Tampere University

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FUNCTIONAL ASSESSMENT OF A NOVEL, IMPLANTABLE EEG ELECTRODE

Faculty of Engineering and Natural Sciences
Master's Thesis
December,2020

ABSTRACT

Archana Kommala: Functional Assessment of a novel, implanatble EEG electrode
Masters Thesis
Tampere University
Masters in Biotechnology and Biomedical engineering
December 2020

This thesis was a project of BrainCare Oy, and the main goal of the thesis is to test and compare the surface EEG measurements of Ultimate EEG electrode to Golden standard electrode for subdermal implantation for epilepsy. The main objective of this thesis is to ensure if the Ultimate EEG electrode and Golden standard electrode can work together. The UltimateEEG electrode belongs to BrainCare Oy, the electrode is coated with platinum and the Golden standard electrode a normal industry-based electrode which belongs to Tampere University Hospital (TAYS). The main component used in golden standard electrode is silver, so it is also called as silver-silver chloride electrode.

The DC offset voltage, resistance and real time impedance measurements were evaluated to compare the UltimateEEG electrode to Golden standard electrode. The tests related to DC offset voltage and the resistance between both the electrodes were evaluated based on a home-based experimental via digital multimeter. The real-time impedance surface measurements were taken by using Video EEG equipment with certain common test procedures performed on healthy individuals and on actual people suffering from epilepsy. The data of DC offset voltage, resistance and impedance measurements were compared to know if UltimateEEG electrode can perform co-ordinately with the Golden standard electrode. It was evident by the results that the working of Ultimate EEG electrode was successful for surface measurements.

Keywords: Electroencephalogram, electrodes, platinum, impedance

PREFACE

The study in this thesis was a project of BrainCare oy and most of the work was carried out in Tampere University Hospital (TAYS). This thesis was done for Tampere Universities (Hervanta Campus). I would like to thank BrainCare oy for giving me an opportunity to work with them with this interesting project. My sincere thanks and profound gratitude to my supervisors, professor Jari viik for helping, guiding me throughout the thesis and for his incredible patience. I also would like to thank Professor Ville Santala for accepting to be the co-examiner for this thesis. I am incredibly grateful to Jukka Pekka Pirhonen, CTO of BrainCare oy for helping, encouraging, and motivating me to complete the thesis. My added thanks to Mirja Tenhumen Associate professor and physicist from Tampere university Hospital (TAYS) for helping me understand and use the EEG equipment's. I am also thankful to my friend Veena Patras for always encouraging me not to give up and being there for me during the hardest phase of my life. Most Importantly, this is the work of the Lord in whom I believe, and his works are always marvellous. I will always bless the lord and his praises shall continually be in my mouth.

CONTENTS

ABBREVIATIONS

BC	BrainCare electrode also called UltimateEEG
Ag-Agcl	Silver-silver chloride electrodes
TAYS	Tampere University Hospital.
BC	BrainCare.
EEG	Electroencephalogram.
ILAE	International League Against Epilepsy.
TUNI	Tampere Universities
ECoG	Electrocortigraphy
ECG	Electrocardiogram
MEMS	Microelectromechanical systems
TUTLI	Tutkimusideoista uutta tietoa ja liiketoimintaa
LFPS	Local field potential
MEG	Magnetoelectoencephalography
TMS	Transcranial Magnetic Stimulation
Parylene	Tradename for poly(p-xylylene)
PDMS	Polydimethylsiloxane
NMDA	N-methyl-D-aspartate receptor
WHO	World Health Organization
DC	Direct Current
AC	Alternating Current
Volts	Voltage
Amps	Ampere
VEP	Visually evoked potential
Ω	Ohm
° C	Degree Celsius
α	Alpha
β	Beta
γ	Gamma
θ	Delta
HZ	Hertz
+	Positive
-	Negative

1 INTRODUCTION

1.1 Epilepsy and the complications it present

John Hughlings Jackson an English neurologist, with his studies and research changed the fate of Epilepsy. Epilepsy was first named as Jackson's epilepsy. Hughlings was working as an assistant physician in the national hospital which was congregated specifically for the paralyzed and the epileptic for their cure and well-being. Now, the hospital is renowned for neurology and neurosurgery and it is called as the National hospital established in Queens square London in the year 1862(Ruben Kuzniecky Graeme Jackson, 2004).

Epilepsy is known as a neurological disorder and it is defined as a group of nerve cells called as neurons in the brain often evoke a seizure (Britannica, 2020). World Health Organization (WHO) 2005 reports that Epilepsy affects about 50 million people worldwide (Prilipko et al., 2005). According to The International League Against Epilepsy (ILAE) in 2005 an epileptic seizure is a brief occurrence; it causes certain unfavourable symptoms due to simultaneous neuronal activity in the brain(Fisher et al., 2005). Nerve cells together produce electrical and chemical signals. These signals are helpful to receive and send electrical impulses all over the body including glands, muscles and neurons which handle human emotions and their behaviour (Review, 1997).

Statistics show that Epilepsy is ranked as the fourth in the aspect of neurological disorders after migraine, Parkinson's, stroke, and Alzheimer's. In the US men and women of all age groups has been affected with their welfare due to Epilepsy (England et al., 2012).

Research shows that there are hardly one or two capable methods to treat Epilepsy and there are certain anti-epileptic drugs available in the market for treating epilepsy. Some of them are Gabapentin, oxcarbazepine, levetiracetam, topiramate, vigabatrin. These drugs have failed to achieve the desired results and have caused side effects(Beyenburg et al., 2004). The ideology of treating epilepsy via surgery is not new. According to Sir Victor Horsley there were three important documented surgeries occurred in the year1886 (Taylor, 1986). The surgeries play a vital role in small group of patients having single solitary epilepsy promoting abnormality in the brain. The medical procedures are considered only if there is a satisfactory control that cannot be reached with medication. The advancement of Epilepsy can be achieved by strong data through research and supervision (England et al., 2012). Epilepsy can be detected through electroencephalogram (EEG). These devices can check and record the electrical activity of the brain.

There are upcoming technologies in the field of medicine to help the patients suffering with epilepsy. Due to lack of prompt referrals, it would be difficult for the patients suffering from epilepsy to get access to the treatment by a neurologist. These innovative technologies happen to have an idea of an implantable electrode which can detect a seizure and gets connected to the cloud through a signal and the data is automatically stored. According to Faraday, Michael (1834) an electrode is defined as a strong electric conductor through which an electric current can enter or leave an electrolytic cell or enters or leaves an electrolytic cell or another channel (Michael, 1834).

According to the above description BrainCare oy has tremendous technologies which has a solution for the people suffering with epilepsy. BrainCare oy focuses on the frontal lobes situated behind the forehead. According to Goldberg, (1992) there is a strong point which is associated with the frontal lobes of the brain referred as the “traffic hub” of the nervous system and it is specialized with a set of neural connections to and several forms of brain structures (Bernard J. Baars and Nicole M. Gage, 2010). As per Hughlings Jackson’s concept of evolution and dissolution (1884) the frontal lobes remarkably have less chances to collapse with the functional aspect. The Jackson’s proposal says that the youngest brain structures are the first to surrender to the cerebral sickness (Franz & Gillett, 2011).

1.2 Current situation of the BrainCare Project

BrainCare oy, is a Tampere University of Technology spin off company set up in 2013, found in Tampere, Finland. This company focuses on technology for long term epilepsy monitoring. According to the past work of Pirhonen (2015) it was mentioned that the baseline for the Tekes TUTLI funded BrainCare’s project has been commenced from D.sc. Katrina Wendel-Mitoraj doctoral dissertation. “The influence of tissue conductivity and head geometry on EEG measurement sensitivity distributions”(Wendel, (2010). This project was carried out in the Department of Electronics and communications Engineering in Tampere University of Technology presently known as Tampere Universities (TUNI) between the years 2013-2015. Pirhonen (2015). The aim of his master’s dissertation was to “prototype an EEG measurement system which would be able to record a patients EEG around the clock” Pirhonen (2015). It was designed for subdermal implantation beneath the skin, the electrode is flexible and has a recording and measuring unit to save the measurement data (Pirhonen, 2015).

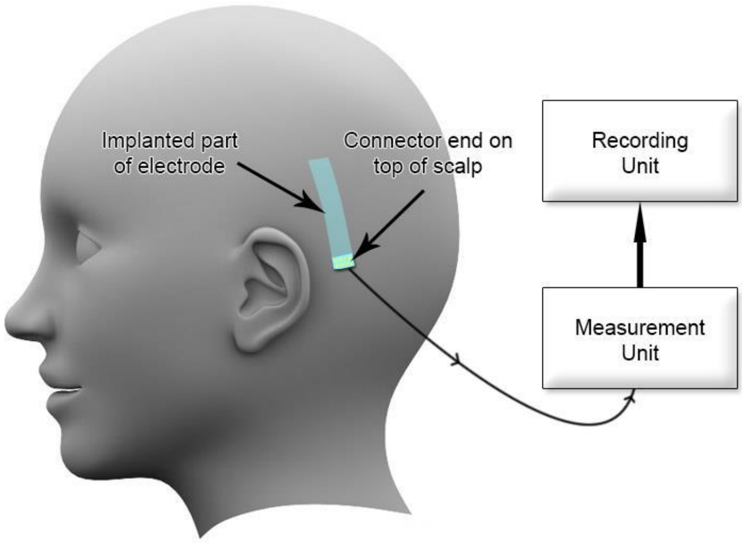

FIGURE 1. BrainCare prototype with measuring and recording unit (Pirhonen, 2015).

The above image is a prototype system for clinical trials. Here the implanted electrode is shown. The electrode stands out and the connector is attached to the electrode’s outer part. The BrianCare electrode is also known as “UltimateEEG”.

The existing situation with the BrainCare electrode is, the subdermal, implantable flexible, electrode is approved for clinical trials in Tampere University Hospital. The electrode will be connected to a standard hospital Video- machine and an amplifier at the same time with silver-silver chloride electrodes to test them at one at the same time.

1.3 Introduction to Tampere University Hospital electrode

The hospital electrodes are from Tampere University Hospital and they are industrial based electrodes. The hospital electrodes are also called as golden standard electrode or silver-silver chloride electrodes. In the further readings of this thesis the terms like golden standard electrodes, silver chloride electrodes and hospital electrodes all mean the same.

1.4 Thesis Overview

The hospital electrodes are industrial based, and they are the best electrodes available in Finland. The aim of the thesis is to test the functionality and measure the surface EEG and compare it to the golden standard electrode and check if both the electrodes can work together. This thesis is a continuation from the past work of J.pirhonen “testing the patented electrode and its potential”. The main achievement of this thesis was the BrainCare electrode was successful with the surface EEG measurements when it was compared to the golden standard electrode. Part of the work related to measuring the surface EEG measurements with both the electrodes was done in the Tampere University Hospital (TAYS) in the Video EEG lab in the neurology department.

This thesis has a total number of 36 figures, 5 tables and it is divided into vi chapters.

Chapter 1 Introduces the basic idea of epilepsy and BrainCare project and the aim of the thesis.

Chapter 2 describes about the background of this work explaining about the hospital devices and the Golden standard electrodes used in the work in detail. The electroencephalogram EEG, the wave patterns and most importantly about the head geometrical propositions of 10-20 electrode system.

Chapter 3 discusses about the Ultimate EEG electrode in detail about the essential characteristics of an electrode and foreign body reaction, and how the electrode was designed, and the materials in the electrode.

Chapter 4 explains about the materials and methods used in the study an elaborated description about the devices used and the different test procedures made for surface EEG measurements. It also discusses about the recent technologies after BrainCare.

Chapter 5 discusses about the results in the positive and negative aspects with proper reasoning’s for voltage, resistance, and Real-time impedance measurements.

chapter 6 presents a detailed discussion about the entire project and the future of BrainCare Oy followed by a conclusion.

2 BACKGROUND

2.1 Brain and its Lobes

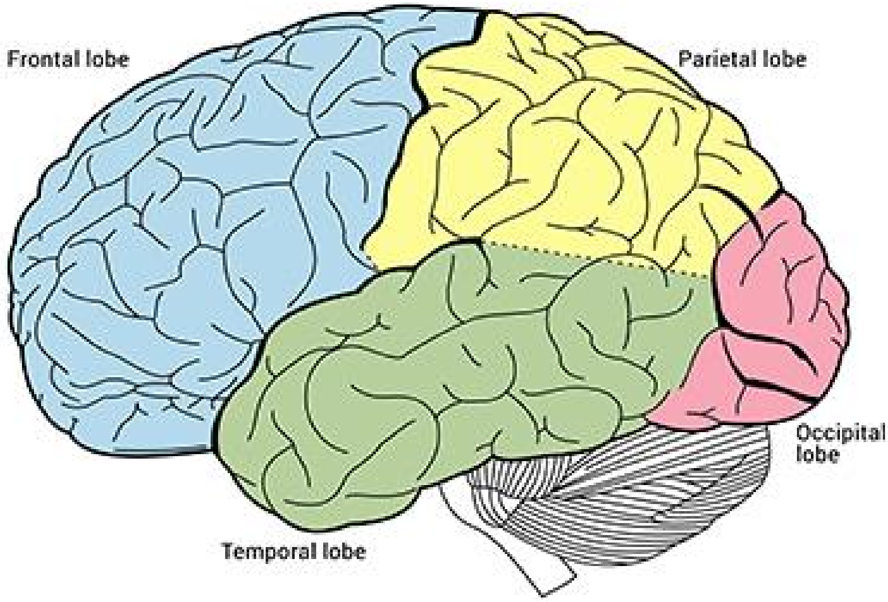

FIGURE 2. Representing Brain and its lobes (The University of Queensland, 2018)

According to Esar Basar (2013) The term neural oscillations refer to the repeated electrical activity produced voluntarily in response to stimuli by neural tissue in the central nervous system (Erol Başar, 2008). At an Organ level the brain is made up of many regions. Cerebrum occupies 80% of the brain and it is the chief part of the brain. Brain is partitioned into left and right halves through interhemispheric gap. This partition separates the brain into four lobes viz: frontal, temporal, parietal, and occipital lobes(J. S. Kumar & Bhuvaneswari,S. Kumar, 2020,2012).

- The frontal lobes are large and are situated behind the region of the forehead. The left frontal section handles managing the speech, language and for controlling the emotions (Collins & Koechlin, 2012).

- The temporal lobes are surrounded near the ears and are in charge for understanding the feelings, noises. These are the largest and accommodate 17% of the cerebral cortex. Hippocampus is an important region, and it deals with memory and emotions. (Kiernan, 2012).

- The Parietal lobes are present behind the frontal lobes. Its leading role is dealing with the coordination of eye to hand development (Erol Başar, 1998).

- The occipital lobe is the smallest part in the cerebral hemisphere. It handles visual processing (Amna Rehman; Yasir Al Khalili., 2020).

To understand the psychological conduct of the cerebrum, there are certain techniques such as examining in the form of signals or images (Kumar & Bhuvaneswari, 2012). According to Kumar et al. (2012) a superior quality of EEG consists of non-ruinous, easy, reaction less, and exact elucidations for some brain infections. For instance, epilepsy, memory loss, Alzheimer's and autism are related to the brain. The brain activity of an individual is examined by certain techniques and they will be discussed in detail (Sarmast et al., &NIND 2015, 2020).

2.2 Electroencephalogram (EEG) Basics

2.2.1 Seizure and its classification

According to Helen E scharfman (2007) "a seizure is a period of abnormal, synchronous excitation of a neuronal population". When a seizure occurs, it feels like an electric storm in the brain. Studies reveal that when a seizure is about to happen the neurons develop about 500 times each, this is unusual when compared to the normal range of a neuron which is 80 times per second. This takes place because there are massive amounts of potassium present inside a neuron and it is surrounded by high sodium concentration externally along with more ions leading to net membrane potential of -60Mv (Scharfmann (2007). If this equilibrium is disturbed it can lead to depolarization promoting an abnormal activity in the brain due to an excessive gush of electrical happening which prompts to certain sensations, emotions, automatic movements, and short-lived aggravations of customary neuron actions leading to loss of awareness (Helen E scharfman 2007).
According to Joseph I Sirven (2015) Epilepsy can be termed as a spectrum disorder because of various seizure occurrence, causes and its impact shifts from one person to another.

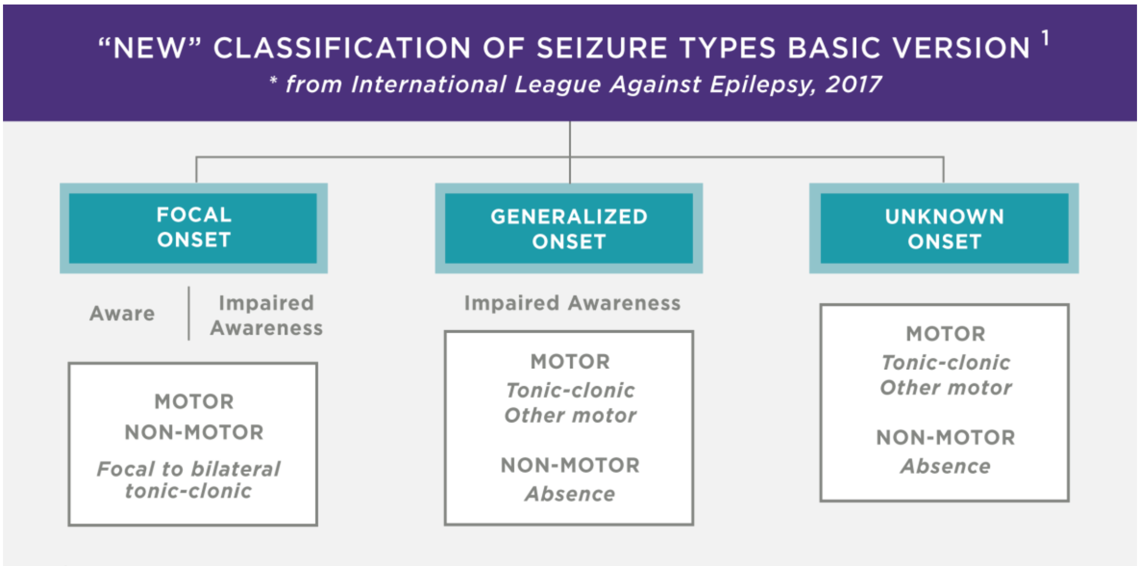

FIGURE 3. Seizure and their classification according to ILAE,2017 (The University of Queensland, 2018)

The above figure 3 describes about the classification of seizures is into three major groups (A clinical guide to epilepsy syndromes and treatment,2nd edition, springer 2009).

The **generalised onset seizures** affect the cells on each side of the brain. specific symptoms include jerking movements, muscle weakening in a tensed condition inflexible with epileptic spasms. The non-motor signs are termed as nonattendance seizures (Chrysostomos P Panayiotopoulos,Epilepsy society, 2009 &2019).

The **focal onset seizures** affect a group of cells which are present at one side of the brain. Here, the seizure attack occurs when the person is awake, this is also known as simple partial seizure. The affected individual can only know this when he is perplexed. The symptoms are like generalised onset seizures which includes jerking, inflexibility of muscles, racing of the heart, gastrointestinal sensations (Chrysostomos P Panayiotopoulos, 2009).

The **unknown onset seizure** occurs when it is not known and is referred as unknown onset seizure (Chrysostomos P Panayiotopoulos, 2009).

Based on clinical semiology in the year 1981, a seizure classification was introduced, and it is presently known as International league against epilepsy (ILAE)(Fisher et al., 2005). The studies according to clinical semiology states that ''ictal symptoms can be created by epileptic impedance of one of the accompanying four ''spheres'' and they are sensorial sphere, conscious sphere, autonomic sphere, motor sphere.'' (Lüders et al., (1998).

TABLE 1. classification of epileptic seizure arrangement (Lüders et al., 1998)

Epileptic Seizure	
Aura	
• Somatosensory aura”	• **Visual aura”**
• Auditory aura”	• **Gustatory aura”**
• olfactory aura”	• **Autonomic aura**
Abdominal aura	• **Psychic aura**
Autonomic seizure”	
Diepileptic seizure”	
• Typical dialeptic seizure”	
Motor Seizure	
• Simple motor seizure”	
Myoclonic seizure”	**Tonic Seizure”**
Epiletic spasm”	**Clonic seizure**
Tonic-clonic”	**Versive seizure”**
• Complex motor seizure”	
Hypermotor seizure”	**Gelastic seizure”**
Automotor Seizure”	
Special seizure	
• Atonic seizures”	• **Astatic seizure**
• Hypomotor seizure’’	• **Akinetic seizure”**
• Negative myoclonic **seizures**”	• **Aphasic seizure”**
Paroxysmal event	

The table 1, stands for the semiological seizure arrangement characterizing the epileptic ‘’seizures of emanation’ ’this happens when the seizure is about to begin. Autonomic seizures are not common at times these seizures might go un-recognised when this seizure occurs it might lead to abrupt neural activity which could lead to confusion, increase of the heart rate, and blood pressure (Devinsky, 2004). There is a new term which is authored to recognise the seizures it is called as diepileptic seizures. The other seizures are motor, simple engine and special seizure. Paroxysmal events happen when an individual accepts or expects a seizure like epileptic seizure, but this does not involve any abnormal emit of neurons. (Lüders et al., 1998).

2.3 Hospital Devices and Measurements

2.3.1 Electroencephalography

Electroencephalography (EEG) is defined as a brain activity recording, using the electrodes attached to the scalp during rest or sleep, lack of sleep, rapid breathing after photic stimulation (C paz, Jaime, (2014). Electroencephalogram (EEG) is one of the procedures for taking the measurements from the brain. It is a non-invasive method; it has a cap embedded with the regular EEG electrodes and is a good fit to the head (Light, 2011).

The other method for measuring the brain activity is done by electrocorticography (ECoG) also known as intracranial EEG it comes under the category of electro-physiological monitoring. Here, the electrodes are placed straight on to the brain via surgery by removing the top layer of the skull. The disadvantage of this method is it is time consuming and there are high chances to the risk of infection which could lead to acute damage to the brain. At times, the signal quality can be misleading with the regular EEG compared to ECoG because the regular EEG cap has high chances of error occurrence and it cannot be controlled by an analyst. To analyse a proper signal there is a requirement of a skilled person in this field (Kuruvilla & Flink, 2003).

According to the illustrations given by Berger in the 1920's a German physiologist and psychiatrist, EEG and its electrical activity was discovered already a century ago (Shure,(2018). To simplify this electroencephalogram records a series of cerebral electrical potentials by electrodes on the scalp. The cerebral electric activity includes action potentials that are mandate and produce limited electric fields which are slower, more extensive and at times could lead to postsynaptic potentials (a change in the membrane potential due to a chemical synapse which could lead to firing of neurons). The measurement of a signal is recorded from a neural generator and analysing it is based upon the solid angle which is diagonal on the electrode and at the same time, the movement of a single neuron can be recorded by an adjacent microelectrode (Binnie & Prior, 1994).

The neurons are the cells which have a prominent character related to the intrinsic electric properties and this activity tends to generate the electrical and magnetic fields. These particular fields can be measured by the electrodes from small distance (local field potentials-LFPs) or from the cortical surface (Electrocorticogram ECoG) as a rule recording finished with longer separations particularly with the scalp and magnetoencephalography(MEG) is essentially connected with the account to the sensors which are exceptionally delicate to the adjustments in the extremely powerless neural attractive fields where these sensors are orchestrated at the shorter separation of the scalp (Mulert, Christoph, Lemieux, 2010). The EEGs were traditionally written on the electromechanical chart recorders but now the technology makes the measurements of EEG easier. The recent technologies which are used for recording EEG are discussed as follows:

Standard EEG recording is done in the work atmosphere and it lasts about 60 minutes. You are recommended for a restless EEG; a person must rest for four hours which achieves strange cerebral waves when the body is pushed or depleted. The evaluation continues for a couple of hours. The unambiguous request will be made to the individual venturing through the assessment about food, drink, and solutions that a person must avoid (Eeg et al., 2018)

Ambulatory EEG, this requires a conservative EEG recorder on a belt around the mid-region of an individual for several days or weeks. This EEG recorder has a diary where the daily step by step activities of an individual is kept under observation (Eeg et al., 2018, National health service ,uk).

Video EEG monitoring is open in explicit habitats for patients suffering irregular seizures or rest issue. The individual ought to be accessible in the centre and is checked by EEG and a camcorder which empowers a person to be seen during a seizure with the aim that the physical activity of an individual can be watched at the same time as EEG (DevinskyMD, 2004)

Electroencephalogram devices are made up of electrodes, a conductive gel, amplifiers, and analogy to digital converters. These electrodes are called leads and they play a crucial role, these leads are necessary to complete the electrical movement from the scalp to the brain. There are several types of electrodes used while preparing and conducting an EEG in clinical applications or research (Boer, 2016). During EEG monitoring the electrodes are applied with small conductive/electrolytic gel. This gel acts as a transitory glue and it is applied below the disc of the electrode. Before the electrodes are attached on to the scalp with the conductive gel an abrasion procedure is done. The conductive gel helps with the ionic current flow from the scalp and the electron so that it adheres to the scalp and improvises the signal quality (Ya-Wen Tang, Yue-Der Lin, 2014). The discs are made with gold tin to silver compositions. Each electrode is fixed with an amplifier when the procedure is continuous. Each amplifier is attached to one pair of electrodes and is directly connected to the EEG recording system. The concept here is that at the final stages there are certain signals which are received from the brain and these signals are then converted into waveforms on the display of the monitor through this the results are recorded. A pair of electrodes generates a channel and by this there is a possibility of a signal to be generated. There are many possibilities for the electrodes to fail, and this can have a high probability of an artefact (Hugdahl kenneth, 1995).

FIGURE 3. Right side: representing EEG amplifiers, left corner: electrode with the disc (Lüders et al., 1998).

Other class of EEG is an EEG cap, EEG caps are helpful with the electrode replacement. It is easier to attach the electrodes to the scalp. The added advantage with the cap is it makes sure that the electrodes are placed accurately and gives enough support to contact the scalp (Shields, 2016). The difficult part is that the electrode caps must be cleaned and dried after its use while an individual electrode can be cleaned with alcohol swabs and are available to reuse instantly. EEG cap can be reused with injecting the conductive gel into the cap holes when necessary this procedure is used for multichannel recording (Shields, 2016). The disadvantage of this EEG cap is, if one electrode tends to give negative result then the entire cap must be changed as it is not easy to trace the disc which caused the failure. According to the studies by Bror-Shing Lin et al; 2019 a smart EEG cap was proposed to perform and execute the function of choosing a channel in the front to end of the device to transfer the EEG signals from the chosen channels. The study's results revealed that the proposed smart EEG cap performed better to recognize motor imagery (Lin et al., 2019).

2.3.2 International 10 to 20 Electrode system

According to Jasper (1958), a standardised procedure is followed to locate an electrode. This procedure is known as international 10 to 20 electrode system, it is a method where the positioning of the electrodes or montages are set up (Bos, 2006). This is a technique which is considered in the application for coil posting in transcranial magnetic stimulation studies (TMS). According to Walsh et al (2003) “Transcranial Magnetic Stimulation has established non-invasively cortical data handling in intellectual neuroscience”(Herwig et al., 2003). A paper related to Herwig (2003) states that “the 10-20 framework is recognizable with anatomical landmarks like nasion, inion (occipital bulge) and preauricular points with sequential arrangements at a particular point at fixed distances from the referential points which are of 10% or 20%, considering to the head”(Herwig et al., 2003).

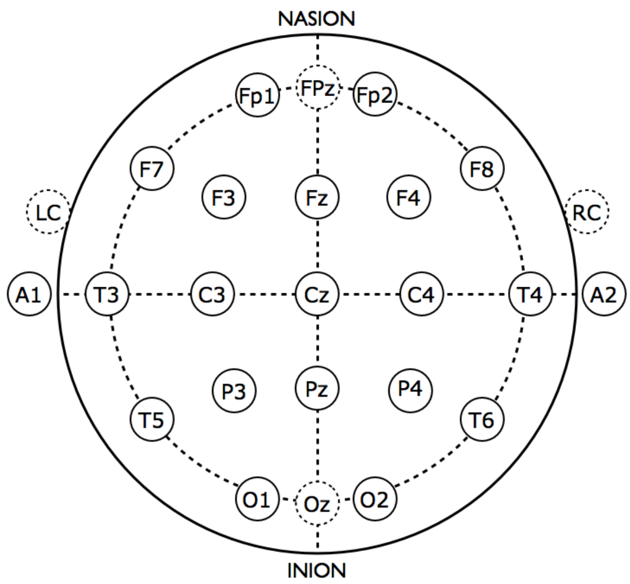

FIGURE 4. Arrangement of 10-20 electrode system on the scalp with landmarks of nasion and inion (Rojas et al., 2018).

Montage is a suitable arrangement of channels including the electrode pairs with waveforms signifying the potential change between the electrodes. The display covers the activity of the EEG for the entire scalp. This shows the activity of the lateral sides of the brain in this manner the location of a specific area of the brain Fp-front polar, F-Frontal, T-Temporal, P-Parietal, OR-Occipital (Jayant N Accharya, 2016). The above picture depicts 1,3,5,7 towards the left, implies to the cathodes present around the left side of the equator and the even numbers

2,4,6,8 is towards the right referring to the electrodes present around the left hemisphere and the (A1,2) portraying the ear. T3, C3, Cz, C4, and T4 they are placed above the head marked at intervals of 10% - 20%. EEG voltage signal shows the contrast between the voltages at two electrodes. To measure the EEG readings from the screen the device can be set up in different manners. EEG can be seen by the accompanying montages (Rojas et al,Hugdal Kenneth 1995 & 2018). Diverse types of EEG montages which are used for EEG activity are discussed below.

Bipolar Montage:

According to Niedermeyer (2017) A set of electrodes combined creates a channel and every channel (waveform) stands for the variance between the two neighbouring electrodes. The entire montage has a series of these channels (Donald L. Schomer, 2017).

Referential Montage:

Referential montage shows that the channels are prominent with a certain electrode type and is labelled as a reference electrode (Niedermeyer, 1999) It is not necessary to follow standard rules for the reference and the recording electrodes as their arrangement differs. Midline positions are applied because they do not amplify a specific signal from one which is attached to both earlobes and mastoids (Niedermeyer, 1999).

Average referential montage:

The amplifiers are taken into consideration i.e., the weighing of the reference electrodes is decided by its interelectrode distances (Lemos, 1991).

Laplacian montage:

In this montage each channel has a contrast between the electrode and an encompassing electrode and this weigh normal. According to Fish, (1999) these montages are not suitable for all circumstances. But with a computerized EEG, all the signals are computerized on a regular basis and are put under a specific montage preferably referential, as any montage can be built in a scientific way (Gordon et al., 2004).

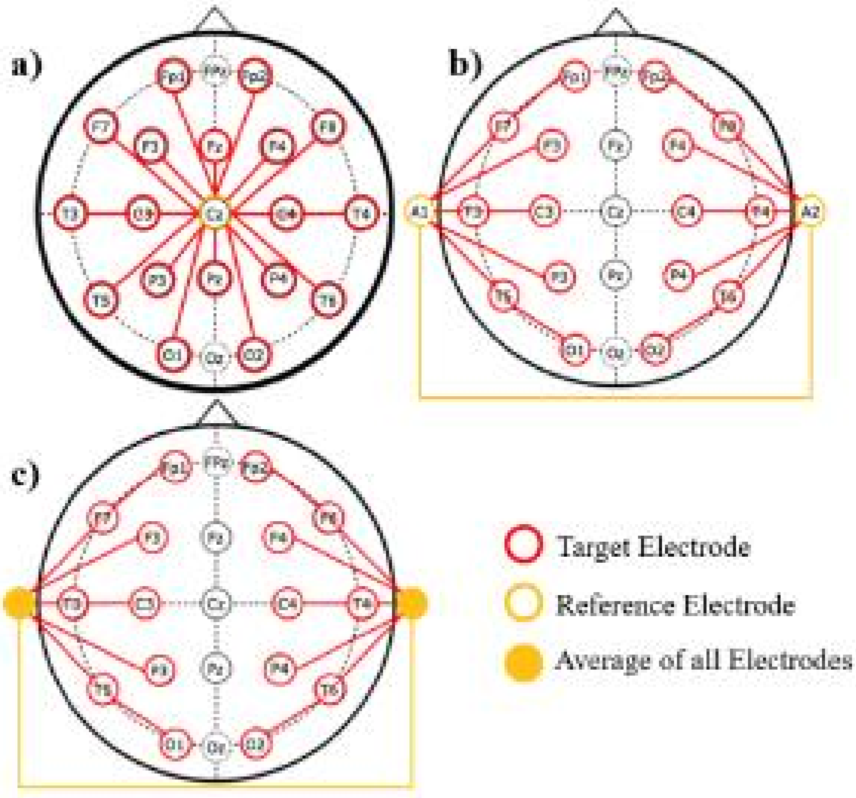

FIGURE 5. Common referential montages a) Common vertex Reference (cz) b) shows the linked ears reference (LE) c) stands for the average potential (AR) (Lopez et al., 2017)

In the figure 5 we can see EEG pattern of the electrode and its common electrical referential points, the electrode references for the scalp which marks different electrical activity. The reference point has the potential to measure its voltage and has a notable impact on its nature. In fact, the transmission of these electrical signals through the brain is highly nonlinear and has a noisy process. The groundings play a key role with the observation of signals and its quality and this is called common reference vortex-electrode. This is used on the centre of the head. Linked ear references (A1+ A2, LE, RE) sites are linked to the ears and mastoid bones. The electrical activity is implanted through one year. The median reference (AR) uses the average of finite number of electrodes as a reference (Lopez et al., 2017).

To understand the electrical activity of the brain the EEG patterns play a vital role. They can be differentiated or highlighted morphologically by the mental activities or conscious states. The frequency bands are divided into five classifications. In the following segment we will be examining the familiar patterns of EEG flags in various conditions in the phases of being alert, rested, undergoing a brain disorder and extraordinary enthusiasm.

2.3.3 EEG signals and its characteristics

Frequency is important for evaluating the variations which occur in clinical EEGs and acknowledging useful practices in psychological research. With billions of neural networks oscillating, the human EEG potentials are referred as eccentric motions with interrupted eruptions of motions which are classified in specific bands 0.5-4 Hz (delta, δ), 4-8 Hz (theta, θ), 8-13 Hz (alpha, α), 13-30 Hz (beta, β) and >30Hz (gamma, γ) (Mehrotra,(2016).

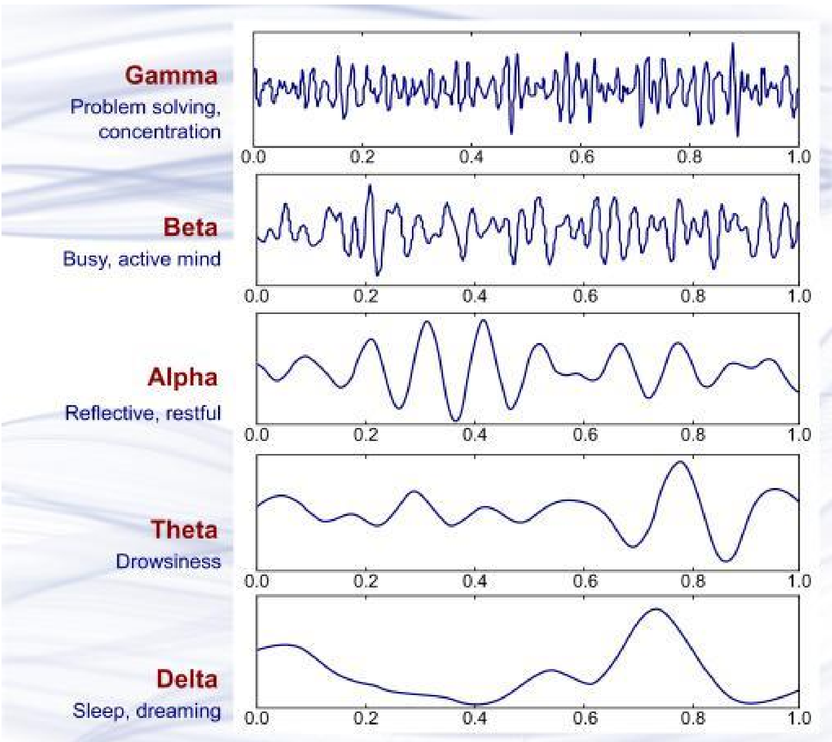

FIGURE 6. Representing Brain Waves and their frequencies gamma, beta, alpha, theta, delta waves (Priyanka A. Abhang, 2016).

Delta wave lies between the range of 0.5 to 4 Hz and its shape signifies that it has the highest amplitudes, and the waves are slow. These waves relate to deep sleep, serious brain disorders while they are awake (Chetan S. Nayak; Arayamparambil C. Anilkumar., 2020).

Theta wave lies between 4 and 8 Hz with an amplitude usually greater than 20 μV. Theta waves take shape from emotional stress, especially from disappointment and insensitive matters, innovative inspiration, and deep meditation (Mehrotra, 2016).

Alpha waves have a frequency ranging from 8 to 12 Hz, with 30-50m μV amplitude, which can be seen in the posterior regions of the head (occipital lobe) when the subject has the eyes closed or open or even in the relaxed state. This is related to the intense mental activity stress and tension. Alpha activity is recorded from sensorimotor areas and it is also called mu activity (Louis & Frey, 2016).

Beta waves, the frequency ranges from 12 Hz-30 Hz. Its amplitude is low, and the frequency differs with the proportionality on both sides in the frontal lobes. When the brain is evoked and is actively engaged in mental activities, it gives rise to beta waves. Beta wave is related with active attention, things and solving concrete problems (Louis & Frey, 2016).

Gamma waves have a frequency from 30 Hz and up. These waves are also described as having a maximal frequency, it ranges from 80 HZ/100 Hz and are linked to different cognitive and motor functions (Louis & Frey, 2016).

In EEG the electrical signals rise from the non-cerebral region of the brain and are termed as artefacts. These artefacts consist of amplitudes and are considerable in size when compared with the amplitude of the cortical signal of interest (Hugdahl kenneth, 1995). This is one of the main reasons why there is a need of a skilful person to interpret the EEGs clinically. The data is mostly contaminated by artefacts. The following subsection discusses about Epilepsy and its seizures with gradually affecting the signals of EEG. The table below stands for the several types of waves differentiating between the behavioural state with its hormone and the location (Kumar & Bhuvaneswari, 2012).

TABLE 2. Several types of waves and behavioural state with hormones and their location (Priyanka A. Abhang, 2016)

Type	Frequency	Behavioural / Psychological state	Neurotransmitter/ Hormone	Location
Delta	0-4	Deep rest, Dream sleep	Human Growth hormone, Melatonin	Frontally in adults, Posteriorly in children
Theta	4-8	Deeply relaxed	serotonin, Acetylcholine, Anti-cortisol, Endorphins, Human Growth Hormone.	Thalamic Regions
Alpha	8-13	Daydream, Calm	Serotonin, Endorphins, Acetylcholine	Posterior Regions
Beta	13-30	Alert, active thinking, anxiety, Panic attack, focus, concentration	Adrenaline, Cortisol, Norepinephrine, Dopamine	Frontal and Parietal
Gamma	30-100	Combination of two senses	Serotonin, Endorphins	Somatosensory cortex

Mu waves range about 8-13 HZ and have definite shape and are related to the motor cortex and the parasagittal regions (Kumar & Bhuvaneswari, 2012).

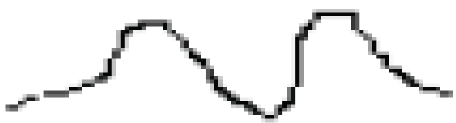

FIGURE 7. Representing Mu waves with their definite shape (Kumar & Bhuvaneswari, 2012)

K-complex waves occur with the flow of theta waves followed by an arousal response here the frequency of the waves is high and there is noise which is created (Kumar & Bhuvaneswari, 2012).

FIGURE 8. Representing V waves during sleep (Kumar & Bhuvaneswari, 2012)

V waves occur in two sides of the parasagittal area and these waves take place during the sleep. The signals appear during the sleep disturbances and is like K complex, it might be present during the deep semi sleep arousals (Kumar & Bhuvaneswari, 2012).

FIGURE 9. Lambda waves during waking and visual exploration (Kumar & Bhuvaneswari, 2012)

Lambda Waves are sharp, transient over the occipital region of walking person during visual exploration. These are triangular and takes place when the eyes stare at a blank surface. The wave patterns can be seen while reading or watching television and it is a normal waveform and be a single wave/short runs/long runs (Kumar & Bhuvaneswari, 2012).

FIGURE 10. Spike waves patterns during an injury (Kumar & Bhuvaneswari, 2012)

Spike waves are seen in all ages but can be seen more in children. The amplitude for this wave is enormous, it is a slow wave around 3HZ (saw in delta wave form) its roots start from the thalamic structures. These wave patterns can be noticed with brain injury and the Lennox-Gas taut syndrome (Kumar & Bhuvaneswari, 2012).

Sleep spindles is also known as a sigma activity which ranges up to 11-15Hz range in the upper alpha level or lower level of beta these are a group of waves which usually occur during the sleep (Kumar & Bhuvaneswari, 2012).

2.4 Hospital Electrodes

The hospital electrodes are silver-silver chloride electrodes, the standard name for the hospital electrodes is Golden standard electrodes which are normal industry-based electrodes available from Tampere University Hospital (TAYS).

FIGURE 11. Representing silver to silver chloride electrodes wire with white patch

In the figure 11 we can see the TAYS electrode with the component cap open in the centre (left) towards the right we can view an individual wearing an ambulatory EEG device with the reference hospital electrodes near the left corner of the eye.

The electrical stability of silver chloride electrodes has been proved repeatedly since the process was introduced in 1900 by Jahn. Electro-chemists use the silver-silver chloride electrode as a reference in the measurement of the potentials developed by ionized solutions. Electrophysiologists use chlorided silver electrodes in recording bioelectric signals (David Daomin Zhou, 2008).

Earlier, the potential is measured but the current is drawn from the electrodes. The electrical impedance of the electrode-electrolyte interface was to be examined. Silver-silver chloride (Ag-AgCl) electrodes are used because of their stability and it has exceptionally low half-cell potential of about 220 mV and it's easy to manufacture (Lee & Kruse, 2008). Ag-AgCl electrodes are non-polar electrodes; they let the current to pass through the interface connecting the electrolyte and the electrode. According to Stephen Lee et al, (2008), non-polarized electrodes are recommended than polarized electrodes because of their denial to motion artefacts and their reaction to defibrillation currents (Lee & Kruse, 2008)
The motion artefacts and the defibrillation happen to charge up the "capacitance form the electrode to electrolyte assembling (Lee et al; (2008). The coating of silver chloride lessens the impedance of the electrode. This is to be considered because the low frequencies are created near the DC and at this point the ECG and the EEG measurements are taken (Lee & Kruse, 2008).

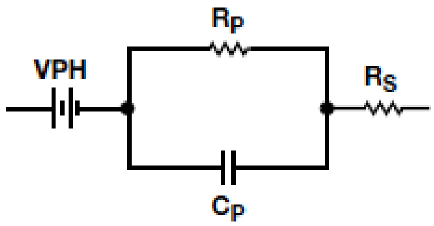

FIGURE 12. Equivalent circuit model for biopotential electrode (Lee & Kruse, 2008)

In an earlier paper Geddes and Baker, (1967) it was shown that silver electrodes which had been chlorided for a brief time showed a decrease in low frequency impedance almost unsusceptible in character(L A Geddes, 1967). When the data was analysed it was shown that the high frequency was escalated. In conclusions, the reason behind this was that the greatest outcome of the current and the time for a specified electrode area would produce the lowest electrode-electrolyte interface impedance (Lee & Kruse, 2008).

2.4.1 DC offset Voltage

Offset voltage is defined "as the voltage that must be applied to the input to cause the output to be 0" (Nihal Kularatna, (2000). Direct Current Offset (DC) occurs with the result of two natural laws: Current shall not change at once when inducted and current must fall behind the applied voltage by the natural power factor. According to M. Jones, (2015) there is standard procedure to be followed to minimize the artefacts due to electromagnetic interference and the electroencephalogram impedance measurements should be 5,000 Ohms or less than that. (Jones, 2015).

There are countless factors which features the quality of an electroencephalograph (EEG) recording which includes reduction of artefacts, stability of the electrode, and a high possibility of signal to noise ratio. There is a possibility that the electromagnetic interference (EMI) can occupy an EEG recording. According to American association of sleep Technologists, (2012); American Clinical Neurophysiology society, (2008). Impedance measurements which are below 5,000 ohms (Ω) has been set as a standard EEG recording (Shellhaas et al., 2011)July, 2012). Modern high amplifiers lower the influence of EMI, it is advised that 5,000 ohms (Ω) is no longer safe if there is a need of skin abrasion (Jones, 2015). According to Kappenman and Luck 2010 in their research told that high electrode impedance might reduce the signal to noise ration and analytical power in event related potentials (ERP) recordings even when the instrument has the capability to withstand the high impedance levels (Kappenman & Luck, 2011).

3 BrainCare ELECTRODE

BrainCare electrode is termed as “UltimateEEG” with its innovative technology it has given rise to a design for long term implantation subdermal EEG electrode. The Ultimate EEG is coated with the metal platinum. BrainCare Oy, is the first company in the world to successfully use Platinum metal in their electrode for subdermal implantation. All BrainCare patterns are regarding how to make flexible electrodes.

The UltimateEEG electrode is flexible, comfortable and user friendly. According to Pirhonen (2015), the electrodes were designed, and the manufacturing methods were developed in Tampere University of Technology now known as Tampere Universities (TUNI). The significance of the electrode is, it is implantable and can be introduced underneath the skin through a small incision which is about a centimetre long. To understand, the neurons in the brain communicate through signals and when the communication occurs a voltage is generated and from this point the electrodes detect and convey the signal through a tiny amplifier. The electrode also has a recording and measuring unit where the data can be stored and automatically updates to the cloud. one can estimate from which location of the brain an epileptic seizure has occurred and this is one of the basic requirements to treat epilepsy.

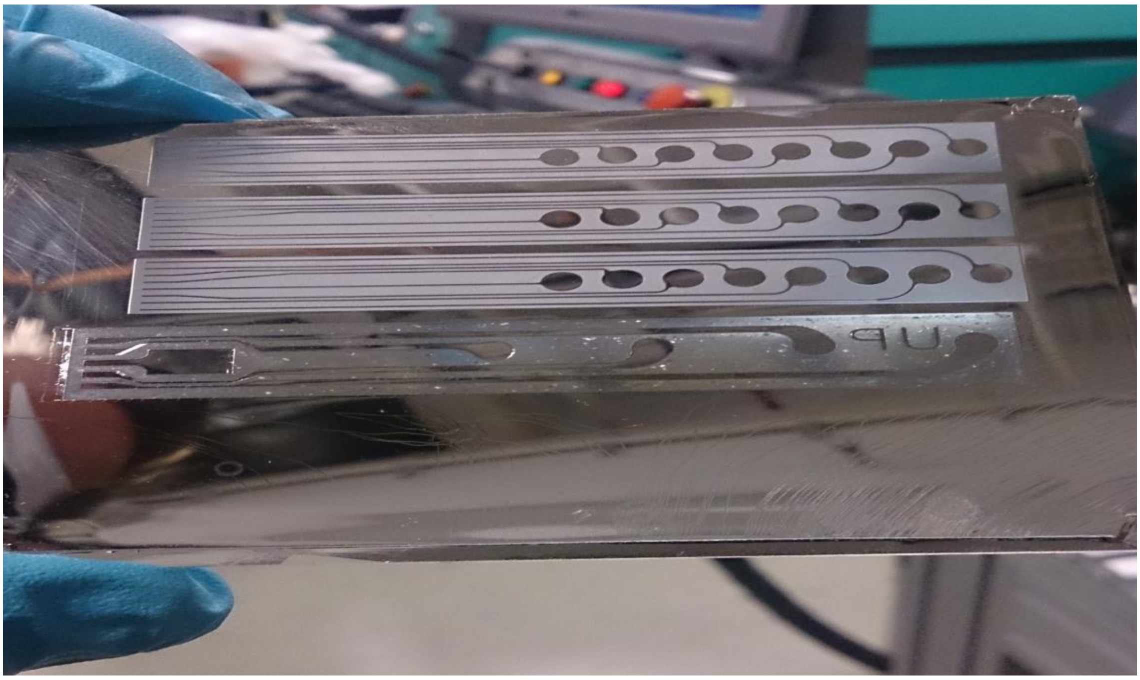

FIGURE 13. BrainCare electrode also called as UltimateEEG representing 8 channels coated with platinum.

The figure 13 depicts a BrainCare electrode with eight channel measurements and the distances of these channels were specially designed to measure various locations of the brain when the EEG signals are accumulated.

For a standard quality electrode certain characteristic are essential and those details will be discussed below:
According to Gulino, (2019) to be successful with the integration, reliability, and durability when the implant is introduced to the brain tissue it must have the following characteristics (Gulino et al., 2019).

- It should be **biocompatible;** the surface of the microelectrode should not be toxic for the neural cells so that the surrounding tissue can be protected.
- It should have the capability to **biomimic** the physiochemical and mechanical attributes of the extracellular matrix. It also must encourage the neurite development towards the surface of the electrode, in this way the triggering and recruitment of glial and fibroblasts can be avoided which contributes to compress the electrode (Gulino et al., 2019).
- Lastly it must be **biostable,** microelectrodes need to continue to support their physical health, electrochemical balance, functionality, and the ability to withstand the highly corroding tissue microenvironment. with this process they do not have to undergo any structural modification (Gulino et al., 2019).

3.1 Biocompatibility

The implantable neuroelectordes has a significant demand in the medical field for treating trauma and neurodegenerative disorders. In fact, there have been caveats associated with clinical applications, some of the electrodes have caused the implant failure due to chronic inflammation in response to the nervous tissue when the injury has occurred over a prolonged period. To overcome these challenges occurred with the implant failure researchers have produced innovative design strategies which can be executed to stop unnecessary damage, and these are called as microelectrode systems. They are designed with innovative materials which are highly biocompatible (Hill et al., 2015)FDA, 2019).
According to Cristina Marin (2010), the surface composition of the implant plays a vital role. The shape, size, firmness of the implant are major considerations of biocompatibility. If the microelectrodes are to be implanted for a long time then

the biocompatibility, durability, and the safety of both the patient and the device matters the most. To reduce the foreign body reactions the young's modulus, electrochemical properties, biological and mechanical properties, the surface morphology, and crystallography should be first examined. Young's modulus is used to measure the elasticity (Gulino et al., (2019)Boer, (2016).

A first-grade microelectrode was designed to assemble microelectrodes or micro-electrochemical systems (MEMES). Microwire comprises of metals that include gold and tungsten. If the special distance between the tissue and the electrode (Youngs modulus) is not proper, then some changes can occur in the resistance or capacitance of the material to be used and this could lead to chronic inflammation and implant failure (Hill et al., 2015).

According to Lai et al; (2012) and Hess et al; (2011) Polyimide and parylene based MEMES electrodes have been seriously examined by researchers to improve mechanical properties, to construct easily and have the capability to introduce bioactive molecules (Gulino et al., 2019). For a long-term interaction with the tissue a persistent stimulation electrode site material is used with the metals which include platinum, tungsten, tantalum pentoxide, titanium pentoxide. These are some of the materials which have been used significantly because of their electrically charged injection properties and biocompatibility (Boer, 2016).

when any healing biomaterial-based device is implanted in an in vivo environment there is a need of surgical actions this could lead to the damage near the area where the implant is embedded. Due to this, there are lot of procedures developed to reinstate the tissue balance all over the implant and this is a common physiological process which occurs as a s tissue response and this is called as wound healing (Lotti et al., 2017) .

3.2 Foreign body reaction due to implant failure

Most of the times when the presence of the implant is long term continuously it could lead to overstimulation in the immune system. This could end up in poor wound healing process and chronic inflammation and this is called as foreign body reaction and due to this there is a high chance of implant failure (Stanisa et & Lotti et al; 2017 , 2014). The below picture figure 14, represents about the foreign body response. It stands for a schematic timeline which discussed about the procedure of neural tissue response to the implantable microelectrode. After the implant is embedded there is a risk that many neurons can be lost straightaway then followed by the interference of the neural membrane damage where the axons can be cut, and this could lead to neuronal damage. The oxidative pressure in the neurons is due to rise in intracellular calcium levels because of the N – methyl – D- aspartate receptor (NMDA) activation (Gulino et al., (2019) created by microglial and astrocytes this leads mitochondrial dysfunction. Then accumulation of proteins occurs due to the microglial cells and astrocytes this forms a scar (Gulino et al., 2019).

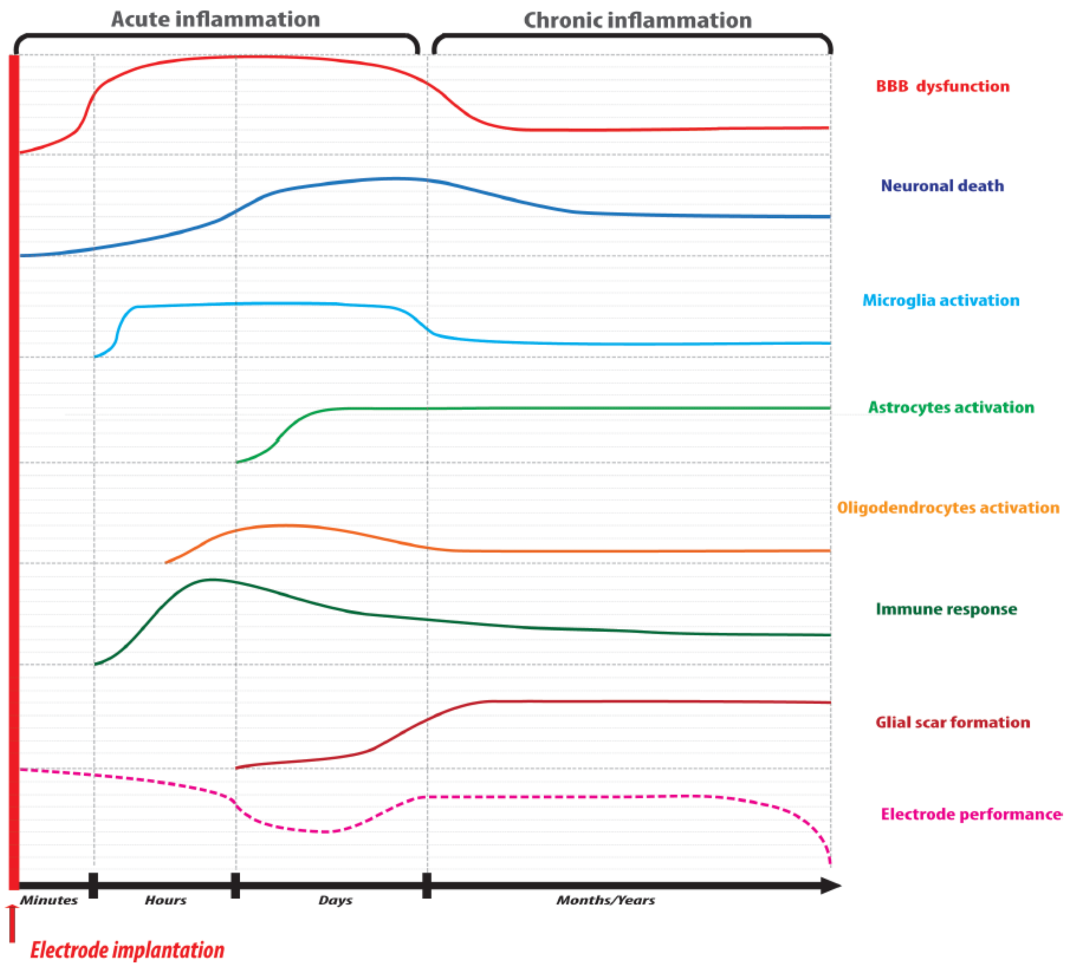

FIGURE 14. Reactions involved in neural tissue response to implantable microelectrodes (Gulino et al., 2019).

3.3 Design of the Electrode

According to the earlier work of pirhonen, (2015). The electrode was designed with three layers first layer with a metal and the other two with the base layer materials. The first layer is coated with a metal called platinum and the base layer materials include parylene and polydimethylsiloxane (PDMS).

FIGURE 15. Design of the electrode with two base and a metal layer (Pirhonen, 2015)

In the above figure 15 we can see the design of the electrode with three layers PDMS A174, parylene C and the metal platinum (Pirhonen, 2015)
There were various metals and alloys which had the probability of an electrode metal. The metals which could be used were Gold (Au), Platinum (Pt), Iridium (Ir) ,Titanium (Ti) , Tungsten (W). Out of all these metals Platinum was specifically selected because it has the smallest encapsulation suitable for long term implantation and has the second-best conductivity than Gold (Au). Parylene (P-xylylene), polydimethylsiloxane (PDMS), polyimide was selected as the biocompatible base layers. According to research and the other studies parylene and PDMS were especially considered to ensure that the electrode does not break during the procedure of implantation and while the implant is removed. Parylene and polyamide-based electrodes are difficult to manufacture when the electrode exceeds 100 µm. However, PDMS was the best choice as the base layer because its thickness is above 100 µm (Pirhonen,2015).

The Table 3 describes about comparison between the three biocompatible implant grade versions. Here, parylene and PDMS seem to be biocompatible as tested inaction of the materials and their properties will be discussed as follows:
TABLE 3. Comparison of biocompatible electrode materials (Pirhonen, (2015

.

	Parylene	PDMS	Polyamide
Biocompatible implant grade versions	Yes Yes 1-20µm	Yes Yes 10µm up to several mm	No No 8-500 µm
Advantages	Low water permeability. Adheres well to the metal. Thermal coefficient close to the metal. Good dielectric barrier.	Easy to manufacture in various shapes and sizes. Excellent mechanical properties. Stiffness can be easily adjusted.	Widely used in electronics. Conventional lithography methods can be used. Durable and good dielectric barrier.
Disadvantages	Difficult to manufacture. Hard by itself.	PDMS metal structures are prone to breakage. Do not adhere well to the metal. Cell growth into PDMS during implantation makes it hard to remove.	Difficult to manufacture in general and in thick layers.

3.4 Electrode Metal

Platinum

According to Fernandez (2017), Platinum is one of the elements which is included in the platinum group of metals. It is inactive, stable, and can withstand corrosion. Studies have shown that the encapsulation caused by platinum implants is the smallest among all tested biocompatible metals (Venugopal, 2006). when compared to Gold, platinum has the higher charge injection potential, and it is chemically stable. The platinum electrodes can be obtained by different procedures like sputtering, electroplating and by mechanical stress. Platinum is being used in a range of medical implants due to its non-corrosive nature and it does not allow any disturbances with the chemical environment in the body (Tashiro Hiroyuki, 2019).

TABLE 4. Properties of platinum materials (Gilbert, 2012)

Oxidation Resistance 1200℃/1600℃	**Electrochemical Oxidation Potential**	**DC corrosion Resistance**	**Relative Radiopacity**	**Electrical Conductivity**
0.1 - 0.3 g m-2 h-1 / 1.2 g m-2 h-1	-1.2V	5-7 mg amp-1 year-1	30 x Ti 6.7 x Ni	9.937 x 106 S m-1

The table 4, describes about the platinum materials properties and their purposes for special medical equipment's. The biocompatibility of platinum has a major benefit that it is useful for long- and short-term medical implantations. Platinum offers high electrical conductivity and good mechanical resistance and acts as an excellent electrode material for various biomedical applications. Chemically Platinum is often described as a “noble metal” as it is inert as discussed earlier. It does not react with oxygen levels in the air and the best part is it does not get rusty or deteriorated and resistant to acid attacks (Gilbert, 2012).

3.5 Electrode base material

Parylene

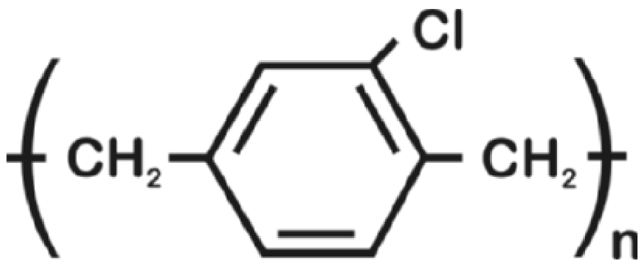

FIGURE 16. Structure of Parylene C (Vincze et al., 2009).

The figure 16 represents the monomer structure of parylene C. Here, mostly ostly parylene C is discussed because it is one of the base layers of the electrode was designed with parylene C. Parylene belongs to the unique polymer series and they were differentiated in the 1940´s in the university of Manchester England. Parylene’s have separate groups with special properties. Some of them are used industrially are Parlelen N, C, and D. Parylene N is linear and highly transparent whereas, Parylene C is easily available in the market and it is produced from the same monomer. Parylene D is called as the third type of polymer which is produced in the same way as parylene C and it has the alike properties like parylene C. Parylene D, is the third member of the series, and it is produced from the same monomer changed by the substitution of the chlorine atom for two of the aromatic hydrogens. Parylene D is similar in properties to Parylene C with the added ability to withstand higher use temperature(SCS, 2015). Parylene is used as a layer of coating material which is applied to substrates using chemical vapour deposition (CVD) (McGuinness, 2020).

According to studies ,Parylene C is one of the best coatings commercialized and it is used widely in the medical devices as a substrate for peripheral nerve electrodes a nerve electrode where the neurons can be connected to a brain machine interface (BMI) and can record neurons (McGuinness, 2020). Parylene C has a good combination of electrical and physical properties and an added advantage is it has extremely low permeability. The table below distinguishes the physical properties of several types of parylene (SCS, 2015).

TABLE 5. Mechanical and physical properties of parylene (SCS, 2015)

Properties(I)	Method	Parylene N (Z)	Parylene C	Parylene D	Expoxides (3)	Silicones (3)	Urethanes (3)
Secant (Young's) Modulus (psi)	1	350,000	400,000	380,000	350,000	900	1,000-10,000
Tensile Strength (psi)	2	6,000-11,000	10,000	11,000	4,000-13,000	800-1,000	175-10,000
Yield Strength (psi)	2	6,100	8000	9000	-	-	-
Elongation to break (%)	2	20-250	200	10	3-6	100	100-1,000
Yield Elongation (%)	2	2.5	2.9	3.0	-	-	-
Density (g/cm^3)	3	1.10-1.12	1.289	1.418	1.11-1.40	1.05-1.23	1.10-2.50
Index of Refraction (n_o^{23})	4	1.661	1.639	1.669	1.55-1.61	1.43	1.50-1.60
Water Absorbtion (% after 24 hrs)	5	lesser than 0.1	lesser than 0.1	lesser than 0.1	0.08-0.15	0.12 (7 Days)	0.02 – 1.50
Rockwell Hardness	6	R85	R80	R80	M80-M110	40 – 45 (Shore A)	10A-25D (Shore)
Coefficient of Friction							
Static	7	0.25	0.29	0.33			
Dynamic		0.25	0.29	0.31			

The above table 5 represents the comparison of parylene groups with other group materials. The series of parylene N, C and D has good yield strength and yield elongation.

Polydimethylsiloxane (PDMS)

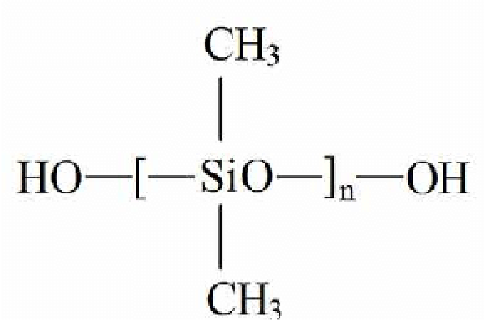

FIGURE 17. Chemical structure of Polydimethylsiloxane (Vincze et al., 2009)

In the above figure 17 the chemical structure of PDMS and the length of the chain can be seen, the more the length the more is its thickness (Vincze et al., 2009). Polydimethylsiloxane (PDMS) is a known as a silicone elastomer. It has enough properties for the development of MEMES and micro fluid components. It is chemically inactive and stable under extremely hot temperatures. The gases are easy to absorb, flexible to handle and use. PDMS ideally has Isotropic and homogenous properties and economically low at cost (Mata et al., 2005).

PDMS is widely used for BioMEMES applications because it is transparent, and it can also balance light. The main strength of PDMS is it is biocompatible, non-toxic, and conventionally used in many medical devices (Mata et al., 2005). One of the main benefits of PDMS is its biocompatibility with the biological tissue. PDMS can reduce the consequences and involvement of the tissue response. PDMS is often poured at layers which are micropatterned the manufacturing process is done by soft lithography and by this a gel like consistency is formed. (AnuradhaSubramaniam, 2014).

3.6 Device used for Designing the Electrode

Laser etching:

FIGURE 18. Laser etching process for UltimateEEG by using a software

In the figure 18 we can see the laser etching device while etching the platinum coated electrodes designed by using a software in sähkötalo Fablab in Tampere University (Hervanta campus).
According to G.Li (2020) Lasers plays a vital role in the upcoming modern technologies, a foundation in science to industrial production. Laser writing saves time in basic research and development industrially. The idea behind the laser etching is that the heat from the beam acts as a source for the external part of the material to melt. A laser etcher alters the final surface of the metals and changes the reactivity of the material and increases the contrast (Li, 2020).
The Laser etching for "Ultimate EEG" was performed in sähkötalo Fablab in Tampere University (Hervanta Campus). The platinum-based electrodes were laser etched specifically marked to cut and the channels of the electrodes and the logo (UP)were designed, and it can be viewed by the naked eye. There was a software available in the system for laser etching and through this software everything necessary for designing the platinum electrode was processed. A skilled person in the field is essential. While doing the procedure all the necessary precautions were taken. The designed platinum electrodes were further for study.

3.7 Current Novel Technologies after BrainCare

There are various companies around the world that have come up with advanced technologies with their research and development after BrainCare for long term EEG monitoring.
24\7EEG subQ from UNEEG Medical company from Lynge, Denmark has designed its device with the capability to capture the EEG signals for longer period.

It consists of two bipolar channels and these channels can be introduced under local anaesthesia. The device comes with a software, the software can sense the seizures automatically. The subQ is home friendly device ideal for using at home. The device is CE marked and at present there are clinical trials going on (Duun-henriksen et al., 2020).

The Epicranial application of stimulation electrodes for Epilepsy from Precsis (Heidelberg, Germany) is known for its neurostimulation for focal Epilepsy. The company uses five subsclap platelet electrodes. The electrodes are uniquely arranged, four smaller electrodes are positioned around the larger electrode and this larger electrode is in the centre. The idea is inspired from the Laplacian concept for improving stimulation in depth. The implant can be made above the lesioned area of the brain and it records the epileptic seizures and supplying the neurostimulation at an individual loop setting. Ongoing clinical trials are made currently (Duun-henriksen et al., 2020).

The Epios system from the Wyss centre for Bio and neuroengineering (Geneva, Switzerland) specialised in understanding the brain and its disease aspires to "offer the flexible configurations, from focal or bitemporal electrode layouts for a broad coverage rearranging the locations of the 10-20 scalp EEG montage to the sub scalp compartment" (J. Dunn -Henriksen et al. (2020). The embedding of the entire montage is performed in less than an hour by setting two to four incisions with epiosteal tunnelling tools (Duun-henriksen et al., 2020)The EEG information is wirelessly transported to a headpiece and then to a body worn unit for power as a momentary storage. The body worn unit supplies the multimodal co-registration including ECG, audio, accelometry broadcasting to a secured base application that supports long visualization of data and analyse it (Duun-henriksen et al., 2020).

Minder from Epi-Minder (Melbourne, Australia) has a sub scalp device, capable of inserting a multichannel electrode leading across the skull by tunnelling procedure, with this both the hemispheres of the brain are covered. Minder has the skill to supply long term and continuous measures of the EEG which is useful for better diagnosis and managing epilepsy. The clinical trial procedures are in process (Duun-henriksen et al., 2020).

The Neuroview Technology (Englewood, NJ) focusing on small implantable intravenous long-term monitor for Epilepsy. It has the subscalp EEG recording system to write down seizures and helps with detection of rare involuntary episodes of altered consciousness or conclusive activity. An added advantage here is the device can record the seizures continuously for a year and there’s no need to recharge the device (Duun-henriksen et al., 2020).

According to Laura M.Ferrai et al. (2020) there are temporary tattoo electrodes which have appeared as the recent development in the field of cutaneous sensors. These are non-invasive inkjet-printed conducting polymer tattoo electrodes These tattoos proved their functioning in the monitoring of different electrophysiological signals on the skin. These epidermal electronic devices present a conformal and gradual contact with the wearer while allowing better quality recordings over time (Ferrari et al., 2020).

4 MATERIALS AND METHODS

4.1 BrainCare electrode testing in saline solution over time

BrainCare electrode is termed as UltimateEEG electrode and the hospital electrodes from Tampere university hospital are industrial based electrodes also known as “Golden standard electrodes”. The ideology is to compare and measure the DC offset and surface EEG with Golden standard and UltimateEEG electrodes.

The main component used in the golden standard electrode is silver. It has a silver paste in it. The main metal used in the BrainCare electrode is platinum (pt) with the base layers coated with parylene and PDMS. As discussed, earlier platinum was considered because it has the smallest encapsulation and furthermore has the potential to be used for long term implantation. An added advantage with platinum is it has the second-best electric conductivity than the Golden standard electrodes. To measure the DC offset voltage, analyse the functionality of the electrode a small home set up is made. The DC offset measurements were obtained by a digital multimeter.

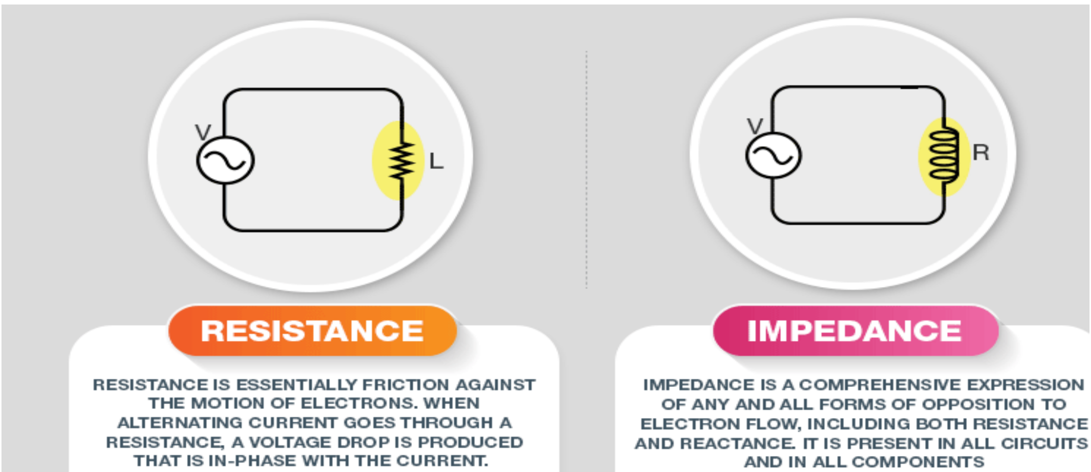

FIGURE 19. Difference between resistance and Impedance (Classes, BJYU'S).

The above figure 19 describes about the difference between the resistance and impedance the resistance changes with the frequency when it is connected with the direct current (DC) and Impedance is measured in the opposition of alternating currents (AC) and this is created due to the inductance and capacitance (BJYU’S classes).

UltimateEEG and Gold standard electrodes were used together in the home-based experimental set up. Both the electrodes were half immersed in the saline solution in a porcelain cup. The reason behind the immersing the electrodes in the saline solution is to stimulate the conditions under the skin. The saltwater acts as a conductor in a circuit with the electrodes. The porcelain cup acts as a circuit with the electrodes in the salt solution due to their conductivity. The resistance measurements were taken by the probes of a digital multimeter. The protocol used for the home-based experimental set up for Dc offset and resistance measurements is explained further.

FIGURE 20. Digital multimeter with black and the red lead probes (Fluke, n.d.)
In the above figure 20 showing a digital multimeter which is used to study the DC offset voltage with the red and the black lead testing probes (fluke.com)

Protocol:

- Boil 1.1litres of hot water and add the given salt (8.5grams) into the hot water. Ensure that the salt is completely dissolved. Pour the saline solution into the porcelain cup and make sure that the salt is completely dissolved.

- Both the electrodes were placed in the cup, in opposite directions immersed in the saline solution. The white patch in the cup denotes the golden standard electrode and the platinum coated one is “UltimateEEG.” Here the voltage and the resistance of the electrodes are measured.

- Golden standard electrode and “UltimateEEG” are partly immersed in the saline solution to the adjacent angles to the porcelain cup as they need to be stable.

According to the plan the voltage readings should be taken every day and the resistance measurements at the end of the week. Electrode A- for 2 weeks, Electrode-B 4 weeks, C -6 weeks. After each consecutive week, the electrode is to be taken out and the resistance measurement should be noted with the lead probes of the multimeter.

But in the study the voltage measurements for both the electrodes were taken consistently for two weeks (14 days). Electrodes A, B and C were measured every day. The resistance measurements were taken after each consecutive week.

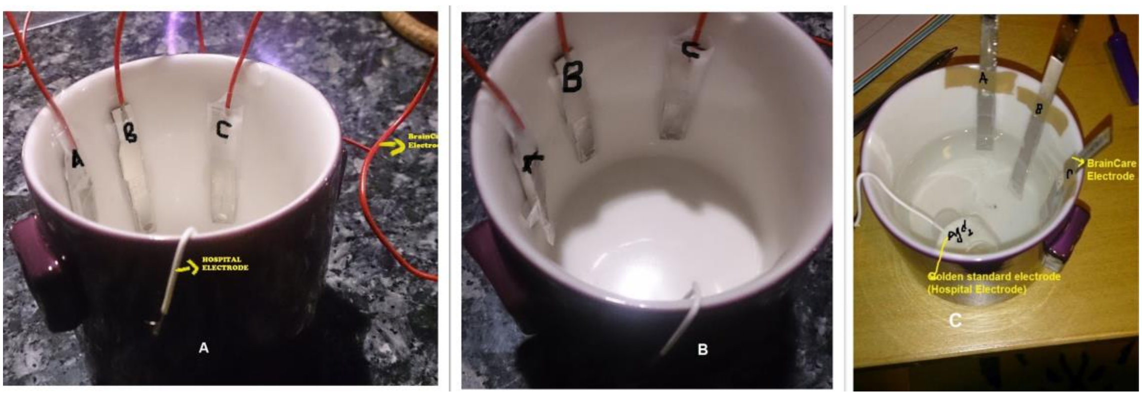

FIGURE 21. Depicting the arrangement of the electrodes in home set up experiment.

The above figure 21 represents the home-based experimental set up with the platinum-based electrodes and A, B, and C and the silver-silver chloride electrodes at the side of the porcelain cup and the electrodes are half immersed in the saline solution. Porcelain cup acta as a circuit.

4.2 To see how DC offset Voltage changes

A digital multimeter has the capability to assess two or more electrical values, such as voltage (volts), current in amperes (amps) and resistance in ohms (Ω). The aim of the experimental set up was to measure the DC offset voltage (200 millivolt) between the two electrodes. As discussed earlier the voltage readings were taken every day and the resistance was measured at the end of the week in this case the electrode was taken out from the saline water and then the values were noted through a digital multimeter.

The digital multimeter is provided with two test probes, a red test probe having the positive charge (+) of the battery and a black test probe denoting the negative charge (-) which connects to the lead of the lightbulb (All about circuits, n.d.). The black testing probe refers to the ground potential. The measurements were taken with the black testing probe placed on the golden standard electrode and the red testing probe on UltimateEEG electrodes A, B, C and red testing probe on Ultimate EEG and black testing probe on golden standard electrode. At the beginning when the experiment was conducted it gave negative results more details will be discussed in results section.

Then the same set up was implemented again and while doing so the measurements were kept under normal room temperatures, in sauna 70-90°C (to analyse and test the stability of the electrode and its DC offset voltage) then freezing temperatures below 0°C. The values seemed to be interesting at the beginning but during the end days of the week there was a drastic change in the values. The temperatures were not planned to be specific during the experiment the idea was just to see the changes and stability of the electrodes under different temperature levels.

4.2.1 Resistance Tests

Resistance is defined as the measurement of electrical friction here the electrons pass through a conductor and the unit to measure the resistance is in Ohm's(Ω).

The UltimateEEG electrode resistance measurements were taken at the end of every consecutive week by removing the electrodes and pat drying them. The black and the red testing probes were placed at the end of the UltimateEEG electrode at the same time. In this manner, the resistance of the electrode was measured. To know if the resistance signal quality is good for the electrode it must surpass certain standard measurement. According to Pirhonen, (2015) the resistance of the UltimateEEG electrode should be under 200 ohms for the signal quality to be considered good enough.

4.3 Hospital surface measurements

The hospital surface measurements were taken from the people who do not suffer with epilepsy with a setup of the reference electrode from BrainCare (UltimateEEG) and Golden standard electrode. The measurements were taken from a 6-channel wireless EEG recording system. Below we will discuss some of the instruments/devices which were used in taking the hospital surface measurements. All the measurements were performed with the instruments/ equipment's from Tampere University Hospital (TAYS) in the department of neurology.

4.3.1 NoX A1

FIGURE 21. NoX A1 ambulatory EEG device (Medicals, Nox)

In the figure 21, we can see an ambulatory EEG device used for taking the EEG measurements.

The NoxA1 PSG system (Nox medical) is an adaptable polysomnography device with its innovative technology. It has made the sleep study simple which conveys secure and exact estimations. According to NoX medicals this device consists of 10 unipolar unit for EOG and EEG and 3 unipolar submental inputs and four configurable bipolar units. This ambulatory device was used because it has the online and portable abilities. The reference electrodes of Brain Care (UltimateEEG) and hospital electrodes (Golden standard electrode) were attached to the ports of the device. The device comes with a belt which is thick and has the “calibrated RIP technology” (respiratory effort sensory system) this belt is used for circulating the thorax and the abdomen (Medicals,Nox).This ambulatory device has a recording software, and it can be used with the external devices via Bluetooth or can connect to a tablet and the measurements of the brain activity can be seen. The measurements can also be captured from the Nicolet EEG amplifiers which allows you to seize the brain activity. This is a wireless amplifier (Medicals, Nox.).

4.3.2 Measurements with the Nicolete Devices

Traditionally EEG recordings were time consuming and there was always need of a skilful individual to do the recordings. The EEG system is used to record the brain activity. NicoletOne EEG is cost effective, high in quality and with its advanced technology it is used to detect various neurological disorders. This device is used for uninterrupted brain activity and can digitally view and do a sleep study and detect seizures most importantly easy to handle. The impedance measurements were measured with this device in Tampere university hospital (TAYS) in the neurology department in video EEG lab. This equipment comes with amplifiers with a separate set of channels. The amplifier channels used here is 32/44 (Natus NicoleteOne.).

The EEG cap was used with a set of electrodes involving both UltimateEEG and Golden standard electrodes as reference electrodes. The reference electrodes are connected to the amplifiers of the device and automatically the brain activity was recorded. The equipment comes with a recording software which can help with the signals of the brain to be viewed. The impedance is measured with this device because the signal measurements taken from this device is larger compared to a usual EEG. There is a bigger scope to see the signals even if an induvial is away with the EEG amplifier in working process during taking the impedance measurements. The impedance is measured in ohms and for a superior quality electrode the impedance measurement must be under 5000 ohms (Ω).

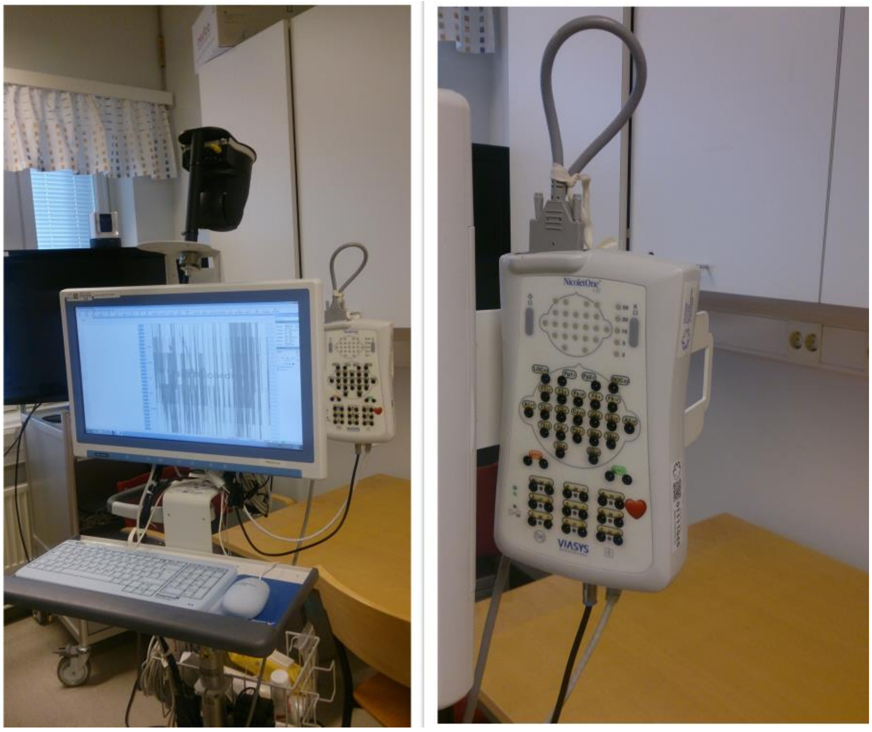

FIGURE 21. Representing the NoleteOne Natus amplifier (Nueronatus.com)

In the figure 21 we can see the NicoleteOne device used in the Tampere university hospital (TAYS) for the impedance measurements the device his connected to the amplifiers with a screen to see the EEG waves.

4.4 Measurements from Healthy Individuals

The common procedure tests were performed on two healthy individuals in Video EEG lab examining the brains electrical activity of the individuals. There are certain fixed test procedures to trigger seizures or to invoke the potentials. To fix the electrodes to the EEG a conductive gel is to be put on. Firstly, a wooden stick was used to rub on to the skin by doing this the outer layer of the skin breaks or opens the pores. After this step propyl alcohol was utilised to clean the area and then the conductive gel was applied. The electrodes were put on the referential points the nose, mastoid, on the forehead as the eyes, the reference points are chosen so that there is electrically a neutral side but technically there have been no prescribed reasons for it and this procedure have been followed traditionally. The “ultimateEEG” electrode and the Golden standard electrodes were attached to the amplifier of the NoX A1 device. The common procedure tests to evoke a potential seizure is discussed below. These tests were done with the referential electrodes.

4.4.1 Flashing light or Blink tests

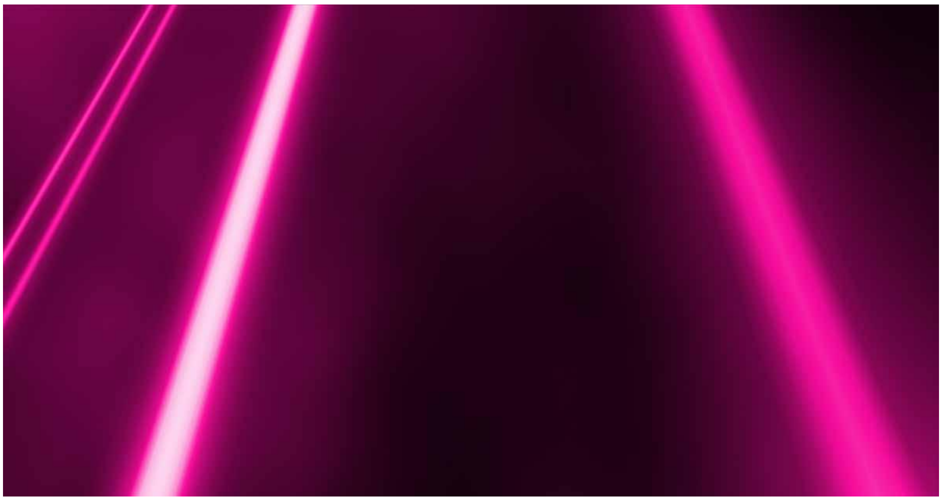

FIGURE 24. Flashing light test to trigger a seizure (Elaine Wirrell MDAngel Hernandez MD, 2019)

In the figure 24, we can see the or flashing lights to trigger a seizure.

The flashing light or flickering light tests are the tests to invoke or trigger a photo sensitive epileptic seizure (Epilepsy foundation 2019).

Some people suffering from epilepsy have seizures that are triggered by flashing lights. Technically, there is a light which flashes at unusual levels of speed. This will trigger to invoke a potential. Normally in the people suffering with epilepsy there is a condition called photosensitivity epilepsy. According to the epilepsy foundation the lights can invoke a seizure in one in 10,000 adults and 4,000 children and adolescents (Elaine Wirrell MDAngel Hernandez MD, (2019). The other lights related to television; video games natural light form the environment are all the vehicles which could trigger a seizure.

In the study these tests were done on healthy individuals to compare the potential functionality off the UltimatEEG to the golden standard electrode. At times there is a possibility to force a seizure in an individual due to these common procedure tests. while the flashing light test the video, EEG was recorded the waves from these tests were collected.

4.4.2 VEP-Checkerboard Pattern

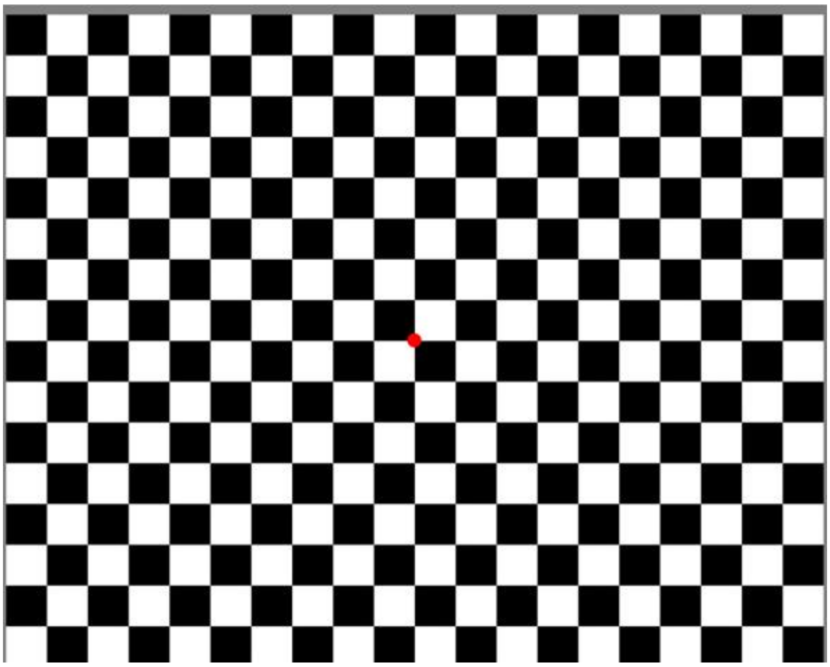

FIGURE 25. Depicting the Visually evoked potential (VEP) (Bos, 2006)

In the figure 25 we Can see the checkboard pattern test where there is red dot in the center this usually this can trigger a seizure in the people suffering with epilepsy.

In this pattern there is a red dot present in the centre of the checkboard with black and white squares. If the person is suffering with epilepsy and has evoked a seizure, then the checkboard will appear with different patterns where the white patterns appear as black and black appear as white. Most of the time these test procedures would force a certain EEG signal from a healthy individual and the actual patient would likely have a seizure. so, this is one of the procedures to test if the person has epilepsy. In all the test procedures a reference electrode was placed on the earlobe and midline on top of the forehead and the times period was in seconds roughly about 200 to 400 milliseconds continuing it number of times. While doing this tests the EEG was recording in the background and the wave patterns will be discussed in the results section.

4.5 Measurements from actual people suffering from Epilepsy

The real time impedance measurements from the patients were performed in Tampere University Hospital (TAYS). Here the subjects head is shaved so that the electrodes can be placed. The below picture represents the electrodes connected to the 13-channel amplifier to measure the impedance, the red wires signify UltimateEEG and the white wires stand for the Golden standard electrodes which relate to the reference electrodes and are fixed to the subject's forehead and behind the head. The golden standard electrode (TAYS electrode) has adhesive, and the ultimate EEG (BrainCare electrode) does not have an adhesive hence it has to be fixed with a tape. Same reference electrode is used to which we compare all the electrode signals, and this makes it possible to easily time sink the measurements.

FIGURE 26. An individual doing a reference electrode impedance test with both the ultimateEEG and golden standard electrode. (Picture is uploaded with the permission of the subject).

In the figure 26 we can see that there is an individual lying with the reference electrodes connected to the amplifier. The red wires belong to UltimateEEG reference electrode and the white wires belong to the golden standard electrodes.

5 RESULTS

5.1 DC offset voltage and resistance measurements

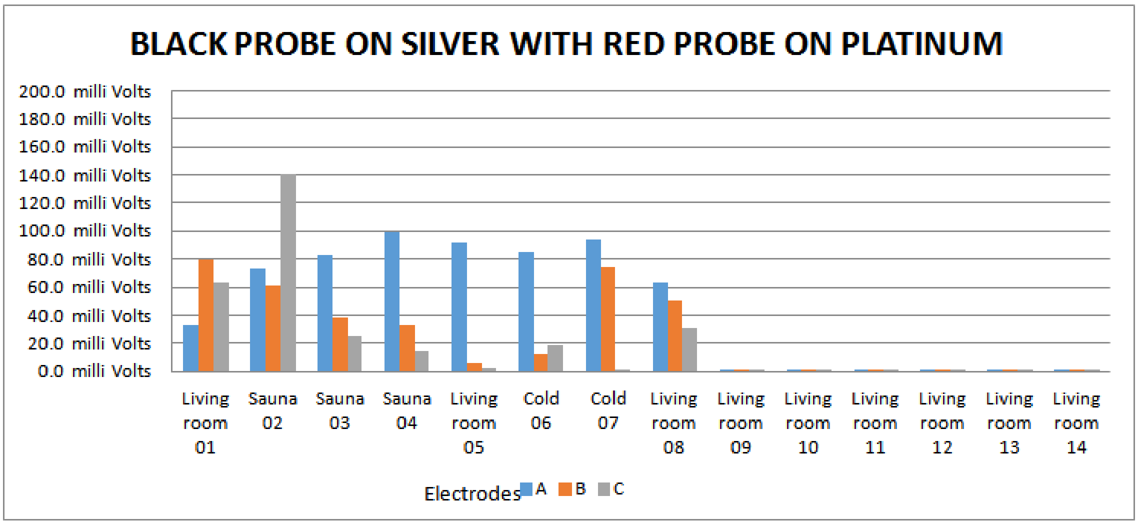

FIGURE 27. Home based experiment measuring DC offset voltage for black probe on silver with red probe on platinum for the electrodes A, B AND C.

***Note**: Black probe refers to the lead test probe of the digital multimeter and silver refers to Golden standard electrode and red probe means the red test lead probe of the digital multimeter and platinum refers to the UltimateEEG electrode.

The above figure 27, the graph black probe on silver with red probe on platinum, depicts the three electrodes, Electrode A, B, C under the conditions of living room, sauna and cold. There variations with the measurements are due to a drastic change in the temperatures. First day the results of the three electrodes were normal, after sauna and freezing conditions there seems to be certain alterations. Under sauna conditions the saturation point is high, and it might be because the salt could not easily get dissolved (day 2,3,4). Then the electrodes were kept under extreme freezing conditions. Henceforth, the salt gathered onto the surface. Once again under normal living temperature the content of the salt could not dilute that's the reason the voltage did not ascend after day 8.

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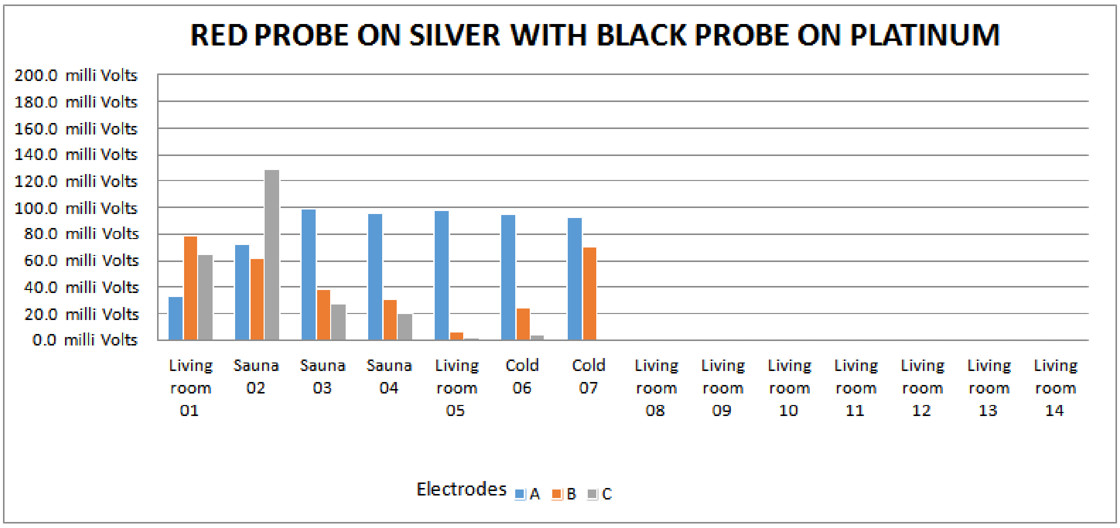

FIGURE 28. Home based experimental set up measuring DC offset voltage for red probe on silver with black probe on platinum for the electrodes A, B and C.
***Note:** The red probe refers to the test lead probe of a digital multimeter on silver means the Golden standard electrode and black probe refers to the ground potential of the digital multimer on platinum referring to the UlimateEEG electrode.

With the red probe on silver and black probe with platinum, the figure 28, explains about the Electrodes A, B, C and their DC offset voltage. when both the graphs are compared the sauna, conditions have shown a balance with the electrode's voltage. Overall, the voltage has not crossed above 120.0 milli volts.But these extreme changes in the measurement does not affect the BrainCare electrodes because if the DC offset is more than 200 milli volts then the Brain Care electrode would not function properly with Golden standard electrode (Hospital-TAYS electrode) and the UlitmateEEG electrode would be useless.

The resistance of the electrode was measured for the all the three electrode A, B and C after removing from the saline solution so that the electrode is dry and can measure, the opposite of the alternated currents can be measure in the circuit. The resistance of the electrodes is measured in Ohms (Ω). The resistance of the BrainCare electrode can be considered as suitable because it has not crossed about 1,2 ohms (Ω). This is due to the standard measurement that the BrainCare electrode pads should be below 200 (Ω)for a better signal quality.

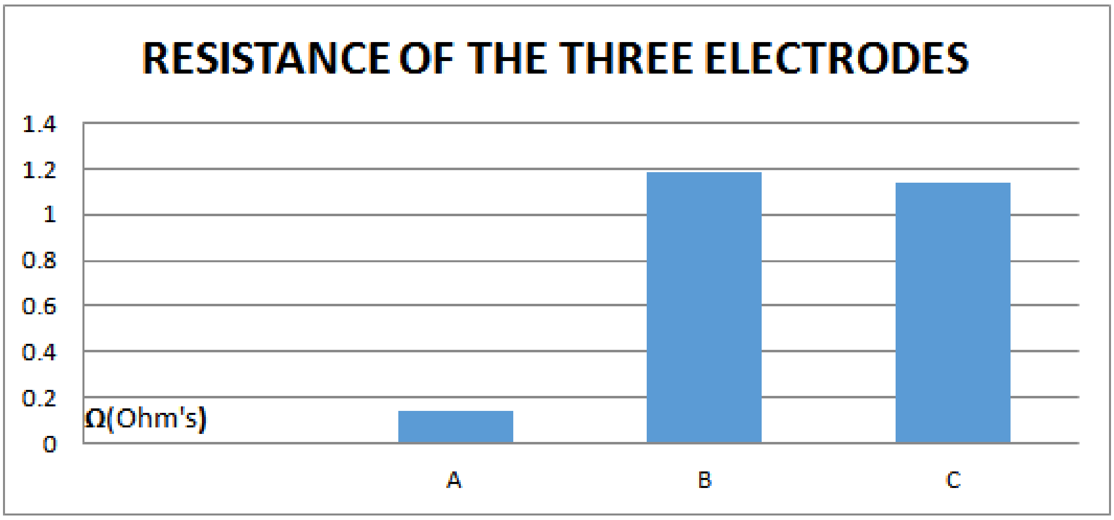

FIGURE 29. Resistance of the three electrodes A, B and C

In the above figure 29, the resistance of the three electrodes A, B and C are measured to check the standard quality of the electrode pads.

5.1.1 Electrodes that failed

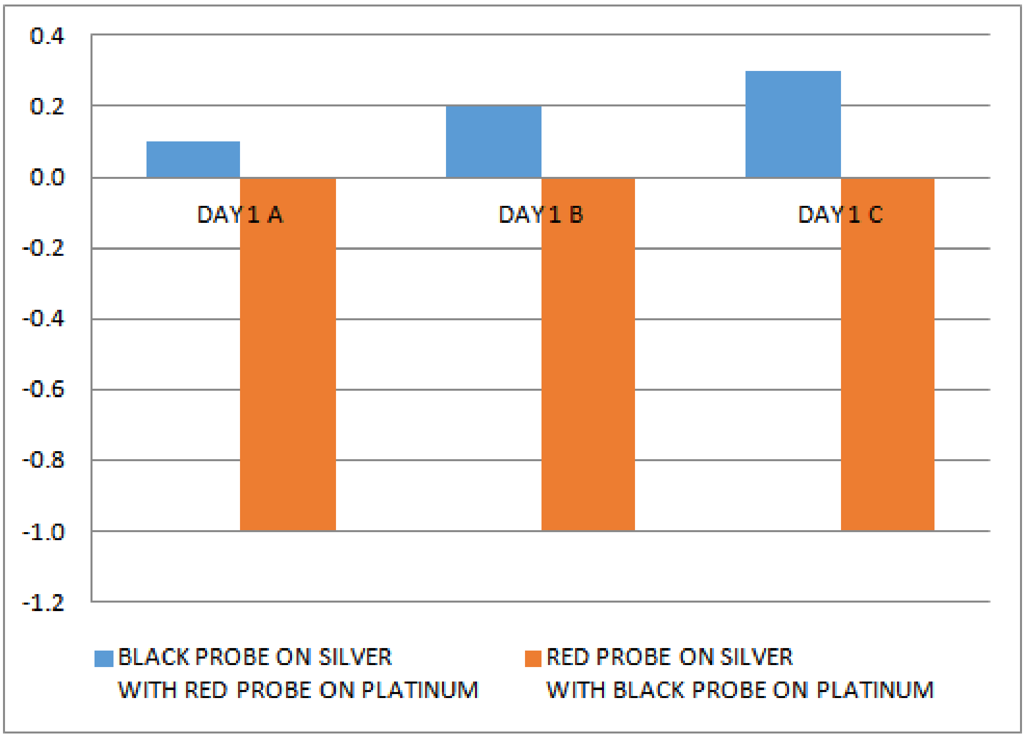

FIGURE 30. Electrodes A, B and C that failed in the beginning when measuring DC offset

The above figure 30, represents the platinum electrode that did not give standard DC offset measurements.

At the beginning of the experiment there was a failure with the DC offset voltage as it provided with some negative results. In the above picture it clearly showed that the electrodes could not reach 200 millivolts. Moreover, the voltage is lower almost nothing.

5.1.2 Reasons, why the electrodes failed?

One of the main reasons was miscommunication. The probes were misplaced while taking the measurements and gave some weird results. After having a re-view update it was understood that the testing probes were not placed right. Secondly when the saline solution experiment was ongoing, the skin or the base layer of the platinum electrode started to peel off because there was a small crack towards the corner and the saline got underneath the layer which also highlights the barrier layer parylene. Platinum as a metal generally has a sharp edge so it started to peel off from the base material.

5.1.3 Electrodes that worked, and why they worked

As the experiment was in process then we had produced an idea to create mock-up electrodes here a tape was surrounded around the electrode where it was to be immersed. Here the tape acts a final layer (better barrier electrode) and as an insulator. It prevents the platinum from peeling or getting cracked up. Be-cause of this the experiment later worked and gave estimated results.

5.2 Hospital surface measurements

5.2.1 Quality compared to hospital electrodes

In the following pictures the two top channels are hospital Ag/Ag-Cl electrodes (Hospital electrodes), and the four following are from the BrainCare electrodes, and the bottom trace is the subject’s heartbeat (i.e., ECG)

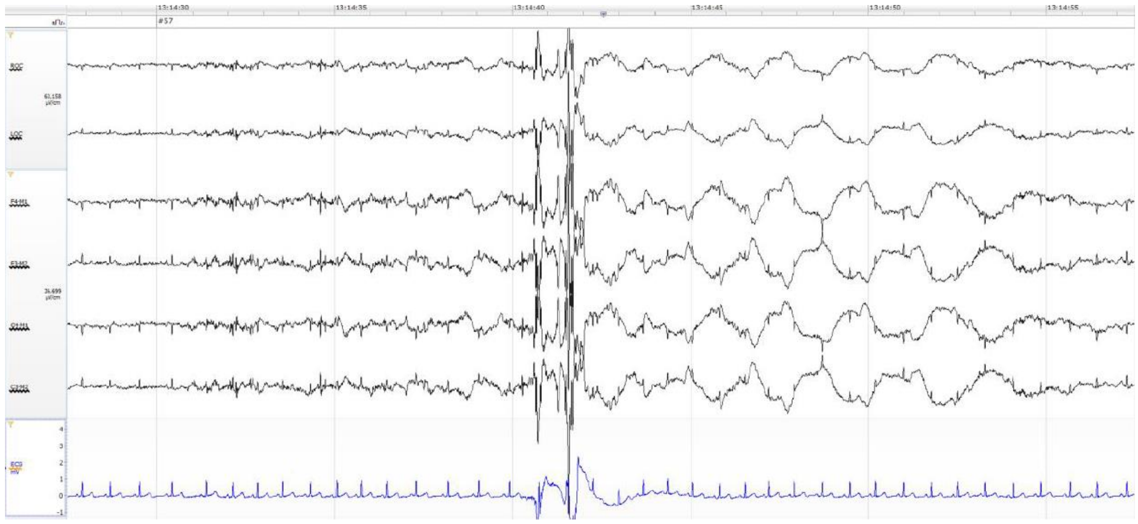

FIGURE 31. Surface measurements for the rapid eye blinking tests (looking up and down).

in the above figure 31, we can see the traces of EEG measurement from rapid eye blinking (in the middle) and then looking upwards and downwards and after that some of the EEG signals look inverted compared to each other, but it is due to traces being on both sides of the head.

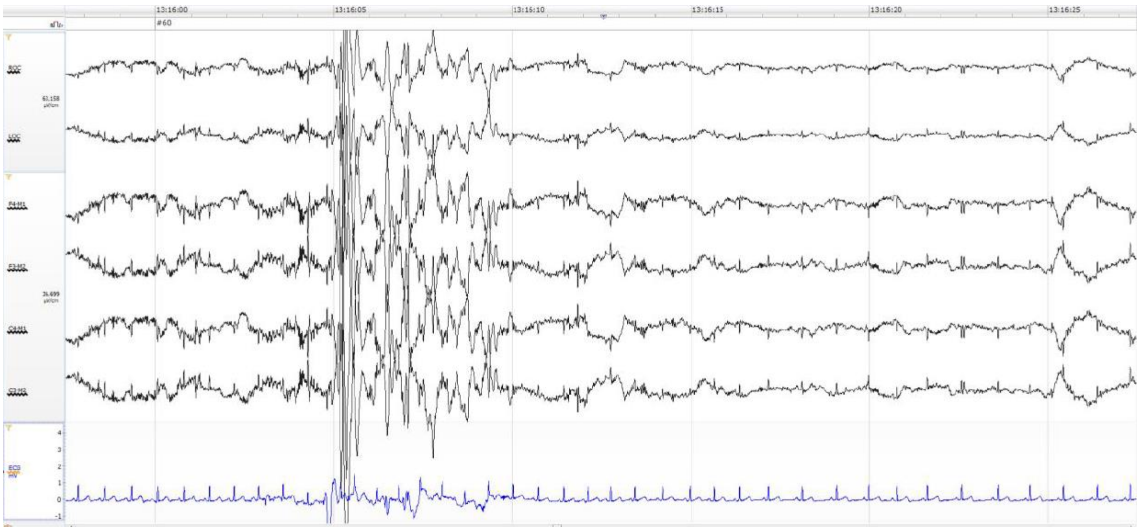

FIGURE 32. surface measurements from the rapid eye blinking tests (looking from left to right)

In the traces, above figure 32, we can see EEG measurement from rapid eye blinking and then looking from left to right. The top two channels are from the golden standard electrode and the rest four from UltimateEEG.

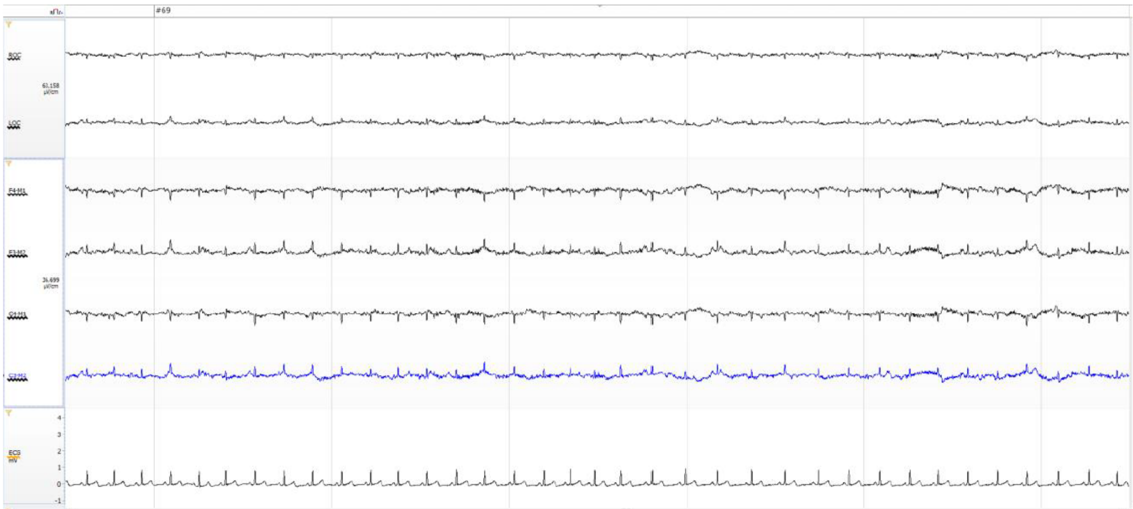

FIGURE 33. surface measurements for an alpha wave test (upper two traces belong to golden standard electrodes and the rest four belong to UltimateEEG and the bottom trace is the heart rhythm (ECG).

In the above figure 33, Here we see measurements from an alpha wave test, during a normal wake test. The subject's eyes were closed, and they were told to relax. We can clearly see the alpha wave differences from regular EEG.

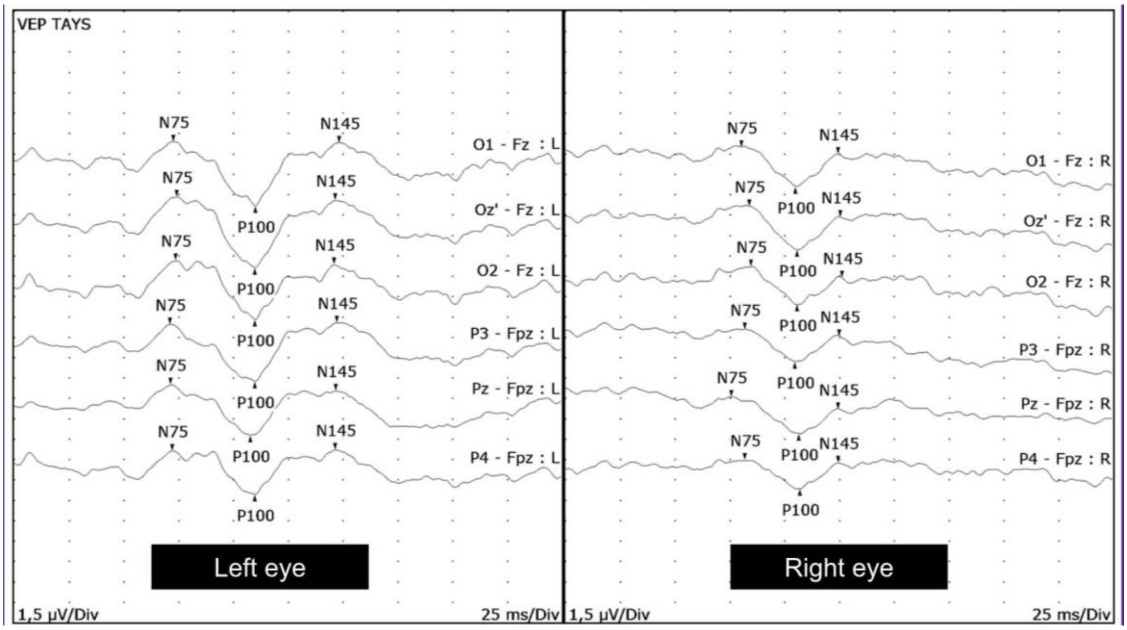

FIGURE 34. Measurement from the VEP-checkerboard pattern-reversal

The above figure 34 represents the Visually evoked potential (VEP) the channels (Oz, O1, O2) belong to golden standard electrodes (Hospital eelctrode) and(Pz, P3, and P4) channels stand for UltimateEEG (BrainCare electrode).

In epilepsy measurements it is often needed to artificially induce a seizure, as the patient is not in his/her natural environment in the hospital and might not have any seizures during the stay otherwise. One of the common tests is a visually evoked potential test, where either a flashing light or a changing checkerboard pattern is displayed to the subject, and they focus on keeping their gaze to a specific spot on the screen. In the figure above, we can see a checkerboard pattern test. The channels marked with Oz, O1, O2 are hospital Ag/Ag-Cl electrodes and the channels marked Pz, P3, P4 are showing platinum i.e., the BrainCare electrode. As we see, there are differences in the electrodes are not visible, even though the BrainCare electrodes are not meant for surface measurements and the hospital electrodes are the best one's hospitals use in Finland.

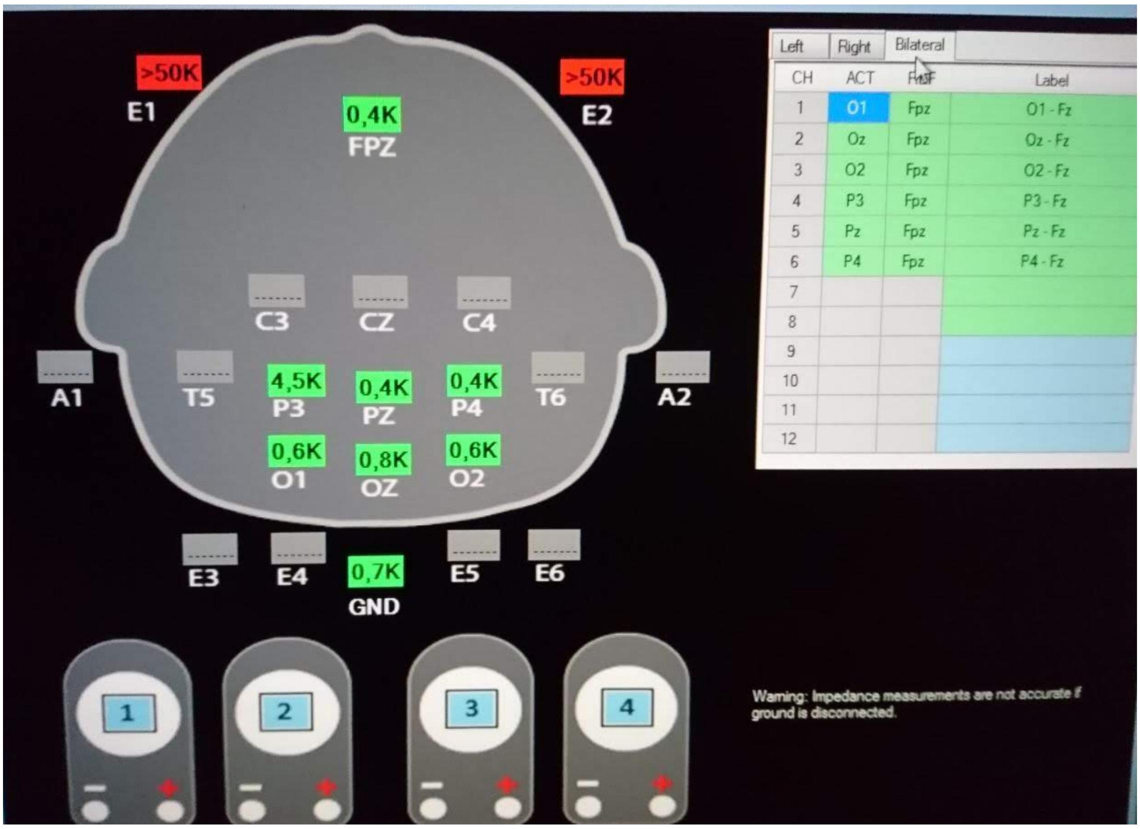

FIGURE 35. Real time impedance measurement from the subject.

In the figure 35, above we can see a real-time impedance measurement from the subject. The setup for the measurement is that the back of the subject's head is shaved, measurement electrodes placed there, and the reference electrode is placed next to the subject's nose. This way the impedance measurement goes all the way through the head. The electrodes marked with O, are hospital electrodes and the electrodes marked with P are BrainCare electrodes. As we see there was something wrong with channel P3 as its impedance is close to the 5000 ohm (Ω) maximum limit. This is due to a bad connection to the back of the head due to hair stubbles being in the way. We can see that the BrainCare electrode performs better than the hospital electrodes (impedance lower) in channels Pz and P4.

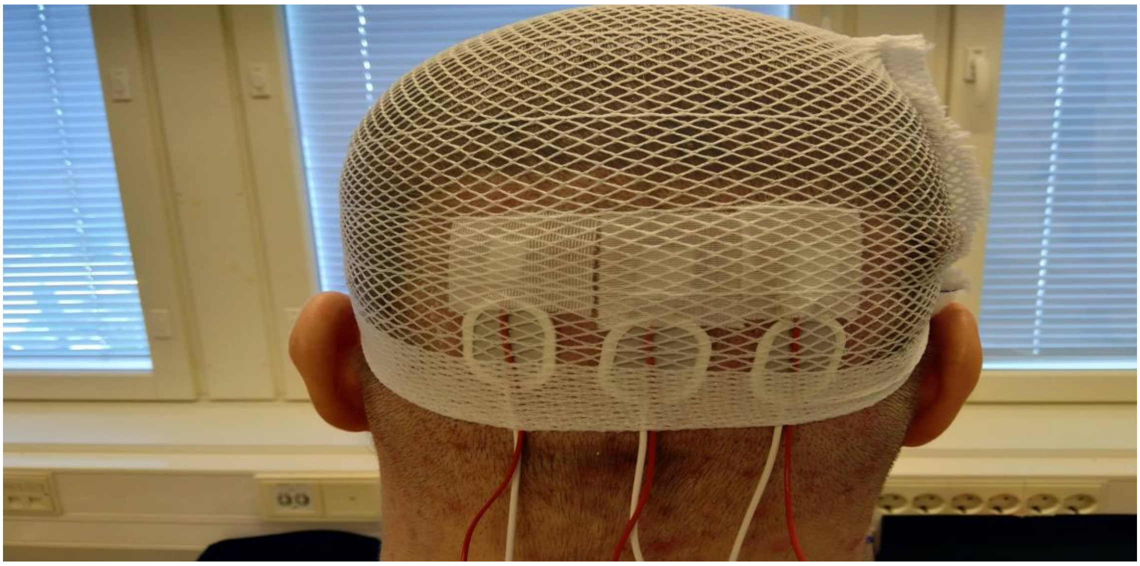

FIGURE 35. The reference electrodes connected for Real time impedance.

In the above figure 35, the subjects head is shaved so that the reference electrodes can be attached to the head when shaved there are tiny hair stubbles the red wires signify the UltimateEEG and the white wires mean golden standard electrodes. This is done to take the real time impedance measurements from both the reference electrodes.

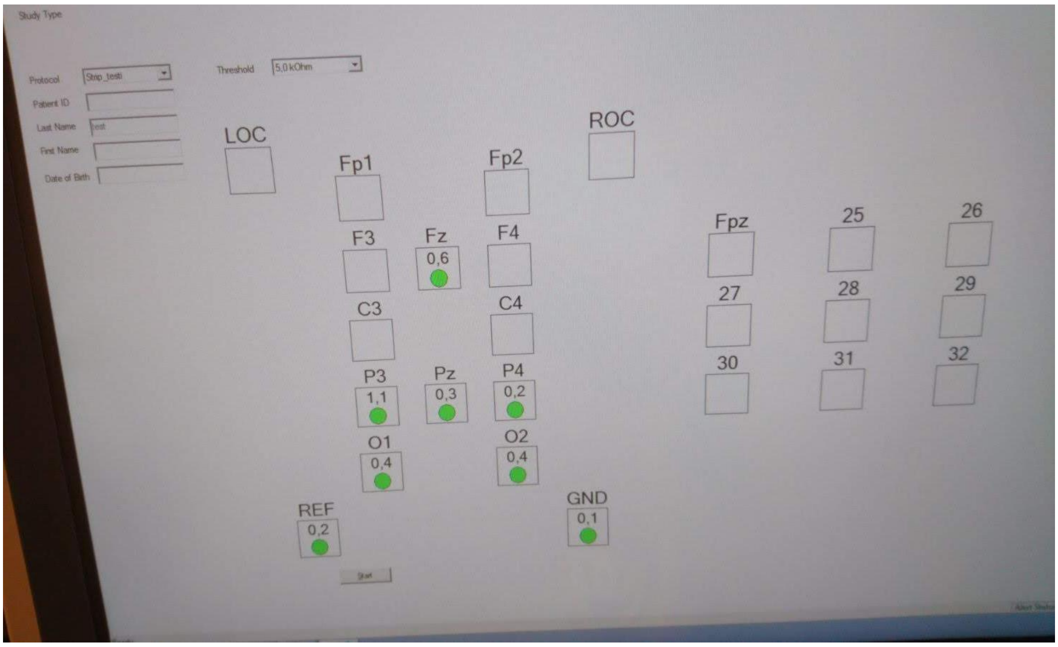

FIGURE 36. Depicting the same impedance measurements after some time

Here in the figure 36, we can see the same impedance measurement a little later, the channel P3 still had some problems that could not be solved. It was still a bad connection between the electrode's measurement pad and the scalp.

6 DISCUSSION

The project was partly done in the Tampere university hospital (Tays) using EEG equipment’s available in the neurology department. The hospital electrodes known as Golden standard electrodes are industrially available, they were collected from Tampere University hospital for experimental purposes. The UltimaateEEG electrodes belong to BrainCare oy and they are coated with the platinum metal and these electrodes were designed and laser etched in the Tampere universitiy (TAU) sakhotalo laboratory.

Then to study the DC off voltage of both the electrodes Golden standard and UltimateEEG electrode, a small saline homemade experimental set up was made. Salt stimulates the conditions under the skin. The main idea was to take the voltage and resistance measurement from both the electrodes and to test their compatibility, functionality and analyse their stability. At the beginning the electrodes gave negative results due to misplacing of the digital multimeter lead probes and due to slight cracks formed within the UltimateEEG electrodes. The DC offset measurements were not standard at the beginning and later the experiment was repeated with a solution by placing the tape around the electrode. Here the tape acted as a protective barrier and as an insulator so the experiment could continue further.

As discussed earlier in the protocol the experiment was supposed to be continued for a month and the electrodes resistance were to be measured in 2,4, and 6 weeks with electrodes A, B, and C. Due to lack of time the same experimental set up was done for two weeks (14 days) under different random temperature conditions. The voltage readings were taken every day and the resistant measurements was measured at the end of every consecutive week. After removing the electrodes from the saline solution to measure the opposition flow of the alternate currents. with the results it was significant that with the home-based experiment the resistance of the Ultimate EEG (BrainCare electrode) pads was under 200 ohms(Ω) and the DC offset voltage was below 200millivolts (mv) which means the electrode is standard and is fit to use for surface implantation. If the voltage value would have exceeded above 200 millivolts (mv) then the UltimateEEG electrode would not have functioned properly.

The reference electrodes impedance measurements (Surface EEG measurements) were done with the Natus NicoleteOne amplifier available in Tampere University Hospital (TAYS) video EEG lab in the neurology department. To get the appointment to use the equipment's there was delay two months due to the busy schedule of the doctors and the nurses. The measurements were taken to check if the UltimateEEG electrode could work along the golden standard electrode and if it is suitable for surface measurements because the ultimateEEG electrode is designed for long term monitoring. So, there were different tests done with the healthy and non-healthy individuals (people suffering from epilepsy) and their surface and real time impedance measurements were compared. when the measurement results were compared to check the functionality of the UltimateEEG to the golden standard electrode it showed that the UltimateEEG electrode worked equally to the golden standard electrode and in fact, the ultimateEEG performed better than the golden standard electrode. In all the measurements every upper two traces belong to the Golden standard electrode (Hospital electrode, TAYS) and the rest four traces stand for the UltimateEEG electrode.

According to pirhonen 2015, a superior quality electrode must have the impedance measurement under 5000 ohm's (Ω) and the DC offset voltagef should be under 200 millivolts (mv). From the above results it was evident that the UltimateEEG electrode is a standard quality electrode as it meets the values for a quality electrode. If the impedance measurements would have exceeded more than the required value, then the Ultimate EEG electrodes would be useless.

Recently BrainCare Oy, got CE marked for their device.BrainCare oy in **future** has a plan to do the pilot study with the actual people suffering from epilepsy and implant the electrode for long term monitoring. Because of the results it was clear that the UltimateEEG electrode can also be used for surface measurements. The future of BrainCare is to use the UltimateEEG electrode for various neurological disorders and to help people to have stress free life and a better future. Hopfefully, one day the UltimateEEG electrode can be commercially available in the market as a solution for the neurological disorders.

CONCLUSIONS

To conclude with the comparative study, the UltimateEEG electrodes were successful for the surface measurements and performed better than the Golden standard electrode according to the real time impedance measurements. There were few challenges at the beginning to analyse the voltage measurements and to get access to the video EEG laboratory in Tampere University Hospital (TAYS) with almost two-month delay. With all odds at the end real time impedance and DC offset voltage measurements show that the UltimateEEG electrodes performed better than the Golden standard electrodes. It is shown that the ultimateEEG can be also used for surface measurements when in actual UltimateEEG electrode was meant for long term EEG monitoring.

The next step is to do a pilot study, with the UltimateEEG electrode to implanted on the patients suffering with epilepsy for long term monitoring with a software named Soenia application, this is like a diary where the seizure information can be stored, and it will be automatically updated in the cloud through the recording and measuring system from the electrode. From here it will be easy for the neurologists to access the seizure information. Hopefully, there will be a day that ultimateEEG will be in the commercialized giving solution to many patients suffering from epilepsy.

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APPENDICES

Appendix 1.Measurements from the DC offset Voltage, Black probe on silver with red probe on platinum.

BLACK PROBE ON SILVER WITH RED PROBE ON PLATINUM				
Days	**Locations**	**Electrode A**	**Electrode B**	**Electrode C**
01	Living room	32.5	79.6	62.9
02	Sauna	73.2	61.1	140.2
03	Sauna	83.3	38.7	25.2
04	Sauna	98.7	32.6	14.2
05	Living room	91.4	6	2.4
06	Cold	85.3	12.3	18.2
07	Cold	94.2	74.3	0.1
08	Living room	63.8	49.8	30.5
09	Living room	0.064	0.052	0.167

10	Living room	0.055	0.064	0.147
11	Living room	0.031	0.059	0.085
12	Living room	0.043	0.064	0.015
13	Living room	0.05	0.021	0.034
14	Living room	0.045	0.02	0.047

Appendix 2: Measurements from the Dc offset voltage red probe on silver with black probe on Platinum.

RED PROBE ON SILVER WITH BLACK PROBE ON PLATINUM				
Days	**Location**	**Electrode A**	**Electrode B**	**Electrode C**
01	Living room	33.2	78.2	64.5
02	Sauna	72	62	129.3
03	Sauna	99.2	38.4	27.6
04	Sauna	96.2	30.3	20.4
05	Living room	98.3	6.1	1.9
06	Cold	95.1	24.6	3.6
07	Cold	92.1	70.2	0
08	Living room	0.06	0.05	0.13
09	Living room	0.06	0.05	0.13
10	Living room	0.058	0.063	0.173

11	Living room	0.03	0.054	0.073
12	Living room	0.039	0.062	0.04
13	Living room	0.061	0.03	0.005
14	Living room	0.036	0.011	0.059

Appendix 3 : Resistance Measurements of the three electrodes A, B and C

Resistance of the three electrodes (Ω)Ohms	
Electrodes	**Readings**
A	0.137
B	1.184
C	1.142