimuli (like S2N). The non-alcoholics group exhibits this behaviour but alcoholics exhibit the behaviour only partially i.e. S2M>S1 but not S2M>S2N. This indicates that alcoholics might have difficulty in deciding whether the second stimulus is matched or non-matched.

Non-alcoholics are also able to recognise object better and make more confident decisions because the P3 amplitude is higher for non-alcoholics as compared to alcoholics. However, the difference is elicited only for simpler tasks like S1 and S2M, while for S2N, the difference is marginal.

The results from the analysis indicate that these differences of P3 amplitudes and latencies between alcoholics and non-alcoholics are significant for stimuli S1, S2M and S2N, in decreasing order.

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