# A review on alcoholic detection from eeg signals

Abstract: This review covers advances of the past decade, in the development of EEG signal processing algorithms for alcoholic detection. In recent years, various computational approaches have been proposed to detect alcoholism from EEG recordings. In this paper, we review some of those approaches, and discuss their limitations and potential In part I, an introduction to the effect of alcohol on EEG is discussed briefly. We review some of the known effects of alcohol on EEG signal in part II. Some of the exiting state of the art signal processing techniques for alcoholic detection in EEG recordings are discussed in part III. A review of various signal processing methods used to classify alcoholics and controls is done. The potential and limitation of such computational approaches are discussed in part IV. A discussion on the potential use of EEG as a biomarker for alcoholism and as a mass screening tool is also discussed . At the end of the paper, we conclude by briefly addressing the future challenges and open problems in part V.

PART I

Introduction

Alcoholism is a social bane that is affecting the human life in all aspects. Not only it causes damage to the human brain and other organs of the body in various ways, it also brings about a lot of difficulties and discomfort to an alcoholic person in his/her social life. A lot of research has gone into finding the ill effects and the extent to which it damages the human body. Some of the harmful effects include lack of coordination between body and mind, loss of vision, imbalance in walking, incoherent speech, memory slips, depression to name a few. These effects can be observed after only a few drinks and they may vanish once the person gives up drinking. However a person who is addicted to drinking large quantities of alcohol for a long time may be affected with these effects that persist for a longer time and severely damage one or more organs of the body. The way in which alcohol affects the brain and the probable reversal of the ill effects caused by heavy drinking on the brain still remain as hot topics in alcohol research [1].

Some of the factors that determine the extent to which alcohol affects the brain are: i) quantity and how frequently a person drinks ii) the age of the subject at which the habit of drinking started and how long it is being continued iii) subject’s age, education, gender, genetic predisposition and family history of alcoholism iv) possibility of prenatal exposure and the overall health condition[47].

Heavy drinking not only affects the human brain but it also damages other vital organs of the body. It is also found that females are more affected than males in the way the alcohol consumption damages the various organs of the body. For example, a few years of heavy drinking in women cause cirrhosis [48] cardiomyopathy [49] and nerve damage [50] than in alcoholic men. However, the studies on sensitivity of female’s brain to alcohol-induced brain damage as compared with males, have not shown any conclusive results [1]. Alcohol intake combined with poor general health condition or with severe liver disease causes damage to the human brain in an indirect manner. For example, thiamine deficiency is common in people with alcoholism which is a result of poor overall nutrition [1]. A large percentage of alcoholics suffer from thiamine deficiency and some may even develop severe brain disorders such as [51] Wernicke-Korsakoff syndrome (WKS)

[52]. The symptoms of WKS include mental confusion, oculomotor disturbances and difficulty with muscle coordination, forgetfulness and frustration and have difficulty with walking and coordination [53] .

One of the organs that severely gets affected by long term alcohol consumption in large quantities is the liver. In a person with a history of heavy long-term drinking, the liver ' s function is to breakdown alcohol into harmless by-products and flush them out of the body. However, the liver may get damaged due to excessive alcohol intake, leading to liver cirrhosis. This condition of the liver can harm the brain, leading to a potentially fatal brain disorder called hepatic encephalopathy [54]. Some of the effects of Hepatic encephalopathy are disturbances in sleep patterns, mood swings, personality changes, anxiety, depression, attention deficits, difficulty in coordination like shaking of the hands ( asterixis). In the worst case, patients may slip into coma ( hepatic coma), which can lead to death. It is indeed difficult to diagnose these effects as related to hepatic encephalopathy. New imaging techniques assist researchers to study specific regions of brain in such patients, which helps them in knowing exactly how hepatic encephalopathy progresses. The studies have confirmed that at least two toxic substances, ammonia and manganese are responsible for the development of hepatic encephalopathy. The severely damaged liver cells allow these harmful toxic products to enter the brain, which in turn harms the brain cells.

Alcohol consumption during pregnancy may lead to physical, learning, and behavioural problems in the developing fetal brain. The most serious of these problems is the fetal alcohol syndrome (FAS). Children with FAS may have distinct facial features [1]. FAS infants growth may be lesser than average. They may suffer from microcephaly. In infants with this syndrome, only a fewer neurons may be present or a fewer neurons may function properly. This will lead to problems in learning and behaviour for a long term.

All alcoholics do not experience the ill effects of alcohol consumption in a similar manner to the same extent. The source of the disease may be different for different patients. This makes it difficult to pinpoint any one parameter as responsible for the brain disorders found in alcoholics. That is why, one of the active areas of research is to study why some patients are vulnerable to brain deficits while others are not [55].

Most alcoholics suffering from cognitive disorder improve in the structure and functioning of the brain within a year of abstinence [56-58]. This may not be true in all cases. Therefore clinicians must devise different types of treatment methods to cater to different patients. They use brain-imaging techniques to determine the course and progress of treatment over a period of time. Researchers use imaging methods such as magnetic resonance imaging (MRI), diffusion tensor imaging (DTI), positron emission tomography (PET), and electrophysiological brain mapping. These methods provide precise and accurate information on structural, functional and biochemical changes in patient’s brain over time. Sometimes, two or more brain imaging methods are used together to correlate the results and monitor when a chronic alcoholic patient stops drinking and again after long periods of sobriety , the possibility of relapse of the drinking habit in the patient [59].

The process of memorization and retrieval depend on factors such as attention and motivation [60]. MRI of brain assist the physicians to study the effects of long time abstinence from alcohol on memory and attention, as well as changes that take place when drinking habit relapses. The aim of these studies is to differentiate between the alcohol-induced permanent effects on the brain and those which are reversible with abstinence. PET imaging assists researchers to visualize, in the living brain, the damages associated with heavy alcohol consumption [61]. This also enables scientists to analyse alcohol's effects on neurotransmitter systems, brain cell metabolism and blood flow within the brain. These studies on alcoholics have shown the frontal lobe disorders, which are responsible for various functions associated with learning and memory and deficits in cerebellum which controls movement and coordination. PET can also be used for monitoring the effects of alcoholism treatment on the affected parts of the brain and may give new directions in developing medications to rectify the chemical deficits found in the brains of people with alcohol dependence.

Numerous studies have shown the ill effects of alcohol on the human brain by observing and analysing the electroencephalogram (EEG) of the alcoholic subject and compared with that of a control subject. Electroencephalography (EEG) is a simple non invasive tool that records the brain's electrical signals by placing electrodes on the scalp. These signals show real-time activity as it occurs in the brain. Many studies have shown that the effect of alcohol on the human brain can be perceived by processing the recording the EEG of an alcoholic subject. The single channel EEG recordings of a control and an alcoholic subject are as shown in fig 1. It can be observed that the time series EEG data of both control and alcoholic subjects are not clearly perceptible to the bare human eye. However, with the help of certain signal processing techniques either in the time domain or frequency domain or time-frequency domain or spatial domain techniques, the latent features can be extracted to identify the effects of alcohol on the human brain. As an illustration, the PSDs of the EEG of both control and alcoholic subject are as shown in fig2. From this it is very clear that the power contained in various frequency components are different for both control and alcoholic subjects.

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Fig 1. Time series EEG data of control Fig2. PSD plot of EEG of control

and alcoholic subjects and alcoholic subjects

Many alcoholic men have low amplitude of their P3 components (fig 3). P3 amplitudes in alcoholic women reduce to a lesser extent than in men. The uniqueness of the reduction in P3 component among other symptoms is that even after the patient drops the habit of drinking alcohol, this reduction in P3 persists[63]. Therefore this parameter can be thought of as a biomarker for alcohol dependence rather than an effect of alcohol consumption. There are many studies conducted on the reduced P3 amplitudes of young people who are not exposed to alcohol but their fathers' being alcoholics [64, 65]. Therefore, P3 can be used as biomarkers to help recognizing people who may be at greatest risk for developing problems with alcohol.

graph

Fig 3 . P3 amplitude in control and alcoholic subjects (Courtesy:[1])

Compared to other imaging methods discussed above, electrophysiological methods such as EEG processing for detection of alcoholics has a lot to offer in terms of mobility and cost involved. Hence it can be used as a mass screening tool for the underprivileged with a history of alcoholism.

PART II

## Effect of Alcohol on EEG recordings

Studies have shown that some of the major effects of alcohol on EEG are: i) enlargement of frontal negative occipital wave component ii) increase in ventricular and sulcal CSF volumes iii) Reduction in p300 component iv)Reduction in pre frontal cortical excitability v)Reduction in the amplitude of Error related negativity vi) Binge drinking effect on δ and fast βwaves vii) Reduction in the power of EEG signal in frontal region and enhancement of θ waves . viii) high β and θ power in the resting EEG, abnormalities in eye movements, in saccadic inhibition during antisaccade tasks.

These effects, however, are not always easily detectable. There tends to be a large variability from patient to patient. As a result, none of these phenomena allow at present to reliably detect the effect of alcohol at an early stage. Many recent studies have concentrated on how to improve the sensitivity of EEG for detecting alcoholism. In the following we briefly review some of these studies.

## A. Enlargement of frontal negative occipittal wave component

Way back in 1990, Jerald Varner et al., reported a study of alcoholic organic syndrome patients using the occipital wave components of the event related potential (ERP) as an electrophysiological parameter [3]. The study was conducted on normal, Korsakoff, and alcoholic dementia patients. The frontal negative occipital wave was observed to be increased in alcoholic organic brain syndrome patients and it was concluded that it was probably due to an attention deficit, indicating a probable frontal lobe dysfunction.

## B. Increase in ventricular and sulcal CSF volumes

Adolf Pfefferbaum et al., [4] quantified brain cerebrospinal fluid (CSF) volumes derived from computed tomography (CT) in alcoholics and controls. The results showed that the ventricular and sulcal CSF volumes in alcoholic patients were greater than was expected for their age. This also proved the previous results obtained from a similar study using CT and MRI showing greater vulnerability of the aging brain to alcohol. The absolute ventricular volumes were similar in MRI and CT, while MRI results showed larger sulcal volume estimates than the CT. It was concluded that MRI slice thickness and its resolution to partial volume effects led to this increase in sulcal volume estimate.

## C. Reduction in p300 component

Shirley Y. Hill et al., studied the effect of alcohol on the p300 component [9] . According to this study , it was found that only patients(female) with comorbid depression had a reduced p300 amplitude , while there was no difference in other alcoholic and control subjects(male and female) . From this study, it was also concluded that the P300 amplitude reduction seen in children prone to developing alcoholism seems to represent a delay in neuron development that normalizes as they grow into adulthood.

In another similar study, Michio Hada et al., used bootstrap analysis method in which P3a current source density (CSD) maps showed distinct topographic mapping between alcoholics and control subjects in all the brain regions [10]. More sources and sinks were seen in the alcoholics than in the control subjects for P3a. The reduced P3a amplitude and sinks in alcoholics coupled with less specificity in their CSD maps, suggested disorganized less efficient functioning of the brain. This suggests a probable underlying CNS hyper excitability in alcoholics due to cortical disinhibition .

## D. Reduction in pre frontal cortical excitability

Seppo Kahkonen et al. [13], reported the effects of alcohol on the prefrontal cortex in nine healthy subjects using transcranial magnetic stimulation (TMS) activated electroencephalogram (EEG) signals. Changes in EEG activity lasting up to 270 ms post stimulus were observed as a response to activation by TMS. The changes were observed more prominently at anterior electrodes suggesting the reduction in excitability in the prefrontal cortex due to alcohol.

## E. Reduction in the amplitude of Error related negativity

A study by Clay B Holroyd et al., indicated that alcohol consumption reduces the amplitude of the error-related negativity (ERN)[14] component of the event related potential(ERP), a sharp negative going signal that occurs in the

EEG at the instant when an incorrect motor response starts ( ie., error commission).

## F. Binge drinking effect on δ and fast β waves

Kelley E Courtney et al. evaluated the spectral power in the δ and fast β waves of EEG recordings of young undergraduate university students who varied in their binge drinking history [18]. The aim of the study was to characterize the effects of binge drinking on central nervous system(CNS) neuroelectric activity in male and female undergraduate subjects. The EEG recordings of these subjects showed enhanced spectral power in the δ (0-4 Hz) and fast- β (20-35 Hz) bands for the high-binge drinkers. Although the dependence of fast- β power on binge drinking still remains unclear, the change in fast- β power indicates that EEG spectral pattern of high-binge drinkers is similar to that of alcoholics. This study indicated that the relative enhancement in fast- β power may be used as a biomarker for potential future alcoholism even in the absence of familial alcoholism.

## G. Effect on β, θ , γ waves , eye movement disorders and saccadic inhibition

Wu Di et al., discussed the change in the power of EEG signal in various parts of the brain after consuming alcohol , resulting in harmful effects on different parts of the brain and the body[19]. It was observed that while in the frontal region the power of the EEG signal decreased with the increase in the quantity of alcohol intake, the power of the EEG signal in central, occipital region increased. This study also revealed that while in the frontal region, the alcohol intake caused a transformation in the fast wave with decrease in the power of EEG signal, the fast wave reduced with an increase in the power of EEG signal in the central and occipital region. It was also observed that while the effect of alcohol in the frontal region indicated nerve stimulation of alcohol in this part, making drinkers to become excited after alcohol intake, in the central and occipital region, the effect of alcohol consumption led to an inhibitory action on the neuron cells, resulting in the weakening of the body coordination and eyesight. Further it was noted that increase in alcohol intake resulted in θ waves generation and gradual enhancement as the subjects were in state of drowsiness and the central nervous system(CNS) of the subjects was inhibited. At the same time, α and β waves were seen to gradually enhance and the region of these waves expanded after consuming alcohol. The study also indicated that the correlation between parts of brain decreased gradually because the clustering of the EEG signal was separated gradually into small clusters with increased alcohol intake. From this observation, it was concluded that too much drinking may lead to the decrease of balance, stability between the parts of the brain.

S. Campanella et al., [41], studied various physiological parameters such as continuous EEG, oculomotor measures, cognitive ERPs and event-related oscillations that are affected in chronic alcoholic patients compared to healthy controls. This study was aimed at identifying links between these physiological parameters, altered cognitive processes and specific clinical symptoms. The result of their study showed:(1) high beta and theta power in the resting EEG, suggesting hyperarousal of CNS (2) abnormalities in smooth pursuit eye movements, in saccadic inhibition during antisaccade tasks, and in prepulse inhibition, suggesting disturbed attention and abnormal prefrontal ” inhibitory” cortical dysfunction; (3) decreased amplitude for cognitive ERPs situated along the continuum of information processing, suggesting that alcoholism is associated with neurophysiological deficits at the level of the sensory cortex and not only disturbances involving associative cortices and limbic structures; and (4) decreased theta, gamma and delta oscillations, suggesting cognitive disinhibition at a functional level.

Ajayan Padmanabhapillai et al.,[71] investigated the early evoked gamma band response in male adolescents at high risk and at low risk groups for a visual stimulus. The results indicate that the deficient early evoked gamma band response may indicate the risk of development of alcoholism and could be a potential bio marker for future addiction to alcoholism.

David A. Kareken et al., [72] used functional magnetic resonance imaging (fMRI) to determine how family history affects the brain's response to subjects' preferred alcoholic drink odours (AO) as compared to appetitive control odours (ApCO). This study suggested that a family history of alcoholism and brain exposure to alcohol odour in heavy drinkers differentially affect the way in which brain responds to alcohol cues.

## H. Whole-genome association study on EEG waves

Variation in resting EEG is associated with common, complex psychiatric diseases such as alcoholism, schizophrenia and anxiety disorders although it can not be used as a diagnostic tool for any of them. Such traits appear to be dependent on the underlying molecular processes than on clinical symptoms, and points to an alternative method for the identification of genetic variation that characterize complex psychiatric disorders. Colin A. Hodgkinsona et al.,[39], performed a whole-genome association study on alpha (α), beta (β), and theta (θ) EEG power in a Native American cohort of 322 individuals to maintain the genetic and environmental homogeneity of this population. Three genes SGIP1, ST6GALNAC3 and UGDH were nominally associated to variability of θ or α power. SGIP1 was estimated to account for 8. 8 % of variance in θ power and this association was replicated in US Caucasians, where it accounted for 3. 5% of the variance. Bayesian analysis of prior probability of association based upon earlier linkage to chromosome 1 and enrichment for vesicle-related transport proteins established the genuineness of the association of SGIP1 with θ power. It was also found that the association of SGIP1 with alcoholism provides validation of the use of EEG as an endo phenotype for alcoholism.

## I. Effect of alcohol on facilitation effect

The aim of this study by P. Maurage et al., [32], was to study cross modal (auditory-visual) processing while the subjects were given an emotional stimuli and specifically the auditory-visual facilitation effect. Twenty patients suffering from alcoholism, and 20 healthy controls were asked to identify the emotion (anger or happiness) displayed by auditory, visual or auditory-visual stimuli. The stimuli were designed to elicit a facilitation effect (namely, faster reaction times (RTs) for crossmodal condition than for unimodal ones). It was observed that the alcoholics showed less significant facilitation effect compared to their healthy counterparts. This lack of facilitation effect may be used as a biomarker for an impaired auditory-visual processing in alcoholics.

# PART III

## I. Signal processing techniques for detection of alcoholism in EEG signal

The Electroencephalogram (EEG) is a bio signal containing information about the state of the brain. The latent information present in the EEG signal may not be visible for the human expert and any subtle variations hence cannot be observed and monitored as and when it occurs. Especially in the time series EEG data, subtle variations can not be perceived by human eye. In such a situation the computational approach becomes very important to extract any such micro variations in the EEG recording, containing significant information about the status of any pathology present. Also, since EEG is an inexpensive method and due to its portability, it can be used as a powerful mass screening tool.

EEG signals are the signatures of neural activities. They are captured by multiple-electrode either invasively or non-invasively, over the cortex under the skull, or certain locations over the scalp, and can be recorded in different formats. The signals are normally presented in the time domain, but by applying simple signal processing tools such as the Fourier transform to perform frequency analysis and some imaging tools to visualize EEG topographies , the brain activities can be visualized in frequency or spatial domains respectively. Various time domain, frequency domain, time-frequency methods, statistical signal processing technique such as Wavelet transform [5], Recurrent Neural network [6], nonlinear systems [7], logistic regression [8], spectral densities of DWT coefficients [16], etc., and chaotic signal processing techniques [2] are used to study the pathology of brain such as epilepsy. These techniques are also used to classify between alcoholic, non-alcoholic and epileptic subjects. In recent years, several research groups have started investigating the potential of electroencephalograms (EEGs) for detecting alcoholism and study the short term and long term effects on the brain. There have been many algorithms developed so far for processing EEG signals. Some of the operations include time-domain analysis, frequency-domain analysis, spatial-domain analysis, and multiway processing. Also, several algorithms have been developed to visualize the brain activity from images reconstructed from only the EEGs. Separation of the desired sources from the multisensor EEGs has been another research area. This can later lead to the detection of brain abnormalities such as epilepsy and the sources related to various physical and mental activities. In this section, some of the signal processing techniques applied to EEG signal for the detection of alcoholism is reviewed.

## A. Extraction of spectral band power and parametric methods

Ong, Kok Mang et al, have shown that VEP (visually evoked potential) could be influenced by long term alcohol abuse [20]. The power spectral density of the recorded VEP was estimated using Burg algorithm (parametric analysis) and the extracted Gamma band power was used as features to train the neural network to classify the alcoholics and non-alcoholics. The authors claim that classification result of 97. 50% accuracy has been achieved, to discriminate alcoholics from non-alcoholics. Kok-Meng Ong et al., have proposed Principal Component Analysis (PCA) method for the optimization of the selection of a subset of channels for single trial Visual Evoked Potentials

(VEP) signals [23]. The proposed method was successful in optimizing a subset of channels that guaruntees high classification accuracy of alcoholics and non-alcoholics

Another similar study by Ramaswamy Palaniappan et al., show that the difference of VEP signals between alcoholics and non-alcoholics can be observed using two spectral power ratios in gamma band (37-50 Hz) extracted from seven channels. This result implies that gamma band spectral power could be used as a biomarker on the lasting effects of long-term use of alcohol on visual response though the studied alcoholics have been abstinent for a minimum period of 1 month. Here Genetic algorithm (GA) is used to optimize the selection of subset of the feature set and classification is done with Fuzzy ARTMAP (FA) classifier [11], using VEP signals. The seven spectral bands of VEP signals are extracted using infinite impulse response (IIR) band-pass filters with constant gain and uniform bandwidth. Spectral power in these bands is calculated using Parseval's theorem and used as features to train the FA and ML-BP classifiers. The proposed technique discriminates alcoholics from non-alcoholics with high accuracy.

In continuation of the previous work, Ramaswamy Palaniappan et al., in their work have derived second order autoregressive (AR) coefficients [21] to discriminate alcoholics using single trial gamma band Visual Evoked Potential (VEP) signals using 3 different classifiers: Simplified Fuzzy ARTMAP (SFA) neural network (NN), Multilayer-perceptron-back propagation (MLP-BP) NN and Linear Discriminant (LD) function . Here elliptic filtering was used in the gamma band spectral range on single trial VEP signals. The average classification errors of 2. 6%, 2. 8% and 11. 9% were obtained from LD, MLP-

BP and SFA classifiers. The high accuracy of LD classification results show the effectiveness of the proposed method to discriminate between alcoholic subjects and controls. Several improvements were proposed to previous work of automated classification of alcoholics and non-alcoholics [24] by the same author. In the previous paper, MLP-NN classifying energy of gamma band VEP signals gave the best classification performance using 800 VEP signals from 10 alcoholics and 10 non-alcoholics. Here, the dataset was extended to include 3560 VEP signals from 102 subjects: 62 alcoholics and 40 non-alcoholic. The classification performance was improved by i) increasing the gamma band spectral range ii) Multiple Signal Classification algorithm was used to obtain the power of the dominant frequency in gamma band VEP signals for feature extraction iii) the use of the k nearest neighbour classifier. The performance was validated by a 10-fold cross validation classification. Modification resulted in an improvement in the classification percentage from 94. 49% to 98. 71% in maximum averaged CVC accuracy.

In this paper by Ramaswamy Palaniappan [30], a method is proposed to discriminate chronic alcoholic from non-alcoholic subjects while the subjects were sober. Energies of EEG signals in multiple gamma bands were used as features while the subjects were asked to do a picture recognition task . A neural network was used for classifying chronic alcoholic subjects from controls. Leave one out cross validation strategy revealed that alcoholics could be discriminated from non-alcoholics with accuracy of 94. 55%. This study shows that the energy in gamma band spectral energy can be used as a biomarker for screening of alcoholics.

The classification of chronic alcoholics from non-alcoholics using the EEG is studied in this paper by A Shahina et al., [27]. Weighted Linear Prediction Cepstral Coefficients were extracted from the VEP and used as discriminating feature vectors. Auto associative neural network was used to classify these vectors into alcoholics and non alcoholics. A recognition accuracy of 52. 5% is achieved. This shows that all the 64 channels do not have the same discriminatory attributes causing a reduction in the accuracy levels. Hence the authors conclude that in order to improve the classification performance, there is a need for the optimization of the number of channels to be considered for classification.

In this study by Tugce Balli et al., [31], they investigated the electrophysiological differences between alcoholic and control subjects using two different approaches namely complexity and energy analysis. The EEG data used in this study were recorded from 77 alcoholic and 44 control subjects while the subjects were performing delayed matching to sample object recognition task for three types of stimuli. The experimental paradigm evokes object recognition, visual short-term memory and decision making abilities. The results indicated that all regions (i. e. frontal, central, temporal, parietal and occipital) in the brain exhibit more complexity and less energy for alcoholic subjects as compared to controls. When different visual stimuli pairs were compared among alcoholic and control subjects, the results from energy analysis showed group wise differences in occipital and parietal regions. These results provide a strong indication on the impairment in brain’s electrophysiological activity for alcoholic subjects due to a history of long term alcohol abuse. Chronic alcoholism is classically associated with major deficits in the visual and auditory processing of emotions. However, the cross modal (auditory-visual) processing of emotional stimuli, which occurs most frequently in everyday life, has not yet been explored.