Detection of Electroencephalography Artefacts using Low Fidelity Equipment

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Abstract: The use of Electroencephalography (EEG) signals in the field of Brain Computer Interface (BCI) has gained prominence over the past decade, with the availability of diverse applications especially in the clinical sector. The major downside is that the current equipment being used at medical level is specialized, complex and very expensive. Our research goals are to further increase accessibility to this technology by providing a unique approach in data analysis techniques, which in return will allow the usage of cheaper and simpler EEG hardware devices targeted for end users. We use non-invasive BCIs designed on EEG, mainly due to its fine temporal resolution, portability and ease of use. The main shortcoming of EEG is that it is frequently contaminated by various artefacts. In this paper we provide vital groundwork by identifying and categorizing artefacts using low fidelity equipment. This work forms part of a wider project in which we attempt to use those artefacts constructively, when others try to filter them out. The main contribution is to create awareness of the extent to which artefacts can be encountered, identified and categorized using off-the shelf equipment. Our results illustrate that we are able to adequately identify and categorize the most commonly encountered artefacts in a non-clinical environment, using low fidelity equipment.

1 INTRODUCTION

This paper discusses the artefacts of a non-invasive BCI (Brain Computer Interface) on the basis of EEG (Electroencephalography) where the signals will be extracted from the electromagnetic (EM) brain functions without the use of muscular activity. Initially EEG was targeted for use in clinical applications with patients that have medical conditions such as Lou Gehrigs disease (Allison et al., 2012). However over the past decade the use of biomedical signals has also increased significantly in non-clinical applications. This has led to the development of a number of devices that can be controlled by signals emitted from the brain.

At the present time, human BCI research has been developing into two main areas; invasive and non-invasive. The most prevalent invasive techniques are called Electrocorticography (ECoG) or intracortical recordings, which have their electrodes in direct contact with the cerebral cortex while the most prevalent non-invasive technique is called Electroencephalography (EEG) which has its electrodes placed along the scalp surface (Dornhege et al., 2007). The qualitative difference between these areas is that invasive BCI has a much better signal quality with higher amplitudes and spatial resolutions; it has a high signal-to-noise ratio and is less susceptible to artefacts; however it requires a surgical intervention for electrode placement. On the other hand non-invasive BCI has a much weaker signal and is prone to a number of different artefacts. However it has an excellent temporal resolution (Ball et al., 2009) and does not require any surgery.

In addition to using non-invasive BCI based on EEG, our research also makes use of low cost off the shelf equipment. The aim is to increase accessibility to this technology by providing a unique approach in data analysis techniques, which in return will allow the usage of cheaper and simpler EEG hardware devices targeted for end users. This paper does not imply that the low fidelity equipment being used could replace medical equipment; as a matter of fact it does not have any certification; therefore it should be employed sensitively for non-clinical trials. (Frey, 2016) states that "*Open-hardware initiative does not aim at medical applications, hence it should be employed in sensitive contexts.*"

An artefact is a signal that is detected by EEG equipment, which is not of cerebral origin but from

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various different sources. In the context of EEG, artefacts are unwanted since they mask the brain wave signals; however they could potentially be used as a primary interface. According to the glossary of the International Federation of Clinical Neurophysiology (IFCN), the term artefact is described as "*A potential difference due to an extracerebral source, recorded in EEG tracings*"; which is expanded to "*A modification of the EEG caused by extracerebral factors such as alterations of the media surrounding the brain, instrumental distortion or malfunction, and operational errors*" (Noachtar et al., 1999). Artefacts have always been given great importance in the context of EEG due to the undesirable affect that these have on the signal of cerebral origin.

The work presented here is part of a larger EEG-based project, and thus it is important to recognise and understand the artefacts that are detectable. These artefacts are usually an unwanted signal in the context of EEG; however we are interested in using them as part of a control interface. In this paper we prepare the groundwork for filtering and using these artefacts, through categorization of artefacts, and their manifest characteristics, using specific low fidelity equipment.

2 EMPIRICAL INVESTIGATION OF EEG ARTEFACTS USING OFF-THE-SHELF EQUIPMENT

Our work is concerned with exploring the capabilities and limitations of low cost off the shelf equipment which in return will facilitate and increase accessibility for EEG applications. We aim to compensate for the low fidelity aspect of this equipment with enhanced software filtering and analysis. This particular part of the work sets the foundations for further work by investigating the way in which various artefacts are detected, identified and categorized with low fidelity equipment.

A way in which an electrode (input1) is connected relative to another electrode (input2) is called a derivation. A collection of derivations are called a montage and there are several different ones in popular use. The intention of using a specific montage is to keep the experiments tractable and to avoid unnecessary complexity. Moreover other types of montage; even the more complex such as Laplacian and Common Average Reference; can be derived from the collected data, since montage reformatting is achieved by performing a simple mathematical operation. In fact (Fisch, 1999) states that "*for this reason, digital EEG systems store the original EEG signal in a referential montage containing all electrodes*". This is of course possible as long as all the electrodes that need to be combined have in some way been referred to each other in the original recording.

For instance when labelling a channel montage as Fp1-A1, a mathematical expression is being created which implies that the signal displayed will be Fp1 minus A1. If a recording has been obtained from Fp1-A1 and Fp2-A1 then Fp1-Fp2 can be derived from:

$$(Fp1 - A1) - (Fp2 - A1) = Fp1 - Fp2 + A1 - A1 = Fp1 - Fp2 \quad (1)$$

Although montage reformatting is possible to be performed instantaneously, this is ideally used for recorded sessions and is not suggested for real-time streaming.

2.1 Equipment Used

The work reported herein is based on an OpenBCI[1] 32-bit board connected with an Electro-Cap[2] using the international 10/20 system for scalp electrode placement in the context of EEG experiments. A basic overview of the equipment being used is shown in Figure 1.

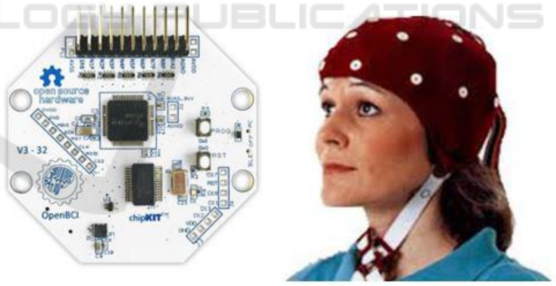

Figure 1: OpenBCI Board and Electro-CAP.

The OpenBCI 32-bit's board microcontroller is the PIC32MX250F128B[3] which includes a 32-bit processor with a maximum speed of 50MHz; storage of 32KB of memory and is *Arduino* compatible.

The board uses the ADS1299[4] IC developed by Texas Instruments, which is an 8-Channel, 24-Bit, simultaneous sampling delta-sigma, Analogue-to-

[1] http://openbci.com/
[2] http://electro-cap.com/
[3] http://www.microchip.com/wwwproducts/en/en557425
[4] http://www.ti.com/product/ADS1299

Digital Converter used for bio potential measurements such as in EEG and Electrocardiography (ECG). The 24-bit resolution gives a huge range of microvolts (μV) that covers +-187mV (187000μV); *the working is shown in section 2.2*. When considering that EEG data ranges are typically between +-100μV, it illustrates that it is able to provide a broad spectrum of flexibility and scalability. Moreover this chip is capable of supporting up to 16,000Hz although the transfer of that much data through an Arduino would be impracticable. There is the ability to use the SD card for faster sample rates, which is discussed below.

The board comes with eight bio potential input channels which can be increased to sixteen channels with the addition of a *Daisy Module*; which plugs itself onto the existing OpenBCI 32-bit board. Our current experiments do not make use of the daisy module, although future experiments may need these extra channels.

The system comes with a pre-programmed USB dongle for wireless communication which communicates with the low cost RFDuino[5] RFD22301 microcontroller built on the OpenBCI board. This microcontroller can communicate wirelessly with any device compatible with Bluetooth Low Energy (BLE). In addition a local Secure Digital (SD) slot is built-in the board, which gives it the ability to store recorded data on SD memory card. This is particularly useful when requiring improved portability and highest data rates.

An additional feature which is included in the OpenBCI board is a 3-axes accelerometer from *ST* with model LIS3DH[6]. This accelerometer is capable of 16 bit data output and of measuring accelerations with output data rates from 1 Hz to 5.3 kHz. This can prove to be quite useful; such as, for sensing change in orientation of the head or sensing rough motion. In these cases the value from the accelerometer would suggest that motion artefacts would be within the EEG data. In our experiments this information was not required, since the board was firmly placed on the desk. However in the future we are planning on using the OpenBCI *Ultracortex MK4* cap, which has the ability of attaching the board to the actual headset, where the data from the accelerometer would be extremely valuable. Figure 2 depicts a graphical representation of these components.

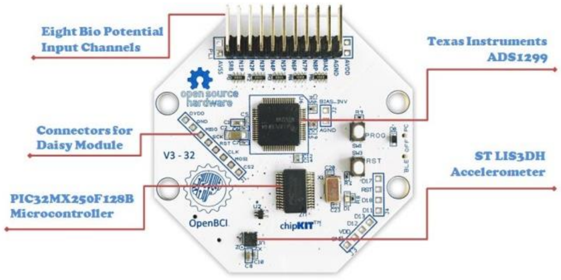

Figure 2: OpenBCI Board Components.

The Electro-Cap being used in our experiments has the fabric which is made from elastic spandex and has recessed pure tin wet electrodes directly attached to the fabric. The term wet electrodes type, implies that the use of an electrolyte gel is required to make effective contact with the scalp; otherwise it may result in impedance instability.

2.2 Experimental Setup

The EEG signals where sampled at 250Hz (this being OpenBCIs default value) while the sampling precision was 24-bit. The recordings where stored anonymously as raw data in text, comma separated value (csv) files. Eight EEG electrodes where used in different regions of the scalp according to the International 10-20 System as shown in Figure 3. This system is the de facto standard for the placement of electrodes along the head. Each electrode is assigned a letter to identify the lobe and a number to identify the hemispheric location. The letters *F*, *P*, *T* and *O* stand for Frontal, Parietal, Temporal and Occipital lobes. In addition, letter *C* refers to the central area of the brain. The even numbers represent the electrodes positioning on the right hemisphere, while the odd numbers represent the electrodes positioning on the left hemisphere. The *Xz* stands for a zero and represents an electrode placed on the midline such as *Fz*, *Cz* and *Pz*. In addition the letter A can represent the reference electrode which will measure the potential difference between itself and the other electrodes and/or the ground electrode for common mode rejection.

The equipment we are using supports the use of eight electrodes. The electrode positions Fp1, Fp2, C3, C4, T5, T6, O1 and O2 are selected because they provide good coverage for detecting these artefacts. These are referenced to the electrode A1 as follows: Channel 1: Fp1; Channel 2: Fp2; Channel 3: C3; Channel 4: C4; Channel 5: T5; Channel 6: T6; Channel 7: O1; Channel 8: O2 as shown in Figure 3. A referential montage was selected to

[5] http://www.rfduino.com/
[6] http://www.st.com/en/mems-and-sensors/lis3dh.html

analyse how artefacts are exposed with this setup, even though no single reference electrode is ideal for all situations. Nonetheless and if required, other types of montage can be reconstructed from the chosen montage by executing a simple mathematical operation; as previously explained. The reference electrode was placed on the left earlobe A1 as shown in Figure 4.

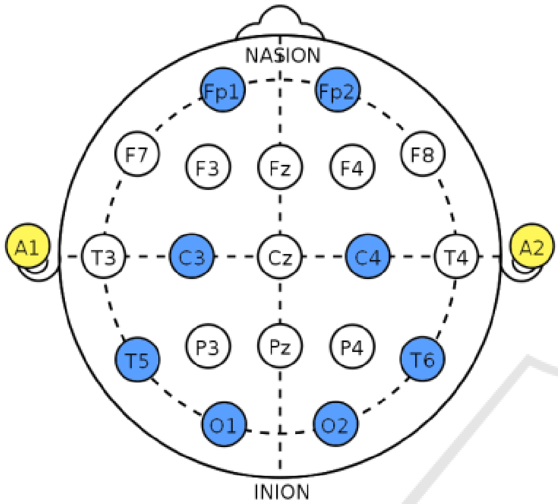

Figure 3: Electrode placement following the International 10-20 system.

EEG signals where obtained from a healthy human subject; male in the age group between 30 and 40 years old and on three different sessions with a few days apart. Before the start of the experiments, the subject was asked to calm down in a seated position and relax for a few minutes. The subject was seated one meter away from the equipment. The researcher and his equipment where situated on the left side of the subject. Then, the subject was instructed on a series of tests such as muscle movement that are designed to detect the artefacts which are discussed in Section 3.

Three trials where conducted for these experiments. The first session results and recordings where archived. The second session was done on a separate day with the same conditions of the first session and the results where archived for comparisons. These two sessions were carried out to familiarize the user with the equipment and the methodology of the experiments. The third session was done a day later with the same conditions of the first and second session and the results are shown in this paper. During the recording the subject received a 2 second beep sound to perform the requested trial and a 1 second beep sound to stop.

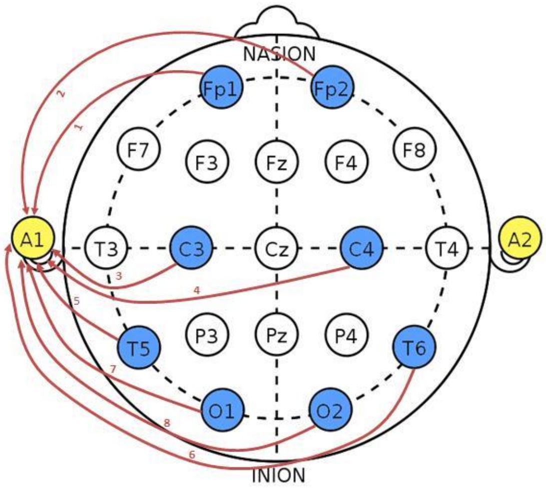

Figure 4: Referential Montage used.

2.3 Processing

The data that was transmitted from the RFDuino module found on the OpenBCI board is considered as 'raw' EEG data in ADC counts. These where transferred as 24-bit integer, since it's the native format used by the ADS1299 chip. Since this is an unusual format, it was immediately converted via the OpenBCI open-source JAVA function '*interpret24bitAsInt32*' into a 32-bit signed integer (Audette, 2014).

Subsequently the *scale factor* was required, which is the multiplier used to convert the EEG values from counts to scientific units like volts. This is found by following the formula in the ADS1299 datasheet table number 7:

$$\text{Scale Factor} = V_{REF} / (2^{23}-1) / \text{Gain} * 1000000 \quad (2)$$

The datasheet also states that the voltage reference input is hardware bound to 4.5volts, while we used the maximum and default gain factor of 24-bit. Thus the formula (2) can be reformed into:

$$\text{Scale Factor} = 4.5\text{v} / (2^{23}-1) / 24 * 1000000 \quad (3)$$

Hence the scale factor value is 0.02235 per count. Therefore the 32-bit signed integer is multiplied by the scale factor and we get the EEG data values in microvolts (µV). This is the actual stored data in the csv file. The full scale of +-187mV (187000µV) discussed in Section 2.1 is achieved by $2^{23} * 0.02235 = +\text{-}187485.388\mu V$.

As previously mentioned the ADS1299 chip is capable of a sample rate of up to 16,000Hz; however in our experiments we used OpenBCIs default rate of 250Hz especially when considering that the data was being transmitted wirelessly through the RFDuino module.

The captured raw data was imported in MATLAB R2014a[7] via the *csvread* command into a MATLAB matrix and any unnecessary rows and columns were removed. These consisted of the first five rows which are superfluous comments; the first column which stored the sample index / packet counter and the last three columns which stored the auxiliary data of the accelerometer.

The MATLAB array was later imported into EEGLAB[8] for processing and for offline qualitative and quantitative analysis. The first process was to apply a 50Hz (60Hz in some countries) notch filter to eliminate the environmental electrical interference, which was only omitted for the 50/60Hz artefact experiment. In addition a high pass filter was applied at 0.5Hz to remove the DC offset and a low pass filter of 49Hz was applied to remove any signal harmonics and unnecessary frequencies which are not beneficial in our experiments. As an alternative a band-pass filter of 0.5Hz-49Hz could have been chosen, however it was not selected since this type of filter does not attenuate all frequencies outside the range. In fact the filter's frequency response function is not very steep; it doesn't completely cut-off at the required frequency, but instead it rolls off more gently with the frequency.

The result from this processing yields a rich EEG signal for our experiments which can be analysed with different tools. The screenshots presenting the EEG signal (see Figures 5-15) where plotted by using the EEGLAB *Plot: Channel Data (Scroll)* menu option. The frequency-time domain screenshots where produced by the *Time-Frequency transforms: Channel-time frequency* menu option. The plot Event Related Spectral Power (ERSP) was employed since it is a statistical measure; the mean of a distribution of single-trial time/frequency transform (Neuper & Klimesch, 2006). In our processing we used the Fast Fourier Transform (FFT) option; 400 time points for the time-frequency decomposition and the frequency was set between one and forty which provides us with enough information for artefacts detection. The baseline was set to the default of 0 for pre-stimulus and the single trial DIV baseline option was used. Subsequently the choice of channel number and time range in relation to the experiment being analysed where entered (such as Channel 1 for FP1; time range 5000ms – 9000ms).

The spectrogram frequency-domain screenshots were produced in Matlab; outside of EEGLAB. The data was filtered using Butterworth filter design of the second order. First a notch filter was used followed by a low pass and a high pass filter; with the same values used for EEGLAB. The actual code for the filtering and the spectrogram are shown in the appendix section.

[7] https://www.mathworks.com/products/matlab.html
[8] https://sccn.ucsd.edu/eeglab/

3 ARTEFACTS - RESULTS

Although a number of research papers have been published showing different types of artefacts such as (AYDEMIR et al., 2012) and (Begum, 2014); these were presented with a "black box" approach or using medical equipment, or otherwise, mentioned in a different context. What we present in this paper are results that are relevant to our own specific low fidelity hardware.

An EEG device is very sensitive and it is easily susceptible to disruption from other electrical activities. Moreover some artefacts are easily distinguishable while others closely resemble cerebral activity and are very challenging to be recognized. Artefacts are usually categorized as physiological (biological) and non-physiological (extra physiological) (Fisch, MD, 2000). The classification mentioned below is not rigorous; for instance, if the subject makes a movement, this may lead to artefacts originating as electrode artefact.

Even though signal artefacts caused by non-brain wave signals can be problematic when studying brain waves directly, the signal artefacts themselves could be used directly as command signals within an interface.

3.1 Physiological Artefacts

Physiological artefacts are bioelectrical signals that are generated from the user's body excluding the brain. These are usually embedded along the electrical cerebral bio-signals in an EEG session. The physiological artefacts include, but are not limited to:

3.1.1 Ocular Artefacts

Ocular artefacts are essentially a result from the eyeball acting as a dipole which becomes pertinent when it develops into a moving electrical field such as when the subject opens and closes his eyes and/or the EMG potentials from muscles in and around the orbit. These generate signals that are detected predominantly by electrodes Fp1/Fp2 and F7/F8.

1) Blink: blink/blinking which is the most common ocular artefact, occurs spontaneously and is very challenging for the subject to control even for short periods of time. When the subject blinks, the eyeball triggers an instinctive upward movement (Bells phenomenon) and hence produces a positive potential in the frontal lobe which is displayed in EEG as a transient, diphasic, synchronous slow wave (Misra & Kalita, 2005) (Stern, 2005) (Sovierzoski et al., 2008) as shown in Figure 5. This image also shows that, the faster the blink the shorter the wavelength, as depicted by the first blink occurrence which was faster than the second blink. When the subject performs a number of repetitive blinks, the displayed EEG could mimic a triphasic wave or resemble rhythmic delta activity as shown in Figure 6. Additional and more frequent blinking can simulate theta activity as shown in Figure 7.

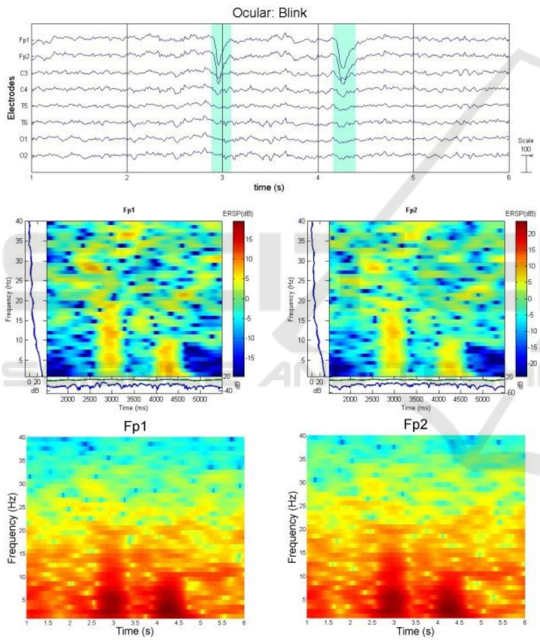

Figure 5: Ocular Artefact - Eye Blink predominantly on Electrodes Fp1 and Fp2 (Plot, ERSP, and Spectrogram).

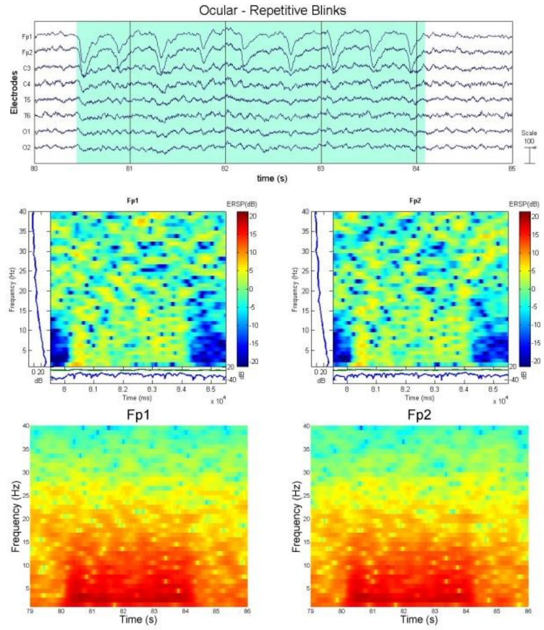

Figure 6: Ocular Artefact – Repetitive Eye Blinks (Plot, ERSP, and Spectrogram).

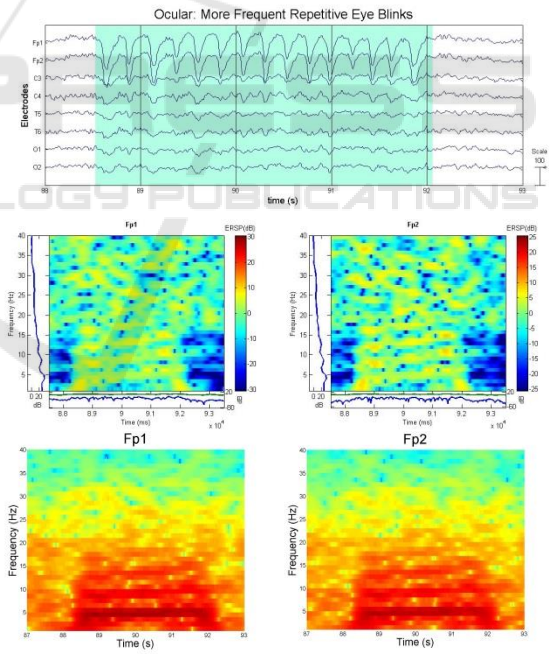

Figure 7: Ocular Artefact – More Repetitive Eye Blinks (Plot, ERSP, and Spectrogram).

2) Eye Flutter: Eye Flutter produces an ocular artefact that is more rhythmic, with higher frequency and lower amplitude as shown in Figure 8.

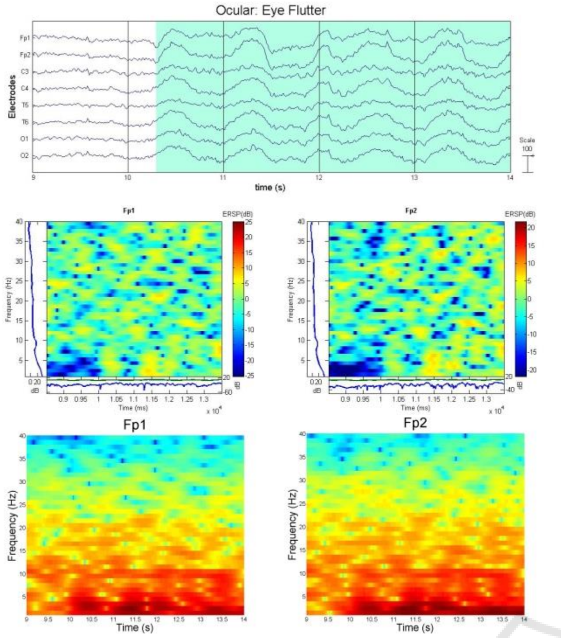

Figure 8: Ocular Artefact – EyeFlutter (Plot, ERSP, and Spectrogram).

3) Lateral Eye Movement: Lateral Eye movement artefact is mostly detected in a bipolar longitudinal montage using Fp1-F7 and Fp2-F8 and may start off with a single sharp muscle potential called lateral rectus spike. In this type of montage a left lateral eye movement will have a positive potential in electrode F7 and an opposite negative potential in electrode F8. In our referential montage, the frontal origin of eye movement artefacts remained indistinguishable due to the reference electrode (A1) being contaminated by eye movements (Fisch, MD, 2000).

4) Slow Roving Eye Movement: Slow Roving eye movement differs from lateral eye movement since no saccades occur; consequently resulting in no abrupt changes. On a bipolar montage these are reflected as smooth lateral movements with phase reversing. On a referential montage using low fidelity equipment, this artefact was not detected.

3.1.2 Muscle Artefacts - EMG (Electromyography) Activity

EMG activity produces artefacts that are due to muscle contraction and are the most common and significant noise source in the context of EEG. Although EMG in itself is useful for electromyography; they are considered noise in EEG, since they overlap and obscure the EEG signal due to their higher amplitude and frequency. If, however, this signal is passed through a low-pass filter set at 35Hz or less, this will change their form and caution is required since these may transpire as beta activity or like abnormal epileptiform spikes. The extent of a muscle artefact depends on the duration of the muscle activity, which might be less than a second and/or throughout the entire session (Stern, 2005) (Fisch, MD, 2000) (Misra & Kalita, 2005).

1) Surface EMG: Surface EMG activities generally occur in regions with underlying muscle such as the masseter and temporalis muscle, which affect the frontal and temporal electrodes. These may also disseminate and diffuse to other channels. Electrodes Fz, Cz and Pz can provide a reasonably pure EEG signal. Figure 9 shows an EMG effect when the subject clenches his teeth. ERSP screenshot doesn't show any recognizable activity.

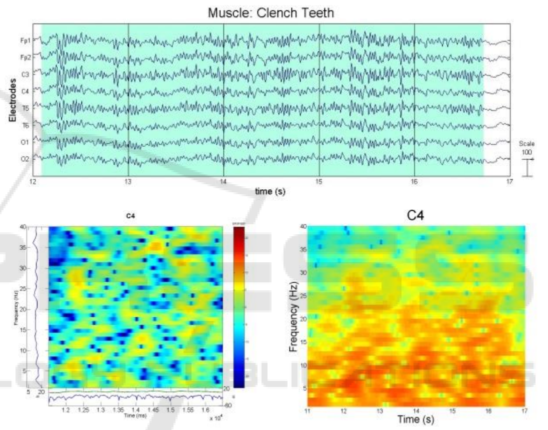

Figure 9: Muscle Artefact – Clench Teeth (Plot, ERSP, and Spectrogram).

2) Glossokinetic: Glossokinetic is an artefact arising from the movement of the tongue. It is similar to the eyeball movement in ocular artefacts, though less sharp. The tongue functions as a dipole where the tip acts as a negative with respect to the positive base. This results in the surging of diffuse delta like activity, which is frequently supplemented by muscle artefact. The tongue has a DC potential and equipment running on DC amplifiers will not record its potential as is the case in the equipment being used for this experiment.

Figure 10 shows the effect of swallowing in our subject which affects the oropharyngeal muscle. This experiment could have been included in the Surface EMG section, since no tongue potential is being recorded, but is being listed here for classification reasons.

3) Intermittent Photic Stimulation (IPS): Intermittent Photic Stimulation (IPS) / is a photomyogenic / photomyoclonic response to a visual stimulation where the subject eyes are presented with intermittent flashes of light. This results in an involuntary time linked facial muscle response to the flash of light which affects the frontal and periorbital regions, specifically the frontalis and orbicularis muscles (Shamsaei, n.d.). At this stage in our work we don't include this.

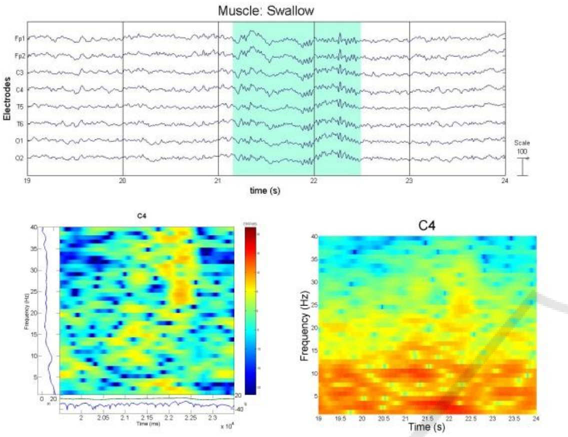

Figure 10: Muscle Artefact – Swallow (Plot, ERSP, and Spectrogram).

3.1.3 Movement Artefacts

Movement during an EEG session may produce two distinct artefacts; instrumental from the movement effect on the electrodes and their leads as discussed in the *Equipment Artefacts* section below; and biological through the generation of electrical fields from muscle contraction; EMG activity; as discussed in the *Muscle Artefacts* section above.

3.1.4 Cardiac Artefacts

Electrocardiography (ECG) is the process of recording electrical activity from the heart. The heart produces a considerable electrical field that spreads to the base of the skull, which is detectable in an EEG session. This artefact is easily detected in a referential montage since there is ample interelectrode distance between the reference which is located on the ear lobe and the other electrodes which are located on the scalp. In addition this artefact is most prominent in subjects with a short neck. This artefact appears as a QRS complex which represents three graphical deflections in an ECG diagram. The QRS complex is preceded by a P wave and followed by a T wave as shown in Figure 11. With clinical EEG equipment using a referential montage setup; a poor QRS complex was formed. This was due to the distance from the heart where the P wave and T wave are not visible (Fisch, MD, 2000) (Stern, 2005). ECG artefact may be reduced or removed by adding a second reference; however it will only work if both reference electrodes are able to detect a pulse (Spriggs, 2010). Unfortunately we were unable to reproduce this artefact using low fidelity equipment. It is true that the artefact is a poorly formed QRS complex which is most prominent in short necks and could have been easily concealed within the noise; but that does not negate the fact that we should have at least encountered it even as a low amplitude signal. We have tried several types of filters but without any apparent result. We were however able to produce an ECG signal on purpose; not as an artefact; with a different set-up, which however is beyond the scope of this paper.

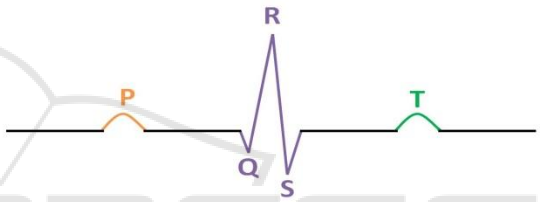

Figure 11: QRS Complex.

3.1.5 Pulse Wave Artefact

Pulse artefact mainly occurs when electrodes are placed over a pulsating artery manifesting a regular pulse beat. These pulsations instigate periodic slow waves that can be misidentified as EEG activity. There is a direct link between ECG and pulse waves; where the QRS complex happens right before (about 200ms) the pulse waves. In our experiments the electrodes where not placed over a pulsating artery and thus it did not show in our experiments.

3.1.6 Skin Potential

Skin potentials where discussed in *Non-Physiological Artefacts*, explicitly under *Equipment Artefacts* which included *Perspiration* and *Salt bridges*.

3.2 Non-Physiological Artefacts

Non-Physiological artefacts are externally generated outside the user's body such as artefacts arising from environmental electrical interference and artefacts relating to the equipment being used.

3.2.1 Environmental Electrical Interference

Environmental Electrical Interference: 50/60Hz Artefact; The most common electrical interference artefacts usually emanate from electrical devices and in close proximity to power lines. The greatest contributor is the alternating current (AC) with a monomorphic frequency of either 60Hz (ex. United States) or 50Hz (ex. Europe). These artefacts can be introduced either electromagnetically, where the strength of the field is determined by the current flowing through cables or by the equipment such as transformers and TV power supplies; and electrostatically due to the capacitance property of objects where the subject or electrodes pick up capacitance potentials from other sources which are in their proximity such as the movement of any charged bodies or objects (ex. plastic, rubber, synthetic fibres) near the subject (Fisch, MD, 2000) (Binnie et al., 1982). Figure 12 shows the effect of a 50Hz noise on our EEG signal.

This artefact can be reduced by grounding the equipment, moving the subject away from power lines and sources that can generate electrostatic interference and keeping electrodes impedance to less than 5KΩ which is the leading cause of the 50/60Hz artefact (Spriggs, 2010). Should these methods not suffice; the artefact can be eliminated by a notch-filter (or similar) which will only remove the 50Hz or 60Hz activity from the signal. The filter should only be used if necessary.

Radio Frequency / Mains-Borne: Other electrical interferences which are less prominent include Radio Frequency when they are modulated in a lower frequency and Mains-Borne interference arising from fluctuating power supplies.

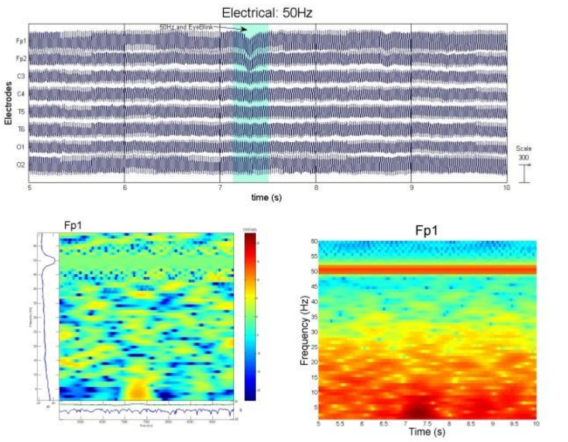

Figure 12: Electrical Artefact: 50Hz (Plot, ERSP, and Spectrogram).

3.2.2 Equipment Artefacts

A number of different artefacts can be caused from the recording electrodes and the equipment being used. Electrode artefacts can manifest as two dissimilar waveforms; low frequency rhythms amidst a scalp area and brief transient morphology which would be limited to one electrode (Stern, 2005).

Electrode Pop: Electrode Pop can occur occasionally when there is an instantaneous change in the electrical potential between the electrode and the scalp, where it is typically followed by a sudden, high amplitude spike in the EEG recording (Barlow, 1986) as shown in Figure 13. This may occur when electrodes are not firmly attached and/or when direct pressure is applied on the electrodes.

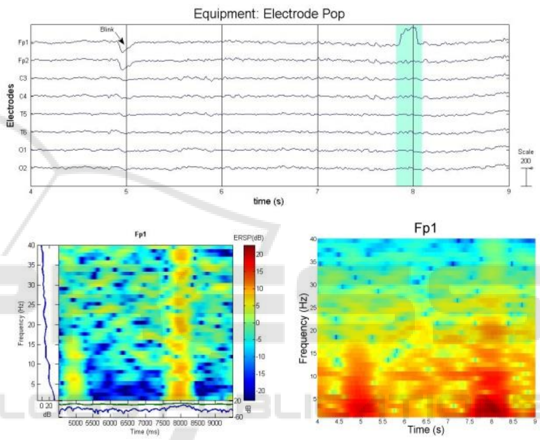

Figure 13: Equipment Artefact: Electrode Pop (Plot, ERSP, and Spectrogram).

Electrode Contact and Lead Movements: A weak Electrode Contact and Lead Movements generate a different artefact that has a less sustained morphology compared to electrode pop as shown in Figure 14. The weak electrode contact results in impedance instability, which will produce waves with fluctuating amplitude and morphology; although if there is a context of rhythmic movement such as from tremors, the resulting waves may be rhythmic as well. Lead movements do not resemble any true EEG activity where the morphology of the wave is incoherent (Stern, 2005).

Salt Bridge: A Salt Bridge artefact can occur when smearing the electrolyte gel between two electrodes or by applying an excessive amount of electrolyte gel, which may result in an inadvertently overlap, thus creating a short circuit between the electrodes. This artefact is usually channel specific and manifested as a low amplitude wave compared to the background. Salt bridge artefact will eventually be prevented by use of dry electrodes; which we plan to do in our future experiments.

Perspiration: Perspiration artefact although not as stable, is similar to a salt bridge artefact where the salinity between electrode locations will merge the affected electrodes as a single entity. It is usually manifested as a slow wave that is typically greater than 2 seconds in duration which is out of the frequency scope of EEG (Stern, 2005) (Fisch, MD, 2000).

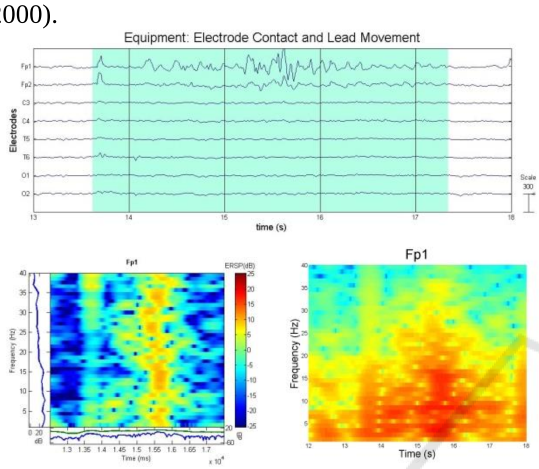

Figure 14: Equipment Artefact: Electrode Contact and Lead Movement (Plot, ERSP, and Spectrogram).

Salt Bridge and Perspiration artefacts can be easily recognized in an EEG session and should be resolved prior to commencement. The salt bridge artefact is eliminated by cleaning the excess electrolyte between the affected electrodes and wiping the subjects forehead with a spirit solution, while the perspiration artefact can be eliminated by providing a cooler environment and reducing the emotional stress of the subject. The experiments reported here where based on a referential montage, where these artefacts where not present. The lack of these findings suggests that an electrolyte bridge is only present amongst electrodes such as in a bipolar montage.

4 CONCLUSION

Non-invasive BCIs designed on EEG provides fine temporal resolution, portability and ease of use however the signal is frequently contaminated by various artefacts. EEG processing and analysis require accurate information and it is vital that these artefacts are recognized and classified so that it would be possible to eliminate or prevent them from occurring, or otherwise, attempt to use them constructively.

Previous investigations in this research area where made using expensive medical EEG equipment and were usually categorized using different type of montages, which made it challenging for comparisons. Moreover only a few of these artefacts have been documented successfully using low fidelity equipment and this documentation has been ad hoc and not categorized properly.

Due to the proliferation of cheap EEG equipment, including user-made equipment such as (Wang et al., 2016), an evident necessity to validate the equipment's suitability was present. Moreover in recent times, a number of researchers and end-users are using low fidelity equipment as a "black box" approach (Lecoutre et al., 2015), without any qualitative testing on the equipment being used.

Part of our contribution was to create awareness of what type of hardware components are being utilized in low fidelity equipment, vis-à-vis the results achieved. This would ultimately facilitate the possibilities of using off-the-shelf EEG equipment as a cheap alternative to medical EEG equipment. It is important to note that this paper does not imply that low fidelity equipment should replace medical equipment; our purpose is to assess the suitability of such equipment for non-clinical trials.

In this paper, a successful approach in identifying and classifying artefacts using low fidelity equipment on a referential montage is presented. The promising results achieved show that the most common artefacts observed in a non-clinical environment are being effectively identified and categorized while using the aforementioned equipment.

5 FUTURE WORK

Future research work includes the capability of low fidelity equipment, to accurately capture Mu and Alpha waves/rhythms which can be processed to perform tasks such as motor control functions. Some initial results are shown in Figure 15, where the Alpha waves are predominantly seen in the occipital lobe, specifically on O1 and O2 electrodes, whereas the Mu waves are predominantly found around the central area of the brain known as "central sulcus", specifically on C3, Cz and C4 electrodes in our figure. In addition we are also interested in exploring the idea of using some of these artefacts constructively in concurrence with actual brain wave signals.

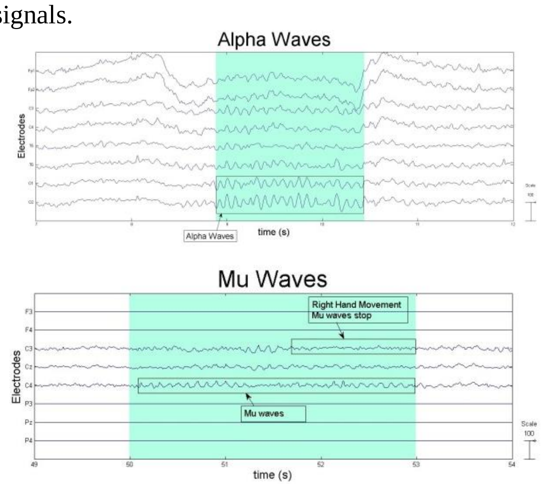

Figure 15: Initial results for Alpha & Mu Waves.

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APPENDIX

Matlab code that includes filtering used for displaying spectrogram screenshots.

```
fs = 250;
nfl = 49;
nfh = 51;
fl = 49;
fh = 0.5;
order = 2;

%Butterworth notch filter
[bn,an]=butter(order,[nfl
nfh]/(fs/2),'stop');

%Butterworth low pass filter
[b,a]=butter(order,lp/(fs/2),'low');

%Butterworth high pass filter
[b,a]=butter(order,fh/(fs/2),'high');

%Spectrogram
spectrogram(eegdata_f,hanning(256),2
55,[1:40],250,'yaxis');
```