## Table of Contents

<table>
<thead>
<tr>
<th>Title</th>
<th>Authors</th>
<th>Page#</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 EEG Neurofeedback Training for Mental Health Issues of Prisoners</td>
<td>Dr K. Jayasankara Reddy, Adithya Ramesh</td>
<td>1</td>
</tr>
<tr>
<td>2 Neurofeedback and Counseling as Integrative Treatment</td>
<td>See Ching Mey</td>
<td>6</td>
</tr>
<tr>
<td>3 A brief literature survey into the effects of coal seam gas</td>
<td>Herbert F. Jelinek, Lynda Olling</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>exploration by-products on Human EEG</td>
<td></td>
</tr>
<tr>
<td>4 Neural Network for Detection of Students’ interest using</td>
<td>Areej Babiker, Ibrahima Faye, Aamir Saeed Malik</td>
<td>22</td>
</tr>
<tr>
<td></td>
<td>Approximate Entropy Features of EEG data</td>
<td></td>
</tr>
</tbody>
</table>
EEG Neurofeedback Training for Mental Health Issues of Prisoners

Dr K. Jayasankara Reddy\textsuperscript{a*}, Adithya Ramesh\textsuperscript{b}

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Abstract

The EEG neurofeedback training is an upcoming intervention concerning many disorders such as Attention-Deficit/Hyperactivity Disorder, Schizophrenia and Depression as well. The main aim of this review was to study the efficacy of this intervention on a vulnerable population like prisoners. Papers for this review were selected from established databases like PubMed, ProQuest, and ScienceDirect among many. The use of neurofeedback in the forensic psychiatric setting did not show a healthy level of applicability as expected. The main reasons for this were the variations in the sample characteristics between the studies, along with the motivation of the prisoners as well. The prison setting also delayed and interfered with the training and could also be alluded to its apparent difficulty in the application of this treatment. There are a small number of studies with even smaller samples in a population that is difficult to engage. These conditions have led to inconclusive results in most cases. There is scope for improvement, and this is an upcoming area of research. Future directions are also discussed.

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Keywords: Neurofeedback, prisons, neurobiology, interventions, & protocols.

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<thead>
<tr>
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<tbody>
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</tr>
</tbody>
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Email: jayasankara.reddy@gmail.com
1. Introduction

“It is said that no one truly knows a nation until one has been inside its jails. A nation should not be judged by how it treats its highest citizens, but its lowest ones.” Nelson Mandela (p. 115, 1994)

The Governments in the interest of public safety and upholding the laws of the land takes the responsibility of prosecuting and meting out punishments as well. In most cases, these are in the form of prison sentences that might vary from being a few years to a lifetime. More often than not, it is believed that by merely isolating the criminals from society, would in a way, take care of the circumstances that lead to the crime in the first place. There is not much done in the prisons in terms of rehabilitation and this has led to an increase in recidivism. The national average in India stands at 10.4% which is also likely to fluctuate between states and union territories (Yadav, 2014). There are attempts at rehabilitation, but these are not effective as these are often viewed as unnecessary by the officials themselves. Rehabilitation, at its core, must be a system to correct the wrongs committed by the criminals and give them the skills and treatment that will facilitate a smooth transition into the general community. The provision of passing qualifying exams in an attempt to educate them and setting up vocational training centres is a good step in the right direction. These vocations, however, tend to involve skills that might not sufficiently interest the prisoners.

The prison system also neglects to cater to the interests and well-being of the prisoners, especially when it comes to their mental health. Syed and Raghavan (2018) noticed a dismal trend when it came to studies in this area. They classify prisoners as a minority and have highlighted the prevalence of chronic mental illnesses like schizophrenia, depression and adjustment issues along with suicide risk as well. In terms of the level of intervention that was implemented within the prisons, it was found that yoga was useful when it came to dealing with anxiety and depression. However, the need for newer techniques was also emphasised, along with mental health clinics and trained professionals within the prison system itself. The current scenario in India usually involves a psychiatrist from a government hospital who visits prisons once a month. This scenario is mostly for medications and treatment for people with substance use disorders. Any emergencies in terms of mental health are usually referred directly to the corresponding hospital. The high rates of recidivism and mental health could be tackled adequately with the introduction of techniques such as neurofeedback training.

Neurofeedback training (NFT) is a technique which teaches clients to control their brain waves and in turn alter brain functioning. This training operates on the principle of operant conditioning and uses electroencephalography (EEG). The client is given feedback on their training in real-time, and this shows them the progress that they make as well. Based on the brain waves targeted, many protocols are available. These can also be tailor-made to precisely certain brain areas as well depending on the goal of the NFT. NFT has also been effective in the treatment of disorders such as attention-deficit/hyperactivity disorder, schizophrenia, drug addiction, depression, anxiety and even pain management. Each of these disorders tends to affect the brain and its waves differently, and the protocols are designed to counter these effects (Marzbani, Marateb, & Mansourian, 2016).

2. Objectives

The main objectives of this review article are to review papers on neurofeedback and their efficacy in dealing with mental illnesses and antisocial behaviour among the prisoners. This would establish a neurobiological technique such as NFT as a useful alternative for rehabilitation in prison systems along with the pre-existing mechanisms of vocational training and providing education as well.

3. Methods

A traditional literature review was done using keywords such as neurofeedback training, prisoners, antisocial behaviour, and mental health in prisons. Papers, as a result, were reviewed from PubMed, ScienceDirect, Elsevier and Taylor and Francis, among others. It included papers from journals such as Basic Clinical Neuroscience, International Journal of Forensic Mental Health, Indian Journal of Social Psychiatry and the Journal of Criminal Justice, among others.

4. Results

4.1 Efficacy of Neurofeedback in Forensic Psychiatric Settings

Neurofeedback is increasingly being used to tackle many types of disorders in the clinical psychiatric setting from anxiety disorders to schizophrenia. However, there is no similar trend when it comes to its usage in forensic psychiatry. The presence of a co-morbidity may counteract with other treatments but would not be treated as a contraindication for NFT (Holtmann, Albrecht, & Brandeis, 2018). Moreover, it is the main reason why it is not frequently used in forensic settings. The forensic psychiatric population includes people who are not wholly responsible for their crimes. Part of the blame lies in the mental illness as well. Fielenbach, Donkers, Spreen and Bogaerts (2018) studied the effects of Neurofeedback on forensic psychiatric patients, about 19 of them with substance use disorder along with any other comorbidity as well. Primarily, in her protocol was to test the ability to reduce impulsivity and restore inhibitory controls within them through increasing SMR and reducing theta. To ascertain whether there was any change due to the NFT, the EEG magnitudes must have changed from the baseline by about 8%. At the face of it, although there were improvements in their impulsivity and craving due to increasing SMR, there were low respondents to the same. This was attributed to the low number of sessions along with the continued use of their prescriptions as well.

Neurofeedback has opened up the possibility of neurobiological approaches to the field of forensic psychiatry and correctional facilities. At present, it does not enjoy widespread attention from psychologists, primarily due to the overemphasis on psychosocial factors of antisocial behaviour and psychopathy. However, traditional forms of psychotherapy are plagued with
problems such as low compliance rates and in multicultural settings, lack of proper communication. This leaves the stage open for newer approaches such as neurofeedback. Neurofeedback therapy proved to be instrumental in dealing with cases of aggression and anti-social behaviour as a result of substance abuse (van Outsem, 2011). It was effective in reducing the craving as well as abstinence was also prolonged. In cases of domestic violence, which are precipitated by the fear of abandonment and pathological jealousy, neurofeedback was used to enhance flexible thinking and emotional response as well (van Outsem, 2011).

When it comes to prisoners, there is the aspect of criminal offending, recidivism, reoffending, aggression, violence, and along with disorder associated with the same like ADHD, schizophrenia, psychosis, cluster B personality disorders, psychopathy and substance use disorder. An important aspect when it comes to EEG is that there is to be actual learning for it to work. This is a criterion that takes prime importance when it comes to studies which employ this intervention. A review paper found that out of a total of 224 articles screened there were only ten that specifically looked at EEG and also included the details on the protocol used along with a specific criterion for EEG learning. Impulsivity and difficulties with inhibitory control did seem to improve, along with hostility and drug use. Recidivism could also be reduced if these symptoms are reduced as well. However, it was uncertain whether improvements in brain waves are always correlated with the behavioural measures utilised. The possibility of randomised control trials might help ascertain the effects of neurofeedback (Fielenbach, Donkers, Spreen, Visser & Bogaerts, 2018). The most interesting study of these 10 was one which looked to study the aspect of brain self-regulation in criminal psychopaths. It utilised slow cortical potentials demonstrated that the psychopaths were able to control brain excitability. There were reduced aggression, impulsivity and behavioural tendencies. There are few psychophysiological treatments as intervention, and neurofeedback continues to be the leading candidate for reducing psychopathic characteristics such as disinhibition, aggression and related behavioural approach tendencies. This was also reflected in self-report measures for physical aggression, although reactive aggression and aggression inhibition were not significant (Koncar et al., 2015).

4.2 Use of SMR and SCP training for Forensic Psychiatry and Substance Use Disorder

Fielenbach, Donkers, Spreen and Bogaerts (2017) explored the use of the sensorimotor rhythms protocol for reducing impulsivity and by extension, the use of substances among the forensic psychiatry population. Impulsivity has been associated with drug use and also a likely cause of it. The use of SMR protocols was expected to significantly reduce impulsivity and the level of craving that the participants experienced. This protocol was further evaluated along with theta waves. The substance use and psychiatric disorders in the forensic psychiatric population increase the likelihood of violence in the future. Hence, it is necessary to address the lack of inhibitory control in the population. According to the protocol, the SMR frequency was enhanced, while inhibiting the theta frequency. The Barratt Impulsivity Scale, along with a Go/No-Go reaction time task, was used to measure impulsivity. The population was male and had been undergoing treatment for their illness as well. Therefore, the neurofeedback sessions were accompanied by treatment as usual (TAU) in one grouping and just TAU in the other. However, this combination did not seem to be better in any sense (Fielenbach, Donkers, Spreen & Bogaerts, 2018).

In an attempt to isolate the effects of the neurofeedback, a clinical case series was done. The benefit of this is that individual differences can be strictly observed while still retaining the validity and stringent standards of an RCT. The control was done with a sham neurofeedback protocol. The theta/SMR protocol was used once again. While there was evidence that there was a decrease in the self-reported scores of impulsivity and craving, it could still not be attributed exclusively to the neurofeedback training. All connections to the intervention were purely speculative. However, there were no significant differences found in the study. This was especially concerning the two patients that underwent the real neurofeedback protocol. While one of them reported a reduction in their impulsivity and level of craving, this was present at baseline as well. The other patient, despite having undergone the same training, did not appear to have a similar reaction to the intervention. This was the result after a total of 8 sessions (Fielenbach, Donkers, Spreen, Smit, & Bogaerts, 2019). This raises several questions concerning whether the intervention can adequately be applied to this population. The type of externalising disorder, its severity, along with the treatment in progress, seems to be a confounding variable when it comes to testing the efficacy of this intervention.

5. Summary of Studies: Pros and Cons

<table>
<thead>
<tr>
<th>Authors</th>
<th>Pros</th>
<th>Cons</th>
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</thead>
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<tr>
<td>Caria, Sitaram, Vest, Begliomini, &amp; Birbaumer (2010)</td>
<td>It used a new approach – real-time functional magnetic resonance imaging to assess the role of the insula in feedback.</td>
<td>Small sample used</td>
</tr>
<tr>
<td>Fielenbach, Donkers, Spreen, Smit, &amp; Bogaerts (2019)</td>
<td>Utilised EEG neurofeedback in a single case experimental design to control impulsivity and craving</td>
<td>Improvements on behavioural reports were not attributable to neurofeedback intervention</td>
</tr>
<tr>
<td>Fielenbach, Donkers, Spreen, &amp; Bogaerts (2017)</td>
<td>Development of an SMR neurofeedback protocol that is designed for forensic patients</td>
<td>The N-of-1 approach may help explain effects encountered to the protocol but loses generalisability</td>
</tr>
<tr>
<td>Fielenbach, Donkers, Spreen, &amp; Bogaerts (2019)</td>
<td>Use of SMR and Theta protocols for craving and impulsivity. There were improvements in the self-reported measures for the same.</td>
<td>Only the craving improvements could be attributed to the neurofeedback training. N=19 means that there is a low scope for generalisability.</td>
</tr>
<tr>
<td>Fielenbach, Donkers, Spreen, &amp; Bogaerts (2018)</td>
<td>Use of SMR/Theta Protocol to reduce craving and impulsivity in substance abuse disorders. A randomised control trial was used with the two groups being neurofeedback and treatment as usual.</td>
<td>There were changes in the level of craving with an increase in SMR activity on an individual level, but this was not found on the group level.</td>
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6. Conclusion and Future Directions

The effects of the neurofeedback intervention do not seem to lend itself to the natural adaptation to the forensic psychiatric population as expected despite having a high level of success otherwise in terms of higher rates of abstinence and lower levels of depression. This comparison is when treated with traditional forms of intervention, such as psychotherapy. This could also be attributed to the protocols used as they differ between researchers as well. The Peniston Protocol uses a form of alpha/theta training, while the articles reviewed focused on SMR instead (Shepard, 2015). There has been much evidence for the use of neurofeedback as an excellent alternative to traditional practices (Marzhani, Marateb, & Mansourian, 2016; van Outsem, 2011). However, this is not easily visible when it comes to the prison system and the forensic psychiatric population. Some of the significant issues in this population is the prevalence of impulsivity and substance use disorders. While many designs and protocols of the Neurofeedback therapy deal with similar issues such as aggression and substance use disorders, they did not show any significant difference pre- and post-intervention. More importantly, these were not restricted to the effects of the neurofeedback itself (Fielenbach, Donkers, Spreen, Smit, & Bogaerts, 2019; Fielenbach, Donkers, Spreen, Visser & Bogaerts, 2018). Other issues which came were the fact that the intervention did not seem exciting enough to keep the prisoners engaged. The number of sessions was also variable between the studies. Some of these were as short as eight and rarely went over 20. This was also attributed to the low level of compliance and motivation to participate in the study.

Along with this, the treatment that the participants were already undergoing did not stop either. This became a confound within the experiments. The criterion of EEG must be used; otherwise, any significant positive changes would be not attributed to the use of neurofeedback therapy. The use of behavioural measures meant that the results were susceptible to participant’s bias. The future course of action can be directed towards increasing the number of sessions and utilising games or animations that are tailored to the population. This would also contribute to keeping the participants engaged in the intervention.

Furthermore, the use of neurofeedback means that the results are not readily visible, hence the improvements must be communicated between sessions to retain the participants. Finally, it has to be considered that the composition of the Forensic Psychiatric Population is varied and it might also lack the necessary training to learn neurofeedback itself (see Fielenbach, Donkers, Spreen, Smit, & Bogaerts, 2019; Caria, Sifaram, Veit, Gaber, Ruiz & Birbaumer, 2010). There were instances where the participants had to be directed to participate rather than stare blankly at the screen actively. The use of a sample that can be standardised to the extent that even the TAU is constant would help emphasise the intervention capability of the neurofeedback training.

References


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Neurofeedback and Counseling as Integrative Treatment

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*Loh Guan Lye Specialists Centre, Malaysia

Abstract

This paper describes neurofeedback as a tool that is suitable for use along with counselling approaches. The benefits of integrating neurofeedback with counselling are discussed. Neurofeedback training offers opportunities for rehabilitation through directly retraining brain activity. For clients with severe symptoms and resistance to many other treatments, neurofeedback has provided a new beginning and has offered hope. In this paper, four cases of patients with presenting problems including insomnia, anxiety, obsessive compulsive disorder (OCD) and depression using this integrated treatment approach are presented. All participants in this case series experienced significant benefits.

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1. Introduction

Counselling is often an important part of treatment in helping patients with mental disorders. It has also been shown that counselling can be even more effective when combined with alternative forms of treatment such as neurofeedback (Goodwin and Montgomery 2006). Neurofeedback relies on principles of neuroplasticity and enables the patient to alter his/her brain wave activity through training for the purpose of improving health, wellbeing and performance. Neurofeedback may be thought of as a three-step process. First becoming aware of a brainwaves response, then learning to control the response, and finally transferring control of the response to everyday life.

It is our view that Neurofeedback offers the mental health professionals a powerful complementary tool that may be integrated with counselling to treat a variety of mental disorders. Furthermore, neurofeedback has the potential to provide researchers a unique opportunity to investigate clinical interventions with biological evidence of their efficacy.

Research is highly supportive of counselling approaches which include therapeutic characteristics of listening, empathic understanding, building relationship of trust, gaining insight, and building on strengths and wellness. The findings also support the notion that awareness of environment, culture and self shapes the individual. The bridge between biological and psychological processes is erasing the old distinction between mind and body, between mind and brain — the mind is the brain.

It is our thesis that the integration of counselling and neurofeedback treatments will enhance the treatment process given to patients resulting in speedy recovery and improved mental health and wellbeing.

2. Role of Neurofeedback In Helping People With Mental Disorders

Research shows that neurofeedback training can be helpful in cases such as anxiety (Kerson, Sherman & Kozlowski, 2009; Scheinost et al., 2013; depression (Hammond, 2013; Wang at al., 2016; Cheon, Koo & Choi, 2016); eating disorder (Bartholdy et al., 2013; Schmidt & Martin, 2016); insomnia (Hammer et al., 2011; Buckelew, Degood & Taylor, 2013; Arns et al., 2014); obsessive compulsive disorder (Sürmeli & Ertem, 2011); post traumatic stress (Gapen et al., 2016) and schizophrenia (Bolea, 2010; Sürmeli et al., 2012).

A common complaint among the adult and ageing population is insomnia, generally defined as the subjective sense that sleep is difficult to initiate or maintain, or that sleep itself is non-refreshing. Neurofeedback has been shown to positively impact sleep. With neurofeedback, most people can train their brain to improve sleep and this improvement can be surprisingly quick for patients who have attempted many other forms of intervention and struggled with sleep for years (Cortoos, 2010; Hammer, 2011).

OCD is characterised by recurrent and persistent thoughts, impulses, images (obsessions) and repetitive behaviours (compulsions) or mental acts that the person is driven to do in order to attempt to control the obsessions. Neurofeedback can help the brain regulate itself better, and reduce the symptoms of brain dysregulation that occur with OCD (AboutNeurofeedback 2012).

Research evidence suggests a neurophysiological basis for depression, particularly in people with a family history of depression (Hammond, 2013). Research indicates that the left frontal area of the brain is associated with positive emotions and approach motivation, which is a desire to be involved with other people. The right frontal area of the brain is more associated with depression and fear, accompanied by motivation to withdraw from and avoid other people. Neurofeedback treatments for depression appear very promising not only in bringing relief from depression, but in modifying the underlying biological predisposition for becoming depressed (Hammond 2013).

3. Role of Counselling In Helping People With Mental Disorders

This paper focuses on four mental disorders - namely, Anxiety, Insomnia, Obsessive Compulsion Disorder (OCD) and Depression. In addition to neurotherapy a number of different counselling approaches were utilised in the treatment of subjects included in this series.

There are many models, approaches and techniques in counselling. Some of the most commonly used counselling approaches for patients with mental disorders are Cognitive Behavioural Therapy (CBT/CEBT), Behavioural Therapy, Psychoanalysis and Reality Therapy.

Patients who are treated using CBT can expect their therapist to be problem-focused, and goal directed when addressing and challenging problems.

Behavioural therapy focuses on human behaviour and looks to eradicate unwanted or maladaptive behaviour. Typically, this type of therapy is used for those with mental disorders that involve unwanted behaviour. Examples of this can include Anxiety, Insomnia, Obsessive Compulsion Disorder (OCD) and Depression. Practitioners of behavioural therapy believe that behaviour is learned and can therefore be unlearned via therapy. As well as the behaviour itself, the therapists will look at the thoughts and feelings that lead to the behaviour or occur as a result of the behaviour to understand it at a deeper level (Hayes 2004). Behavioural therapy is an action-based therapy that looks to foster positive behaviour change (Cherney 2013).

Psychoanalysis is another approach based upon the theory that our present is shaped by our past (Channel 2008). Past experiences that are hurtful can remain in the unconscious and subconscious mind, influencing present mood as well as behaviour. This can lead to problems with self-esteem, personality, relationships and work. Psychoanalysis helps a patient take control of these influences by tracing them back to their origins and understanding how they have developed over time. This awareness offers the patient the opportunity to deal constructively with the way these influences have affected their present life.

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Reality Theory maintains that all human behaviour is internally motivated. Behavioural choices represent the best attempt at any one moment to meet one or more of the basic needs which are built into the generic structure (Burke 2012). This theory holds that all human beings have the same five basic needs and they are the drivers of all human behaviour. The theory suggests that all human beings have the same behaviour system and that behaviour is driven by a person’s attempt to meet their basic needs. (Glasser 1998). With this approach, patients are guided to make choices and control their own behaviour, not someone else’s - human behaviour is seen as determined by what goes on inside of the person due to external forces. Reality therapy focuses on the future by helping individuals to take ownership of and responsibility for their actions, which allow them to direct their own lives (Burke 2012).

4. Case Presentation

Four patients with presenting problems including Insomnia, Anxiety, OCD and Depression are presented in this paper. These patients were diagnosed by the psychologist and given integrative treatment using neurofeedback and counselling. Their age ranges from 40 to 70 years old. Below is a summary of treatment and outcomes. In all cases neurofeedback protocols have been determined by clinical experience of the author and also a number of other neurotherapists based on the principle of “what works”. While rewarding activity in the Delta range might be seen as controversial by some, we have had successful outcomes using the protocols outlined in these case studies. These protocols used are described below along with the goal that the training hopes to achieve.

Neurofeedback Protocols

Case 1: Patient diagnosed with anxiety

Patient A Detail:

<table>
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<tr>
<th>Gender</th>
<th>Female</th>
<th>Age</th>
<th>Diagnosis</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>42</td>
<td>Generalised Anxiety Disorder (GAD)</td>
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</tbody>
</table>

Patient A was diagnosed with GAD. She had symptoms of anxiety such as constant worrying, sense of fear, restlessness, and negative thinking about events/things around her resulting in her responding emotionally over small matters. She appeared calm on the outside, but she said her brain never stopped thinking. She also had problem falling asleep, muscle tension, and shortness of breath. She had extensive fast brainwave activity in the right frontal lobe of the brain, which would seem to corresponded to her complaint of being unable to shut her mind off from her worries and thus, I also hypothesise that it is linked to her sleeping problems.

The patient did not want to be put on medication so the integrative treatment was recommended. Neurofeedback aimed to decrease the level of arousal, and thus, training aimed to activate middle or low frequency brain wave activity instead of high frequency activity (Jacobs 2013). After about 6 sessions of neurofeedback, the patient said that she was able to fall asleep easily and slept for 6-8 hours without waking up, managed her worries and fear, and had less muscle tension.

The protocols used for the patient and their associated goals were T6 Beta: Improve social behaviour; F7 – F8 Delta: Reduce running thoughts; P4 Delta: Improve sleep; and T3 – T4 Delta: Improve calmness.

The patient also underwent counselling sessions using CBT and Behaviour Therapy forthnightly for the months of June and July, and once a month in the months of August and September.

Neurofeedback Sessions:

<table>
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<th>Month</th>
<th>Session</th>
<th>Treatment Protocol</th>
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<tr>
<td>June</td>
<td>Session 1 – Session 5</td>
<td>T6 Beta, F7 – F8 Delta, P4 Delta, T3 – T4 Delta</td>
</tr>
<tr>
<td>July</td>
<td>Session 6 – Session 10</td>
<td></td>
</tr>
<tr>
<td>August</td>
<td>Session 11 – Session 12</td>
<td></td>
</tr>
<tr>
<td>September</td>
<td>Session 13 – Session 16</td>
<td></td>
</tr>
<tr>
<td>Total sessions</td>
<td>16</td>
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</table>

*** P4 & T3 – T4 Delta treatment is alternated based on the symptoms she was displaying at the time.

Findings:

<table>
<thead>
<tr>
<th>Presenting Problem</th>
<th>Outcome</th>
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<tbody>
<tr>
<td>Constant worrying</td>
<td>Was able to challenge her irrational thinking</td>
</tr>
<tr>
<td>Negative thinking</td>
<td>Was able to manage her worries</td>
</tr>
<tr>
<td>Emotional when she was dealing with people at home and at her workplace</td>
<td>Able to manage her emotion while dealing with people</td>
</tr>
<tr>
<td>Running thoughts resulting in her inability to fall asleep</td>
<td>Able to control outburst of emotion</td>
</tr>
<tr>
<td></td>
<td>Can fall asleep and stay asleep for 6-8 hours</td>
</tr>
</tbody>
</table>

Case 2: Patient with insomnia

Patient B Detail:

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<tr>
<th>Gender</th>
<th>Female</th>
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<th>Diagnosis</th>
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<tr>
<td></td>
<td></td>
<td>48</td>
<td>Insomnia</td>
</tr>
</tbody>
</table>

Patient B had difficulty falling asleep or staying asleep. She complained that she felt tired after waking up. She experienced fatigue and could not focus or concentrate on her work. She lacked motivation and experienced mood swings.

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The patient had difficulty initiating sleep and staying asleep. There is some evidence that theta training is suitable for patients who have difficulty initiating sleep while delta training benefits patients who have problems maintaining sleep (Diaz, Sloot et al. 2012).

The protocols and associated goals used for the patient was T3 – T4 Delta: Improve calmness; P4 Delta : Improve sleep; F2 Beta : Improve motivation; and F3 Beta: Improve Mood.

The patient underwent counselling weekly for the month of July and fortnightly for the month of August. The psychologist used Behaviour Therapy and CBT in the counselling sessions.

### Neurofeedback Sessions:

<table>
<thead>
<tr>
<th>Month</th>
<th>Session</th>
<th>Treatment Protocol</th>
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<tr>
<td>July</td>
<td>Session 1 – Session 7</td>
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<tr>
<td>August</td>
<td>Session 8-16</td>
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<tr>
<td>Total sessions</td>
<td>16</td>
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*** F2 Beta is alternated with F3 Beta starting from Session 6-16.***

### Findings:

<table>
<thead>
<tr>
<th>Presenting Problem</th>
<th>Outcome</th>
</tr>
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<tbody>
<tr>
<td>Tired after waking up</td>
<td>Using the techniques trained in the counselling session, she is able to fall into sleep and sleep through the night without waking up</td>
</tr>
<tr>
<td>Fatigue all day</td>
<td>Felt rested in the morning</td>
</tr>
<tr>
<td>Could not focus nor concentrate</td>
<td>Able to focus and go about her daily activities</td>
</tr>
<tr>
<td>Mood disturbances</td>
<td>Cheerful</td>
</tr>
</tbody>
</table>

### Case 3: Patient with Obsessive Compulsive Disorder

**Patient C Detail:**

| Gender | Male |
| Age | 72 |
| Diagnosis | Obsessive Compulsive Disorder (OCD) |

Patient C held a high position in a corporate company and had always realised that he had some symptoms of OCD, but was never diagnosed nor had he sought help. When he retired, he realised that his problems affected his homelife and this led to further stress.

The patient expressed obsessive thoughts and displayed compulsive behaviour. Frontal lobe overarousal has been associated with repetitive thoughts, worries and urges (Jacobs 2013). Delta training at frontal lobe sites aims to lower beta and hi-beta activity in order to reduce anxiety and obsessive thoughts.

The treatment protocols and associated goals were F3 Beta: Reduce depression; T4 Delta: Emotional calming; and T3 – Fz Delta: Reduce obsessiveness.

The patient was rational and had insight. He was determined to change. He attended weekly counselling for two months and completed all the assignments given by the psychologist. Techniques from CBT and Reality Therapy were used.

### Neurofeedback Sessions:

<table>
<thead>
<tr>
<th>Month</th>
<th>Session</th>
<th>Treatment Protocol</th>
</tr>
</thead>
<tbody>
<tr>
<td>November</td>
<td>Session 1 – Session 5</td>
<td></td>
</tr>
<tr>
<td>December</td>
<td>Session 6 – Session 11</td>
<td></td>
</tr>
<tr>
<td>Total sessions</td>
<td>11</td>
<td></td>
</tr>
</tbody>
</table>

### Findings:

<table>
<thead>
<tr>
<th>Presenting Problem</th>
<th>Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fear of contamination or dirt</td>
<td>Reduced fear of contamination or dirt</td>
</tr>
<tr>
<td>Having things orderly and the way he wants it to be</td>
<td>Able to walk away if things are not orderly and as he wants it to be</td>
</tr>
<tr>
<td>Unwanted repetitive thoughts</td>
<td>Noted unwanted repetitive thoughts and able to challenge the irrational thoughts</td>
</tr>
<tr>
<td>Aggressive or horrific thoughts about harming himself or others</td>
<td>Able to pause and review aggressive or horrific thoughts about harming himself or others</td>
</tr>
</tbody>
</table>

### Case 4: Patient diagnosed with depression

**Patient D Detail:**

| Gender | Female |
| Age | 41 |
| Diagnosis | Depression |

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Patient D was diagnosed with early on-set of depression. She was feeling low in spirit, and sometimes felt that life was no longer worth living. She complained of persistent feelings of sadness and loss of interest. This was accompanied with feelings of hopelessness, worthlessness, helplessness and restlessness, along with suicidal ideation and a suicide attempt.

In neurofeedback therapy with patients who have depression, brain training typically focuses more on the patient's frontal and temporal lobes. Hammond (2005) concluded that neurofeedback not only moderates depression but also mitigates anxiety and rumination.

During neurofeedback, the protocol and associated goals were F7 – F8 Delta: Reduce running thoughts; C4 Delta: Calm unconscious mind; F2 Beta: Improve motivation; F3 Beta: Reduce depression; and T3 – T4 Delta: Improve calmness.

Patient D came for counselling every fortnight. Using psychoanalysis techniques, she was able to identify the events and people who made her sad. She explored her past experiences with the goal that understanding these experiences would help her to manage her anger and the thoughts of ending her life.

### Neurofeedback Sessions:

<table>
<thead>
<tr>
<th>Month</th>
<th>Session</th>
<th>Treatment Protocol</th>
</tr>
</thead>
<tbody>
<tr>
<td>August</td>
<td>Session 1 – Session 2</td>
<td>F3 Beta, T4 Delta, T3 – F2 Delta</td>
</tr>
<tr>
<td>September</td>
<td>Session 3 – Session 9</td>
<td></td>
</tr>
<tr>
<td>October</td>
<td>Session 10 – Session 16</td>
<td></td>
</tr>
<tr>
<td>Total sessions</td>
<td>16</td>
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### Findings:

<table>
<thead>
<tr>
<th>Presenting Problem</th>
<th>Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Less motivated to do tasks</td>
<td>• Able to occupy herself with beneficial activities</td>
</tr>
<tr>
<td>• Running thoughts</td>
<td>• Able to control her running thoughts</td>
</tr>
<tr>
<td>• Annoyed by past and present family issues</td>
<td>• Resolved inner conflict and became calmer when she delt with family members. Does not get annoyed easily</td>
</tr>
<tr>
<td>• Sad feelings with suicidal thoughts</td>
<td>• No more suicidal thoughts</td>
</tr>
</tbody>
</table>

5. Implications and Recommendations

This case series is limited to just four cases, each with very different presentations. The interventions are personalised and thus vary between cases. This represents an exploratory study of outcomes where neurofeedback is integrated with various counselling approaches as an intervention for different mental health disorders.

Future research might focus in more detail on one particular mental health disorder and investigate different protocols for treatment. Follow up studies should ideally include objective measures to assess outcomes and use standardised treatment protocols and procedures.

6. Conclusions

This exploratory case series provides some support for an integrative treatment model incorporating neurofeedback along with psychotherapy/counseling approaches. There are many questions and issues outstanding, but this case series indicates some promising directions for clinical interventions and for future research.

### References


simple-therapeutic-interventions-for-rewiring-the-maladaptive-brain/00011117.


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A brief literature survey into the effects of coal seam gas exploration by-products on Human EEG

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Abstract

Environmental toxins are rapidly increasing as more new chemicals are synthesised and applied in agriculture, nutrition and industry including conventional and unconventional mining exploration. In the coal seam gas (CSG) exploration industry, fracking or fracturing and venting are common methods of extraction where several hundred known and unknown chemicals are used or released from the ground during the mining and venting process. Chemicals associated with fracking can lead to headaches and migraine, stress and anxiety, toxic encephalopathy as well as dizziness/balance problems and seizures. Quick and accurate as well as economical diagnostic tools are required for confirming neurological disease or toxic encephalopathy. Quantitative electroencephalography (qEEG) is one such tool for obtaining baseline data that may be associated with toxic encephalopathy. Characteristic EEG findings from the literature are focal or generalised slowing in the delta and theta frequencies or fast beta rhythms indicative of diffuse or focal cerebral structural damage and dysfunction. This paper discusses some of the common chemicals associated with CSG mining and associated EEG findings.

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Keywords: Encephalopathy; Coal Seam Gas, toxins; Electroencephalogram

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<th>ARTICLE INFO</th>
<th>* Corresponding author.</th>
</tr>
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<td>September 18, 2019</td>
</tr>
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<td>REVIEWED</td>
<td>October 24, 2019</td>
</tr>
<tr>
<td>ACCEPTED</td>
<td>February 23, 2020</td>
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</tbody>
</table>

Email: herbert.jelinek@ku.ac.ae
1. Introduction

The Environmental Protection Agency of the United States of America reported the use of 84,000 chemicals by 2012, which does not include chemicals produced in low volumes. The number of new chemicals added each year is approximately 1,000 to 2,000. Ensuring public health has become increasingly difficult despite improvements in large scale monitoring, better awareness of health risks and increased human relevance associated with the increase of chemicals into the environment (Pool & Rusch, 2014). Neurological problems such as headaches, dizziness, disorientation, depression and encephalopathy have been associated with products listed by coal seam gas mining (CSG) companies. Characteristic, although not specific EEG changes have also been reported following exposure to products associated with coal CSG mining such as chemicals and heavy metal particulate matter, which may be signs of toxic encephalopathy.

2. Encephalopathy

Encephalopathy is defined by nonfocal or symmetrical brain dysfunction caused by histopathological changes, in the cortical and subcortical areas of the brain but is in many cases asymptomatic depending on level and length of exposure (Kim & Kim, 2012). Encephalopathy is associated with altered mental states, memory loss, cognitive decline, and personality changes, lack of concentration and attention and lethargy. There are many causes of encephalopathy including bacteria, viruses, solvents, drugs, radiation, paints, industrial chemicals, and some metals as well as metabolic or mitochondrial dysfunction. The most common encephalopathy discussed in the literature is metabolic encephalopathy, which is characterised by systemic organ dysfunction including the liver and kidney leading to increased toxic metabolites and cerebral histopathology (Perugula & Lippmann, 2016).

The National Institute of Neurological Disorders and Stroke listed 836 clinical trials related to encephalopathy in 2019 with one trial addressing carbon monoxide poisoning, 138 for hepatic encephalopathy, seven mitochondrial encephalopathy studies, seven sepsis-related encephalopathy studies, 26 substance-related disorders of which two addressed hepatic encephalopathy and 17 listed as toxaemia, which included five associated with septic encephalopathy (Clinical Trials). No clinical trials on toxic encephalopathy or environmental encephalopathy were listed. However continuous exposure to various environmental, industrial, nutritional and/or agricultural toxins is increasing and can lead to peripheral or central nervous system dysfunction and hallmarks of toxic encephalopathy. Examples of toxic encephalopathy with possible encephalogram anomalies include spastic paraparesis caused by \( \beta \)-N-methylamino-L-alanine (BMAA) in lathyrus sativus peas, exachloraphene encephalopathy, mercury encephalopathy, acute ethylene glycol poisoning and organic solvent encephalopathy (Dobbs, 2011; Valk & van der Knaap, 1992). A closer look at signs and symptoms of possible neurotoxicity that may show EEG anomalies include severe fatigue, weakness, headaches, spontaneous nose bleeds, numbness and paraesthesia, twitching or unusual movements, clumsiness or unsteadiness (McCarron, 2013).

2.1 Toxic encephalopathy diagnostics

Toxic encephalopathy may be an outcome of exposure to environmental toxins. Both physical and neurological examination is required to establish the presence of toxic encephalopathy. Diagnosis of toxic encephalopathy can be divided into acute diffuse toxic encephalopathy or chronic toxic encephalopathy. To date only a limited number of physical signs have been identified that are associated with specific environmental toxins and include blue gums following lead intoxication (Rao, Vengamma, Naveen, & Naveen, 2014). Acute diffuse toxic encephalopathy is relatively easy to identify as there is a distinct correlation of symptoms with time since exposure and place of exposure to a known toxin. Acute diffuse toxic encephalopathy is characterised by mild euphoria, stupor or seizures, which can lead to coma and death. Chronic toxic encephalopathy involves continuing diffuse injury to the brain resulting from cumulative or repeated exposures over months or years to solvents or heavy metals and involves varying degrees of impairment (Firestone & Longstrength, 2004). Chronic toxic encephalopathy is more difficult to diagnose and consists of a number of subcategories depending on severity and length of exposure. Chronic toxic encephalopathy manifests as mood disorders, deficits in attention, memory and learning as well as decreased psychomotor function. Cerebellar syndromes include gait ataxia, dysarthria, intention tremor, gaze-evoked nystagmus, most often due to methyl mercury, methyl bromide, dimethyl and trimethyl compounds. Manganese and carbon disulphide can lead to Parkinsonism and vascular encephalopathy respectively (Kim & Kim, 2012). Encephalogram (EEG) changes associated with encephalopathies are similar, whether due to septic, metabolic, toxic, or structural causes. Non-invasive and simple EEG analysis may provide some indication of structural changes due to encephalopathy including toxic encephalopathy.

2.2 EEG findings

Assessment of EEG rhythm characteristics provides information on focal or lateralised abnormalities of the brain, which could suggest a structural basis for an encephalopathy if the intermittent or persistent focal slowing is observed consistently and hence corresponds to a focal or generalized cerebral dysfunction or both (Andraus & Alves-Leon, 2011). EEG records associated with drug or toxin encephalopathy can show focal or generalised slowing in the delta and theta frequencies indicative of diffuse or focal cerebral dysfunction, or fast beta rhythms (Smith, 2005). However, in more severe encephalopathy cases burst-suppression, background suppression and cerebral electrical inactivity can also be present. In addition less common patterns include alpha coma, spindle coma and triphasic waves (Altwegg-Boussac et al., 2017).
3. Chemical Use in Coal Seam Gas Exploration

The number of chemicals used in CSG mining, fracking and venting is estimated to be approximately 1,000. An investigation by the United States Committee of Energy and Commerce in 2011 published results from a survey of 14 oil and gas service companies about types and volumes of hydraulic fracturing products used between 2005 and 2009 (Kim & Kim, 2012). Results indicated the use of more than 2,500 products containing 750 chemicals and other components. Although some were harmless to health, others that are hazardous to health included benzene and lead and for many exposure to these is occurring daily in non-CSG mining areas such as petrol stations. Twenty nine of the 750 chemicals and components are known to be possible human carcinogens and were contained included in the list of the 2,500 products. BTEX compounds – benzene, toluene, ethylbenzene and xylene were part of 60 hydraulic fracturing products (Waxman, Markey & DeGette, 2011). Most chemicals used in CSG mining are either not disclosed or not been assessed for toxicity and short or long term health effects. In the USA between 2005 and 2009 the 14 companies investigated reported using 94 million gallons of 279 products that contained at least one product that was undisclosed (Waxman, et al., 2011). Disclosure of chemicals used in mining and fracking is not required in Australia or in the United States of America. A Bill passed by the American Government in 2005 which exempts fluids used in the natural gas extraction process of hydraulic fracturing from protection under the Clean Air Act, Clean Water Act and Safe Drinking Water Act and from regulation by the Environmental Protection Agency is referred to as the Haliburton Loophole (Palmer, Short & Auch, 2018). However, approximately 40-50% of chemicals used during CSG mining could affect the brain or nervous system, of which some at concentrations below current recommended as hazardous (Colborn , Kwiatkowski , Schultz & Bachran, 2001). An example of what has been proclaimed as clean energy and hence not hazardous by the CSG Industry is the emissions of the Curtis liquefied natural gas plant which released 4,800 tonnes of carbon monoxide, 4,300 tonnes of nitrous oxides, 620 tonnes of volatile organic compounds and 190 tonnes of carcinogenic formaldehyde (Lloyd-Smith & Senjen, 2011). A report compiled by Wayne Somerville (Somerville, 2014) lists some of the chemicals in use for CSG mining in Australia (Table 1).

Table 1. Known chemical used in CSG mining operations in Australia

<table>
<thead>
<tr>
<th>Drilling Fluid</th>
<th>Hydraulic Fracturing</th>
<th>Fracking</th>
</tr>
</thead>
<tbody>
<tr>
<td>Viscosifiers (benzontine, polycrlylamide)</td>
<td>Gelling agents (guar gum, diesel, alkans/alkenes)</td>
<td>Corrosion inhibitors (e.g., formamide, methanol, naphthalene, naphtha, nonyl phenols, acetaldehyde)</td>
</tr>
<tr>
<td>Weighting agents (barium sulphate)</td>
<td>Gel stabilisers (sodium thiosulphate)</td>
<td></td>
</tr>
<tr>
<td>Bactericides/biocides (glutaraldehyde)</td>
<td>Gel breakers (Ammonium persulfate, sodium persulfate)</td>
<td>Scale inhibitors (e.g., ethylene glycols)</td>
</tr>
<tr>
<td>Salts (KCl, NaCl, CaCl&lt;sub&gt;2&lt;/sub&gt;)</td>
<td>Friction reducers (polyacrylamide, mixtures of methanol, ethylene glycol)</td>
<td>pH adjusting agents (sodium or potassium carbonate)</td>
</tr>
<tr>
<td>Breakers (diassium peroxysulphate, hemicellulose enzyme)</td>
<td>Surfactants (isopropanol, 2-Butoxyethanol /2-BE)</td>
<td>Diluted acid to dissolve minerals (e.g., hydrochloric acid, muriatic acid)</td>
</tr>
<tr>
<td>Scale inhibitors (anionic polycrlylamide, acrylamide copolymer)</td>
<td>Biocides (glutaraldehyde, Tetraks hydroxymethyl phosphonum sulfate/THPS, 2-Bromo-2-nitro-1,3-propanedio (Bromopol), 2,2-Dibromo-3-nitriopropionamide)</td>
<td></td>
</tr>
<tr>
<td>Emulsifiers and demulsifiers</td>
<td>Clay stabilisers (tetramethyl ammonium chloride)</td>
<td></td>
</tr>
<tr>
<td>Polymer stabilisers (Sodium sulfite)</td>
<td>Buffer fluids and cross-linking agents</td>
<td></td>
</tr>
<tr>
<td>Defoamers (glycol blends, light aromatic and aliphatic oil, naptha)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrosion inhibitors (zinc carbonate, sodium polyacrylate)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lubricants (chlorinated paraffins)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The National Toxins Network in Australia reported that of the 23 compounds it has identified as toxic, only two have been assessed by the National Industrial Chemical Notification and Assessment Scheme (NICNAS) (Lloyd-Smith & Senjen, 2011) despite glutaraldehyde, brominated biocides, propargyl alcohol, 2-butoxyethanol and heavy naphtha having been found to be dangerous at concentrations near or below chemical detection limits (Somerville, 2014). Additional substances known and reported to be associated with CSG mining are shown in Table 2.

Table 2. Additional CSG Chemicals

<table>
<thead>
<tr>
<th>Compound</th>
<th>Storage</th>
<th>Hazardous Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>2-methyl phenol</td>
<td>Chloride</td>
<td>Silver</td>
</tr>
<tr>
<td>Acrylamide polymer</td>
<td>Copper</td>
<td>Styrene</td>
</tr>
<tr>
<td>Arsenic</td>
<td>Cyanide</td>
<td>Uranium</td>
</tr>
<tr>
<td>Barium</td>
<td>HMX (Octogen)</td>
<td>Diesel</td>
</tr>
<tr>
<td>Benzene, Toluene, Ethylbenzene, Xylene (BTEX)</td>
<td>Methane</td>
<td>Radon</td>
</tr>
<tr>
<td>Cadmium</td>
<td>Poly-aromatic hydrocarbons</td>
<td></td>
</tr>
</tbody>
</table>

Only a limited number of these compounds have been assessed for their neurological effect using any available modality such as MRI, PET or EEG.
3.1 CSG chemicals and EEG findings

Organic solvents and other substances containing toluene associated with CSG exploration are known to cause multifocal neurologic pathology and mental disorders, cerebral, cerebellar and brain stem atrophy, and diffuse focal white matter abnormalities detectable by MRI and EEG changes in animals and humans (Takeuchi & Hisanaga, 1977; Valk & van der Knaap, 1992). A closer look at some of these and other compounds associated with CSG exploration follows.

3.2 Carbon dioxide and radioactive emissions

Atmospheric enrichment of carbon dioxide and radon-222 gas has been reported in the Tara coal seam gas fields in Australia (Tait, Santos, Maher, Cyronak & Davis, 2013). Increased carbon dioxide leading to blood alkalosis can interfere with cerebral function by a relative increase in low frequency power in the delta (1-3 Hz), theta (4 to 7 Hz) and alpha (8-13 Hz) range of the quantitative EEG (qEEG) spectra indicating reduced brain arousal (Kety & Schmidt, 1946; Posner & Plum, 1960; Xu et al., 2011). Default mode network investigation has also indicated a significant reduction between normocapnia and hypercapnia in the connection between the posterior cingulate cortex, bilateral inferior parietal regions, medial prefrontal cortex, and medial temporal lobe. With similar results in the sensory motor networks of the brain using fcMRI (Xu et al., 2011). Radon-222 (radon) has been studied extensively as an environmental toxin and has been shown to be associated with lung cancer. However, radon gas may also affect different parts of the brain with different areas having different susceptibility to radon gas. The amygdala and hippocampus being the most susceptible with the proviso that susceptibility differs between individuals. What increases susceptibility is not known and hence setting threshold values may not prevent radon-caused toxic encephalopathy (Momčilović, Lykken & Cooley, 2006). However, radiation therapy, which has a different dose exposure to possible radon emissions from CSG mining has led to leukoencephalopathy in some patients with EEGs characterised by diffuse background slowing consistent with moderate to severe toxic encephalopathy and no focal or epileptiform waveforms (Cummings et al., 2016). No publications were found discussing EEG findings associated with increased environmental cesium-137 or lead-210, two substances also found in areas of CSG exploration.

3.3 Lead and cadmium

Lead poisoning is one of the earliest reported occupational diseases known and already common in Ancient Greece and the Roman Empire (Woolley, 1984). Lead and cadmium effects on sensory evoked potentials and qEEG have been reported from the early 1980s (Benignus, Otto, Muller, & Seiple, 1981; Otto, Benignus, Muller & Barton, 1981; Thatcher & Lester, 1985). Thatcher and co-workers reported an increase in the amount of slow wave activity in the EEG and a decrease in the amplitude of the EEG. To note is that lead and cadmium have different affinities for cortical and subcortical regions and susceptibility to altered CNS function and convulsion varies with age and exposure levels (Thatcher, McAlaster, Lester, & Cantor, 1984). Examination of qEEG z-scores reported by Cantor showed one third of cases with anomalous findings in the frontal regions with increased θ-band relative power and abnormal hypercoherences (Cantor, 2000). Alpha and β activities of the EEG may also be more abundant in long term exposure to lead (Kovala et al., 1997). Mani et al. (1998) however did not observe any EEG anomalies in their cohort. Quantitative EEG findings included θ- and δ-band amplitude that decreased with age. Scalp sensor location at P3 and P4 indicated a greater amplitude at P3, and bilateral community increased with age in the δ-band. These EEG changes were observed with low level lead exposure without any clinical or behavioural symptoms present (Benignus, et al., 1981). A more recent case study using MRI reported bilateral symmetric anomalies of the thalamus, lentiform nucleus, external capsules, and sub-cortical white matter suggesting toxic demyelination (Rao, et al., 2014). Cerebellar white matter and demyelinating peripheral neuropathy have also been reported with lead poisoning and seizures may also be present due to inhibition of gamma-aminobutyric acid (GABA) transmission (Landrigan & Todd, 1994; Mani, Chaudhary, Kanjalkar & Shah, 1998; Silbergeld, Miller, Kennedy & Eng, 1979).

3.4 Nitrous Oxide

Nitrous oxide is a NMDA receptor antagonist and used clinically for sedation and possibly for depression. Nitrogen oxides are generally non-toxic at low concentrations, and are a by-product when CSG is treated for sale. Nitrous oxide emissions have risen from 710 tonnes in 2013-14, to 1,300 tonnes in 2014-15 (McCarron, 2013). Neurological assessment has shown a dose-dependent reduction in P-300 amplitude and prolongation of P-300 latency of evoked potentials when psychomotor impairment was present following an acute dose of nitrous oxide. However, these changes in brain function were not apparent with EEG suggesting that measures of evoked potential are possibly more sensitive compared to EEG (Estrin, Moore, Letz & Wasch, 1988). In another study five increasing concentrations of nitric oxide were investigated and administered for 15 min. EEG was recorded bilaterally at the frontal poles. At the highest concentration the EEG showed increased θ-band, β at the 40-50 Hz, and 70-110 Hz band powers (Rampil, Kim, Lenhardt, Negishi & Sessler, 1998). Emerging slow wave rebound activity may also be present once nitrous oxide is withdrawn.

3.4 BTEX in coal seam gas mining

BTEX which stands for benzene, toluene, ethylbenzene and xylenes is a Volatile Organic Compounds (VOR) found in tar, crude petroleum, diesel and petrol fuels and a variety of petroleum-related products and used by the CSG industry as a solvent. Naturally occurring BTEX compounds are typically found in seawater around areas of natural gas and petroleum deposits, coal
deposits and in gas emissions from volcanoes and bushfires. BTEX has been banned by both the NSW and Queensland Governments for use in CSG mining however due to naturally occurring BTEX found in soil and released in the flowback water, ground water contamination can still occur and become a health hazard (Waxman et al., 2011; Webb et al., 2018).

Solvent toxicity generally manifests as diffuse or localised δ-band activity. Reported prevalence of EEG anomalies associated with industrial solvents including benzene ranged between 35% to 80% (Seppäläinen, 1988). No specific data was located for effects of benzene on EEG. EEG findings associated with ethylbenzene are most often generalised with paroxysmal changes (Indulski, Sineczuk-Walczak, Szymczak & Wesolowski, 1996).

Toluene toxicity has been reported in several studies with concomitant EEG findings. Toluene leukoencephalopathy is the main neuropathology associated with white matter damage. Other neuro- and psychopathology includes ataxia, tremors, emotional lability and mental changes (Folley, Halliday & Kleinschmidt-Demasters, 2004; Satran & Dodson, 1963). An animal model of toluene exposure indicated that EEG characteristics vary with toluene concentration and with sleep-wake cycle as well as with respect to CNS location. In a study comparing the highest exposure group to the lowest indicated that for the highest toluene concentration δ1 diminished and β1 and β2 cortical components increased significantly. In contrast in the lowest toluene exposure group, δ1, θ and α bands were significantly reduced but β1 and β2 bands showed no significant change (Takeuchi & Hisanaga, 1977).

Xylene is generally considered to be more acutely toxic than benzene, but similar to toluene (Bergman, 1979). Acute effects of solvents including xylene on the central nervous system can be observed already at very low concentrations (Gamberale, Annwall & Hultengren, 1978). Xylene can lead to giddiness, anorexia, and vomiting and exacerbate seizures in susceptible individuals. Occupational exposure to xylene has been associated with anaemia, thrombocytopenia, leukopenia, chest pain with ECG abnormalities, dyspnoea and cyanosis, in addition to CNS symptoms (Langman, 1994). Exposure may increase the dominant α-band frequency and percentage. However, the effects of short-term xylene exposure on EEG were minor, and no deleterious effects were noted (Seppäläinen et al., 1991).

3.4 Carbon monoxide

Carbon monoxide is emitted during flaring and from machinery. Acute carbon monoxide poisoning can lead to lateralized sharp waves and a focal electrographic seizure discharge within hours of the exposure as well as delayed toxic encephalopathy and cognitive sequelae. MRI findings found bilateral abnormal white matter changes within the cerebral hemispheres and abnormal signal intensity within the basal ganglia putamen and caudate nuclei (Neufeld, Swanson & Klass, 1981; Tapeantong & Pourvarin, 2009). No EEG reports associated with carbon monoxide were found.

3.5 Sulfur dioxide and hydrogen sulfide

Hydrogen sulfide occurs naturally in some gas formations and can be released when gas is vented or flared, or via fugitive emissions. Hydrogen sulfide, is a potent neurotoxin. Sulfur dioxide and hydrogen sulphide are components of coal seam gas but are also produced by diesel equipment (Esen, Özer, Soylu, Rend & Fiske, 2018). These gases lead to oxidative stress and neurotoxicity (Zhang, Vincent, Halliwell, & Wong, 2004). Exposure to sulfur dioxide and hydrogen sulphide can lead to decreased mitochondrial DNA and loss of ATP, which may have an effect seen by EEG as a consequence of energy failure and toxic encephalopathy (Tzoulis et al., 2010). Hence increased δ-band activity may be assumed in response to loss of ATP to conserve energy (Dworak, McCarley, Kim & Basheer, 2011).

3.6 VOCs, formaldehyde, glutaraldehyde and styrene

Volatile organic compounds (VOC) contain benzene and ethyl-benzene, which have adverse neurologic and respiratory effects. Formaldehyde forms when methane is exposed to sunlight and then transforms to carbon dioxide by photo-oxidation in ambient air (Kaden, Mandin, Nielsen, & Wolkoff, 2010). Formaldehyde, naphthalene and benzyl chloride were reported to be used in 34% of all hydraulic fracking operations in the United States between 2010 and 2011 (https://www.ecowatch.com/2013/cancer). Formaldehyde, naphthalene and benzyl chloride were reported to be used in 34% of all hydraulic fracking operations in the United States between 2010 and 2011 (https://www.ecowatch.com/2013/cancer). Increased formaldehyde around CSG fracking sites is a threat to the local environment. Formaldehyde may lead to thirst, headache, dizziness, apathy, and inability to concentrate. The effect of formaldehyde on EEG is unclear with studies reporting a dose-dependency but in some instances no EEG changes have been observed (He'ldman & Bonashevskaya, 1971; NRC, 1980).

Sarin is a nerve gas and belongs to the group of VOCs, which has been extensively studied and EEG analysis reported. EEG analysis to sarin exposure, indicated long-term effects on EEG. Statistically significant effects of sarin were marked desynchronised EEG with increased β-band activity, increased δ and θ band slowing, and decreased α-band activity. At higher doses, VOCs may lead to convulsions and muscular paralysis, characterised by a general slowing of the EEG and spike wave discharges (Duffy, Burchfield, Bartels, Gaon & Sim, 1979). VOCs share similar structures and pharmacological action and therefore this study may be extrapolated to VOCs associated with CSG mining and venting.

Glutaraldehyde has similar properties to formaldehyde and is also used as a biocide by the CSG industry. It is present in produced water as part of the fracking operation (Campa et al., 2018). A suspected case of glutaraldehyde poisoning was reported in 2002 with headache, loss of attention, dizziness, anxiety, drowsiness and alteration of homeostatic reflexes (Proietti, Longo & Duscio, 2002). No specific reports discussing the toxic effects of glutaraldehyde on EEG were located in the current study. Glutaraldehyde however has led to a significant increase in deaths due to leukaemia, and brain, colon and prostate cancers in a group.
of embalmers, anatomists and pathologists compared to an age controlled group (van Birgelen et al., 2000). Glutaraldehyde may also lead to mitochondrial dysfunction and ATP depletion and therefore may cause similar changes to the EEG as discussed above for sulfur dioxide (Lin, Yuan, Deng, Niu & Chen, 2019; Tiffert, Garcia-Sancho & Lew, 1984).

Abnormal EEG were found in 24% of participants in a study of styrene exposure reported by Seppäläinen (Seppäläinen, 1988). EEG anomalies included were excessive diffuse θ-band activity and localized slow waves in the posterior regions. Bilateral spike and wave (S&W) discharges may be present as well as focal slow wave activity. Continuous exposure to VOCs may also lead to environmental chemical odour intolerance or chemical sensitivity, which has a different presentation to environmental toxin exposure (Miller, 2001). Common signs and symptoms may include decreased REM percent and longer REM onset latency (Bell et al., 1996).

3.7 Diesel

Diesel exhaust is a mixture of combustion derived nanoparticles (CDNP) and hydrocarbons, carbon monoxide, nitrous oxides, polycyclic aromatic hydrocarbons (PAHs) and redox metals (Crüts, et al., 2008).

Particulate matter in the nanoparticle range such as found in exhaust diesel can translocate into the brain via the olfactory nerves leading to extensive oxidative stress (Oberdorster, et al., 2004). Carbon monoxide, nitrous oxides and hydrocarbons may also lead to decreased θ and α, and increased β and γ-band EEG changes via vagal reflexes from the lungs (Koo, 2001; Lewine, Paulson, Bangera, & Simon, 2019; McQueen et al., 2007). A recent study of exposing volunteers to dilute diesel exhaust as a model for ambient particulate matter exposure indicated a significant increase primarily in the β1 power frequency (20-32 Hz) in the frontal cortex at Fp1 and Fp2 and F3, F4 following 30 minutes of exposure. Median power frequency changes spread to central C3 and C4 as well as to parietal sites, P3 and P4 but no significant change in β2 power was observed. β1 activity (15–20 Hz) also increased during diesel exposure at the frontal cortex, but was not significant, whilst no significant change was observed for δ, θ and α-bands when compared to the sham group. The findings suggested increased left frontal cortex activity (Crüts et al., 2008).

Many more chemicals and particulate matter have been investigated and found to have toxic effects. Of those in public lists, not all are known to lead EEG anomalies. For a list of these the reader is referred to the various Government publications and also for a comprehensive list by Geralyn McCarron and the publications by Mariann Lloyd-Smith (Lloyd-Smith & Senjen, 2011, 2016; McCarron, 2013). Further research is therefore required to establish biomarkers for substances associated with Coal Seam Gas mining and venting and their association with neuropathology and EEG findings. Table 3 provides an overview of location and effects of some of the main chemicals associated with fracking but is not exhaustive as more research is required for many of the chemicals listed and those mentioned in the tables above.

Table 3. Local, EEG characteristics and neurology associated with known fracking chemicals.

<table>
<thead>
<tr>
<th>Chemical</th>
<th>Location</th>
<th>EEG Characteristic</th>
<th>Neuropathology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Organic solvents</td>
<td>Multiple sites</td>
<td>Increase in low frequency power</td>
<td>Multifocal neuropathology</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Mental disorders</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CNS atrophy</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Reduced brain arousal</td>
</tr>
<tr>
<td>Carbon Dioxide</td>
<td>posterior cingulate cortex, bilateral inferior parietal regions, medial prefrontal cortex, and medial temporal lobe</td>
<td>Possible diffuse background slowing</td>
<td>Alzheimer’s disease</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Radon-222</td>
<td>Amygdala, hippocampus, temporal lobe, frontal lobe, occipital lobe, parietal lobe, substantia nigra, locus ceruleus, nucleus basalis</td>
<td>Increase slow wave activity and decrease in EEG amplitude</td>
<td>Seizures, irritability, headache, mental dullness and attention</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>difficulty, memory loss, tremor, and hallucinations</td>
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<tr>
<td>Cesium-137</td>
<td>Frontal regions P3 and P4 Thalamus, lentiform nucleus, external capsules, and sub-cortical white matter, cerebellar white matter</td>
<td>Increased θ-band relative power in posterior areas</td>
<td>Atrophy, changes in corpus callosum, Extensive white matter change in both hemispheres</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>giddiness</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Focal seizures</td>
</tr>
<tr>
<td></td>
<td></td>
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</tr>
<tr>
<td>Nitrous Oxide</td>
<td>Frontal areas</td>
<td>Increase in 10-30 Hz, and 70-110 Hz band powers</td>
<td>Motor, behavioural, and cognitive deficits</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Dementia</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Headaches, dizziness, apathy, and inability to concentrate</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BTEX</td>
<td>Lateralised sharp waves, Bilateral white matter change</td>
<td>No changes in EEG reported</td>
<td>convulsions and muscular paralysis</td>
</tr>
<tr>
<td>Carbon Monoxide</td>
<td></td>
<td>δ, β1 and β2, θ, and α bands</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sulfur Dioxide &amp; hydrogen Sulfide</td>
<td>hippocampus</td>
<td>Increased δ-band and θ-band activity</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Formaldehyde &amp; Glutaraldehyde</td>
<td>unclear</td>
<td>Possible increased θ-band and θ-band activity with glutaraldehyde</td>
<td></td>
</tr>
<tr>
<td></td>
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<td></td>
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</tr>
<tr>
<td>Sarin</td>
<td>General slowing of EEG</td>
<td>desynchronised EEG with increased θ-band activity, increased δ and θ band slowing, and decreased α-band activity</td>
<td></td>
</tr>
</tbody>
</table>

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4. Prevention and Treatment Options for Toxic Encephalopathy

Foremost is the removal of the toxic substance from the environment or in most instances removing the person from the source of the toxin. Regular detoxifying by workers exposed to fracking may reduce exposure caused neuropathy. Toxic encephalopathy needs to be carefully investigated as it may be asymptomatic or signs and symptoms of toxin exposure may have a similar presentation to psychiatric signs and symptoms, metabolic, inflammatory, carcinogenic and neuropathological signs of diverse etiology (Schaumburg & Spencer, 1987). Therefore, it is essential to have an accurate occupational history and detailed neurological examination result. Treatment is then based on the extent of the signs and symptoms displayed by the patient and the toxic substance causing the neuropathology (Berisavac et al., 2017).

Prevention should be considered in all cases by reducing exposure to toxins and providing sufficient safeguards such as protective clothing. Neurofeedback is an adjunct or alternative therapy often found efficacious for epilepsy, anxiety and psychosis often associated with toxic encephalopathy. Neurofeedback treatment protocols focus on training alpha, beta, delta, theta, and gamma or a combination of these. Alternative modes include amplitude training or z-score training amongst others. The observation that seizure incidence due to inhalation of lunar landing fuel by NASA astronauts was lowered significantly by sensory-motor rhythm neurofeedback training (Sterman & Egner, 2006) suggests that neurofeedback may be useful in normalising EEG rhythm patterns or reducing the incidence of toxic encephalopathy in toxin exposed workers by enhancing neuronal or brain reserve by enhancing the capacity to compensate for dysfunction. However, caution needs to be exercised when providing neurofeedback as an incorrect protocol may result in an increased blood flow to the brain and hence increase the toxic effects of the chemicals. This application of preventative neurofeedback requires further research to address the increasing use of industrial chemicals.

References


Neural Network for Detection of Students’ interest using Approximate Entropy Features of EEG data

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Abstract

Studies have found that optimizing course contents or lecture materials according to student’s interest could improve learning outcomes. In this work, we advocate the use of Electroencephalogram (EEG) as a modality to qualify student’s interest based on their respective brain activities. An EEG-based detection of interest in real classroom environment using Approximate Entropy (ApEn) is proposed. The method involved the use of Artificial Neural Networks (ANN) to discriminate the EEG data as relevant to either high or low situational interest. The qualitative assessment was performed by Personal Interest (PI), Situational interest (SI) questionnaires and knowledge tests which were considered as ground truth for the classifications. An accuracy of 100\% and $R^2=0.996$ was achieved in classifying 17 students as high SI or low SI. The results show that the proposed features could be used to differentiate brain activities based on student’s interest.

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Keywords: Situational interest, EEG, classroom, Approximate Entropy and ANN.

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<td>ACCEPTED</td>
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* Corresponding author. Email: areej555@gmail.com
1. Introduction

Researchers divided interest into personal and situational interest, while both lead to focused attention on the object of interest, situational interest is easily triggered and controlled by the situation. Therefore, many studies were carried out to explain the science of interest development and how to utilize it for the benefit of learners. For a field like mathematics “Proficiency in mathematics is a major advantage in industrialized nations” (Maloney, Schaeffer, & Beilock, 2013) where many students are scared of and not willing to do the effort, situational interest have remarkable effect. In recent study (Bernacki & Walkington, 2018), it was reported that the increase in situational interest caused by personalizing 4 units of algebra story problems to students lead to greater interest in mathematics and higher score in class tests for those students compared to control group.

One way to study this interest is by studying the underlying brain activities. Electroencephalogram (EEG) is among the most effective non-invasive equipment in this case due to the advanced technology that made it available with relatively low cost. Moreover, the signals produced by EEG cannot be manipulated by participant unlike questionnaires. Therefore, its used extensively in classroom experiments to detect student’s attention and engagement e.g. (Poulse, Kamronn, Dmochowski, Parra, & Hansen, 2017), (Ko, Komarov, Hairston, Jung, & Lin, 2017) and (Sezer, Incl, Çağdaş Seçkin, & Uluçınar, 2015). These studies presented the potential of EEG to indicate attention or engagement but didn’t investigate the possibility of classifying attentive and inattentive students during stimulation or in real time.

To analyze the EEG data, Approximate Entropy (ApEn) is proposed. It is an index of signal disorder and complexity which makes it proper for time series data that is changing overtime. In studying the cognitive load and brain activities ApEn is recommended (Li, JIANG, HONG, DONG, & YAO, 2016), (Cavanaugh, Mercer, & Stergiou, 2007). The features extracted by ApEn are then fed into Artificial Neural Networks (ANN) classifier to design and validate the model that can best show the differences between high and low SI students. ApEn and ANN are popular in classification process for Brain Computer Interface (BCI) systems. ApEn is widely used in analyzing physiological time series data (Alcaraz & Riet, 2010) because of its robustness on moderate length time series data while ANN has a great ability to mimic the neural activities of the brain and achieving high accuracy in cognitive task classifications reaching 98.8% in (Zarjam, Epps, & Lovell, 2015), average of 90% in (Heger, Putze, & Schultz, 2010), (Mazher, Aziz, Malik, & Amin, 2017). Moreover, ANN is non-parametric method which eliminates possible errors resulted from parameter estimation. It also suits well non-linear data such as EEG.

The structure of this paper is as following: section 2 describes the materials and methods used in this study, section 3 presents the result of applying the proposed methods and discusses its implications. Section 4 concludes the paper.

2. Materials and Methods

2.1 Participants

The participants of this experiment were engineering students from Universiti Teknologi PETRONAS (UTP) first-year undergraduate, who have no records of mental illness and not under any medication. The experimental procedure was approved by UTP Ethical Committee. The participants were selected based on a questionnaire regarding joining mathematics club in the university. The questionnaire was run as a pre-evaluation for the level of personal/ individual interest of students and hence a balanced group with high, low and moderate interest participants were selected. Some recent studies showed no significant differences between females and males in terms of academic performance e.g. (Moldovan, Ghergulescu, & Muntean, 2017) and therefore was not considered in this study. Overall 30 students (4 females) participated in this experiment. Selected participants were notified through emails and thoroughly briefed about the experiment and each participant was compensated for their time.

Upon the arrival of participants, researchers assisted them in wearing the 8-channels Enobio EEG cap. After that, baseline data of 4 min eyes opened and 4 min eyes closed were acquired followed by about 22min of lecture. The presentation was delivered through projector to a projector screen. After the EEG recording, Situational Interest (SI) questionnaire and post-knowledge test were undertaken.

From the situational interest questionnaire result, subjects scored ≥ 77 out of 100 were considered high SI students while subject scored ≤ 63 out of 100 were considered low SI students. Subjects scored between 76 and 63 were considered to have moderate situational interest. This evaluation was selected based on trial and error to achieve proper separation between classes/groups while maintaining proper number of subjects in each group. This procedure yielded 17 subjects, 10 high SI and 7 low SI subjects. Presentation questionnaire was used to validate the interestingness of the lecture as described in the below section.

2.2 Stimuli

A lecture on Laplace transform (duration about 22 min) that followed the curriculum for Ordinary Differential Equation (ODE) course was designed and presented in an interesting way to first-year undergraduate students. This was done by relating the materials to everyday life through a careful selection of a Laplace applications and meaningful content throughout the lecture. Using colors, fonts, shapes and pictures along with the animation to facilitate presenting the contents was helpful. A brief history of Laplace transform was added to the original lecture. The presentation slideshow was sent to experts for improvement and feedback. It was then tested with different group of students to rate the interesting points and improve the slides further. The novelty of the content i.e. being new to participants, was ensured by selecting participants who have not taken the course or the lecture before.

To test the effect of these stimuli during the experiments, a questionnaire was run at the end of each session followed by a verbal, non-formal interview. The questionnaire result showed that 83.34% agree that the lecture was interesting, and all participants agree that they look forward for similar lectures, suggesting the stimuli was interesting for majority of participants.
2.3 Methods

Entropy can extract very useful information from EEG especially when changes in time is expected to occur frequently. Entropy value is higher when signal irregularity is higher and entropy value becomes lower with regular signal (Wei et al, 2013). High SI students are hypothesized to have high ApEn value while low SI students will have low ApEn value. Two parameters were specified to calculate the ApEn, the tolerance: \( r = 20\% \) of the standard deviation and the embedding dimension: \( m=2 \) which are preferred values according to similar previous studies (Vega et al, 2013), (Hosseini et al, 2011). The ApEn was calculated as following:

\[
ApEn(m, r, N) = \phi^m(r) - \phi^{m+1}(r) \quad (1)
\]

where \( \phi^m(r) \) is denoted to be:

\[
\phi^m(r) = \frac{1}{N-m+1} \sum_{i=1}^{N-m+1} \ln C_i^m(r) \quad (2)
\]

where \( N \) is the number of points and \( \ln \) is the natural logarithm of the correlation integral \( C_i^m(r) \).

Since EEG is subjective measure and differ from one to another, the baseline data (eyes opened) were used to obtain reliable measurement for each subject and to avoid such subjectivity. The baseline condition data were processed in similar way to the lecture condition to obtain the ApEn features. The percentage of change was calculated by subtracting this baseline-ApEn from each lecture-ApEn values then divide the result by the baseline-ApEn. This procedure was performed for each of the 17 subjects (10 high SI and 7 low SI).

ANN was used to classify the features obtained by ApEn as either high or low SI. It is consisted of multiple artificial neurons that mimic the information processing and interactions of the brain. The neurons work together to form nonlinear decision boundaries which makes it suitable for the non-stationary and nonlinear EEG data. Therefore, it can recognize and create non-linear relationship between the input data and/ or outputs to yield optimum pattern recognition result.

Six networks shown in Table 1 were designed and tested to obtain the optimum classification result.

<table>
<thead>
<tr>
<th>Layers</th>
<th>Net 1</th>
<th>Net 2</th>
<th>Net 3</th>
<th>Net 4</th>
<th>Net 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input</td>
<td>39</td>
<td>39</td>
<td>39</td>
<td>39</td>
<td>39</td>
</tr>
<tr>
<td>Hidden</td>
<td>5</td>
<td>10</td>
<td>15</td>
<td>20</td>
<td>25</td>
</tr>
<tr>
<td>Output</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
</tbody>
</table>

The input layers in all the networks contained 39 neurons corresponding to the 20 min of the lecture which were segmented into 30 s comprising 40 points. The first 30 s was removed because it contained some noise at the start of recording, hence, the input layer consisted of 39 neurons. The network had two classification outputs which are high and low SI. The number of neurons in the hidden layer was determined by increasing 5 neurons each time until reaching the least mean square error (MSE) and coefficient of determination \( R^2 \).

The data were randomly divided such that 6 subjects out of 17 subjects were used for model validation and therefore were not part of the training data that used to design the model (remaining 11 subjects) which is about 35.3% of data used for validation. During designing the model (training phase), the training dataset (11 subjects) was further divided randomly into 70% for training, 15% for validation and 15% for testing the model. The training process was repeated several times with different parameters each time to obtain the best performance with the least Mean Square Error (MSE) and coefficient of determination R2. The best network model was exported and tested with the validation dataset (6 subjects) that were not part of the training set.

MATLAB 2017 toolbox was used for the implementation of ApEn and ANN.

3. Results and Discussion

This section is divided into two divisions that study the result of employing ApEn and the result of classification using ANN.

3.1 ApEn Result

The result of employing ApEn through about 20 min is shown in Figure 1. The figure shows the ApEn values for the average of randomly selected 7 high and 7 low SI subjects. The first 8 min doesn’t have consistent differences between the two classes. After that, clear differences indicating high values for high SI subjects compared to low SI as expected. These high values that show the complexity of the signal due to the brain activities are also found at the 3rd and 7th minute for the high SI subjects. For the low SI subjects, the values were high only at the beginning of the lecture and decreased significantly after the 8th minute till the end of the lecture. It suggests that high SI subjects could keep their brain performance till the end of the lecture unlike the low SI ones.
3.2 Classification Result

The MSE value was decreasing by increasing the number of neurons until reaching 30 neurons where the MSE started to increase. Figure 2 shows the performance of each network described in Table 1.

Figure 2 shows the effect of the size of neural network on the system performance using two statistical standards the MSE and R2. Network 3 and Network4 had comparable performance while the least error was achieved with 20 neurons (Network4) MSE = 8.7E-04, R2 = 0.996. Network5 and Network6 had the highest MSE because of the generalization drop effect that could be caused by overfitting. Increasing the number of neurons further increases the time required for processing. Therefore, 20 neurons network was found to give the best performance with less processing time.

The obtained model was validated using new 6 subjects (division of data into training and validation sets is described in methods section). The proposed algorithm has achieved 100% accuracy in classifying correctly the 6 subjects as high or low SI which is higher than the nearest similar study (Zhu et al, 2017) that achieved 98.99% in classifying high and low SI students. It also showed that ApEn is suitable for describing the changes of EEG signals that could be caused by cognitive functions occurring in the brains. ANN was found suitable for training the model with the acquired features using the artificial intelligence to understand the relationship between the values of ApEn and the output classes.

This study has some limitations. Even though the selected sample size was 30 subjects, only 17 of them were classified as high and low SI based on the criteria described in participants section. Therefore, future studies are encouraged to increase the number of samples to confirm and support the result obtained in this paper. It is also highly recommended to perform the experiment for different subjects/ materials, for example, science or art and compare the results to gain better understanding about interest phenomenon.

4. Conclusion

Increasing students’ situational interest during learning focuses their attention and therefore maximizes their learning and knowledge gain. Assessing the performance of these students in terms of high SI and low SI, and feeding back this information to lecturers and educators assist them to improve teaching strategies in a way that triggers and maintain student’s interest in the class. ApEn features obtained for the raw EEG data and fed into ANN model achieved optimum result with R2 = 0.996. This result suggests the possibility of a real-time monitoring of student’s situational interest in classroom.

5. Acknowledgement

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