Pertanika J. Sci. & Technol. 30 (1): 19 - 33 (2022)

SCIENCE & TECHNOLOGY

Journal homepage: http://www.pertanika.upm.edu.my/

Review article

Data Acquisition and Data Processing using Electroencephalogram in Neuromarketing: A Review

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ABSTRACT

Electroencephalogram (EEG) is a neurotechnology used to measure brain activity via brain impulses. Throughout the years, EEG has contributed tremendously to data-driven research models (e.g., Generalised Linear Models, Bayesian Generative Models, and Latent Space Models) in Neuroscience Technology and Neuroinformatic. Due to versatility, portability, cost feasibility, and non-invasiveness. It contributed to various Neuroscientific data that led to advancement in medical, education, management, and even the marketing field. In the past years, the extensive uses of EEG have been inclined towards medical healthcare studies such as in disease detection and as an intervention in mental disorders, but not fully explored for uses in neuromarketing. Hence, this study construes the data acquisition technique in neuroscience studies using electroencephalogram and outlines the trend of revolution of this technique in aspects of its technology and databases by focusing on neuromarketing uses.

Keywords: Consumer sciences, EEG advancement, and revolution, EEG technology, future VR-EEG integration, neural signal processing, neuromarketing

ARTICLE INFO

Article history:
Received: 01 April 2021
Accepted: 15 September 2021
Published: 06 December 2021

DOI: https://doi.org/10.47836/pjst.30.1.02

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INTRODUCTION

Electroencephalogram (EEG) is a widely used neurotechnology that detects electrical impulses in the brain, passed through

ISSN: 0128-7680
e-ISSN: 2231-8526

the neurons and axons of the brain to measure brain activity (Casson et al., 2018). The impulses arise from the interactions of one neuron to another, with potassium and sodium ions passing through the synaptic clefts. Electrodes of the EEG are attached to the head to capture the brain impulses, which are later amplified, and potential differences are calculated to represent the brain activity. EEG on Human was initially introduced by Hans Berger, a German Psychiatrist which in the year 1929. This technique follows the principle of an Electrocardiogram (ECG or EKG), which detects the electrical signal triggered by the heartbeats (Tudor et al., 2005). Berger first performed his study of brainwaves using Novocaine injection and electrodes in the periosteum in a 17-year-old boy undergoing neurosurgery by Dr. Nikolai Guleke (Kaplan, 2011). Using this event as a steppingstone, he began developing the non-invasive method used and revolutionised today (Coenen & Zayachkivska, 2013).

EEG in Clinical Research and Studies

According to Deolindo and colleagues, the ability of EEG to detect and measure neuronal oscillations which is also known as magnetic fields, enables access to information of functional and effective connectivity of neurons in the brain (Deolindo et al., 2020). It can also provide deeper understanding on the process of specific information coding, state of brain attention, and providing evidence on cognitive impairments. As EEG depends on event-related potentials (ERP) with time-locked-evoke stimulation or spectral analysis, aside spontaneous potentials, neurocognition in human being can be tested (Xue et al., 2010). Spontaneous EEG has been used as a measure for quite some time in evaluating seizures and epilepsy but rarely in cognitive neuroscience research. However, studies often incorporate ERP as a measuring tool up to this day. It heavily provides insight in the field of science, technology, medicine, education, and marketing. The study of neuroscience with the aid of EEG enables us to understand which region of the brain is responsible for which activity, enhancing understanding on neurodegenerative diseases as well as help in understanding human behaviours and discovery of the effective methods in learning, teaching, and marketing (Casson et al., 2018; Deolindo et al., 2020)The immense importance of the study of brain oscillation study in knowing neuropsychiatric disorders helps in determining disturbances between excitations and inhibitions of the networks between each neuron which can be seen in Schizophrenic and Autistic individuals as well as those with Attention Deficit Hyperactivity Disorder (ADHD)(Deolindo et al., 2020). Abnormal cortical oscillations were also depicted, especially in the attention and control areas of the brain. There is arising question on whether these oscillations can one day be a biomarker in clinical diagnostics or neuro disorders. Besides that, a future that can rely on EEG as an evidence provider in brain inattention is also being investigated and might become a breakthrough in Neuroscience studies.

EEG has been used for various neurology and cognitive science studies, especially in the medical field (Reyes et al., 2019). It includes:

- Monitoring anaesthesia process
- Seizure or epilepsy diagnostics
- Assessment of head injuries
- Brain tumour detection
- Detection of encephalitis
- Determining brain activity of coma patients
- Detection of Alzheimer's Disease onset
- Post-stroke assessments
- Sleep disorders assessment
- Confirmation of brain death
- Brain activity measurements in disordered neuro patients

Among these clinical uses, EEG maintains to execute its vital role in diagnostics of seizures and epileptic episodes with every abnormal brain activity in ictal and interictal conditions characterised by abrupt frequency changes in every measurement, enabling detection and determination of types of seizure which is important in order to determine the suitable medication as well as predicting prognosis (Siuly et al., 2016). The application of EEG in clinical studies has always been vast as it poses multiple advantages compared to other techniques, especially in health care. However, the usage of EEG in neuromarketing is also growing and evolving, especially with the emergence of wearable EEG that is more accessible and affordable to the masses where the study of neuromarketing via EEG can delve into the studies of emotions to study human preferences (Suhaimi et al., 2020).

EEG in Neuromarketing and Consumer Neuroscience

The methodology in this study is composed of data collection and several pre-processing techniques, such as data cleaning, annotations, and eventually, automatic classification by three ML algorithms [Naïve Bayes (NB), Sequential Minimal Optimization (SMO) & Decision Tree (DT)]. The application of neuroscience methods allows unbiased and accurate marketing data to be obtained in response to self-reports which may carry intrinsic biases (Suhaimi et al., 2020). As an alternative, neuroscience allows a more refined understanding of the cognitive process that entrains consumerism and its underlying mechanisms, which cannot be obtained via surveys. Nevertheless, this field of study has not been used widely despite the increasing revolution of techniques and feasibilities, which proves to be beneficial to business owners and consumer brand managers. However, big brands such as Coca-Cola and Campbell's have started to venture into using functional imaging modalities such as functional magnetic resonance imaging (fMRI), which is commonly used, followed by electroencephalogram (EEG) and eye-tracking (Lin et al., 2018).

The application of EEG in marketing is usually focused on Event-Related-Potential (ERP) via time-locked activity or neural oscillations called spectral content, which captures brain responses when triggered by stimuli in the form of brainwave that rises from multiple sensory and cognitive processes, influencing the neural activities (Lin et al., 2018). Following its advantages, EEG proves to be gaining attention in the world of marketing research. Not only is it non-invasive and less costly, but it is also extremely beneficial in capturing objective as well as direct data to understand human cognitive processes and emotions (Suhaimi et al., 2020). ERP allows the identification of branding recognition based on categorisation processes. Whether positive or negative, emotions play an important role in influencing brand preferences and behaviour on good luxury purchases. Furthermore, with the study of EEG, the role of emotions in decision making can be further characterised. The relevant cognitive processes are involved in marketing-based EEG (Lin et al., 2018). These studies are: (i) Affect and emotions; (ii) Attitude and preferences, (iii) Decision making based on available information and (iv) Attention and memory.

Data Repositories for EEG Data

There is an increasing need for Big Data Analytics, especially as we are approaching the Industrial Revolution 4.0 (IR4.0), where we move towards automation (Husain & Sinha, 2020). Hence, increasing the need for data for machine learning algorithms. Big Data is known as the complex dataset library, which provides a variety of datasets retrieved from research studies that can be used as a reference and even benchmarks for upcoming studies (Ibrahim et al., 2020). These libraries are often established with security and privacy, querying, data storing and analysis, as well as data transfers. For example, the data for EEG is mostly archived in databases where some of them are publicly accessible (Bhagchandani et al., 2018).

A database can be a private and closed source as well as open access known as open-source, which is free to be accessed and used. In the aspects of EEG itself, the data recordings of EEG represent various network-wide connections in the brain (Ibrahim et al., 2020). These sanctioned computational processes of the human brain allow extensive studies towards measuring brain functions and applying such knowledge to future innovations such as robotics, artificial intelligence, and automation in machinery. EEG data is stored in the form of ".eeg, .txt and.xls". A reliable database is important, especially with the robust amount of pre-existing data to make established practices possible, such as determining the best biomarkers for various psychiatric diseases and neurological impairments (Bhagchandani et al., 2018). Unfortunately, a scarce well-known database is designated for EEG, unlike other modalities like fMRI and PET. However, there are a few open-source databases for data storing and sharing made by a group of individuals and institutions (Table 1).

Table 1
EEG databases

Database	References
OpenNeuro Database	openneuro.org
Collaborative Research in Computational Neuroscience	crcns.org/
NeuroImaging Tools & Resources Collaboratory (NITRC)	nitrc.org
Physionet Database	physionet.org
UCI Machine Learning Repository	archive.ics.uci.edu
BNCI Horizon 2020	bnci-horizon-2020.eu
DEAP Dataset	www.eecs.qmul.ac.uk
European Epilepsy EEG Database	epilepsy-database.eu
Patient Repository of EEG Data	PRED+CT: predictsite.com
Github Sharing Open Access	hgithub.com/meagmohit/EEG-Datasets
MyNeuroDB	myneurodb.cs.usm.my
Temple University Hospital Repository	www.isip.piconepress.com/projects/tuh_eeg/
IEEE DataPort	ieee-dataport.org
Zenodo EEG and audio dataset	zenodo.org

Technical Aspects of EEG System

Forms of EEG Data. EEG data are often in the form of sinusoidal frequencies, which are repeated wave frequencies. These frequencies can be in rhythmic waves, consisting of stable constant frequencies, arrhythmic waves consisting of unstable, non-patterned waves and dysrhythmic waves that are rarely seen in normal samples (Husain & Sinha, 2020). These frequencies come from neurons which are vital for information transmission and reception of information through synapses. Hence, the electrical currents from information transmission in the neuron give rise to brainwaves of different frequencies that EEG can detect. Each brainwave is represented by different wavelengths, as shown in Figure 1.

Alpha and Beta waves are small sharp waves that are often observed when subjects are induced with interaction, which is the opposite of a relaxed state (Seal et al., 2020). Frequencies of brainwaves are divided into five distinct categories with one additional category for spike potential, as described in Table 2.

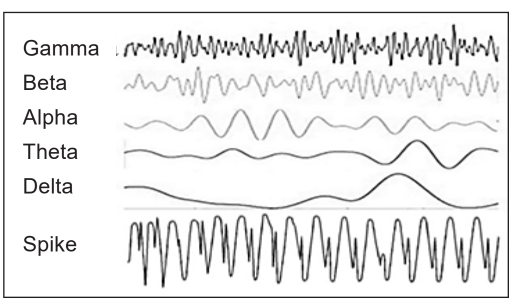

Figure 1. Patterns of brainwave (Reyes et al., 2019)

Table 2
Waves and frequency (Reyes et al., 2019)

Waves	Frequency (Hz)
Gamma	>30
Beta	13-30
Alpha	8-13
Theta	5-8
Delta	0.5-4
Spike	3

These signals captured through electrodes on the scalp's surface are measured as voltage against actions. These signals are then classified between free-running, hybrid, and evoked components (Koudelková & Strmiska, 2018). Delta waves are low-frequency waves observed when deeply relaxed individuals, such as deep sleep or deep meditation. Technically, when the body is in deep rest. These brainwaves are vital for the rejuvenation of the body and brain (Seal et al., 2020).

Additionally, theta brainwave represents relaxation or sleep, much like delta waves. The difference is that these waves indicate that the individual is dreaming and focusing, which causes the brainwaves to be more energetic. As we begin to be awake, our brain begins to produce alpha waves. Activities that are considered restful such as praying, exhibits alpha waves instead of beta waves. On the other hand, Beta waves are a sharper and higher wave frequency exhibited most during attentive thinking and working. The brain is said to be fully awake and active. During rapid brain activity, gamma waves may occur. Gamma waves are often associated with the brain, which requires attention and perception of cognitive and behavioural processes (Koudelková & Strmiska, 2018; Seal et al., 2020).

Data Acquisition in EEG System

Previously EEG applied its electrode channels in the deep intracerebral region and later revolutionised to extracranial measuring (Husain & Sinha, 2020). However, it is said that depth study allowed more focal details to be captured but with restrained spatial clarity causing the inability to study the brain function at extensive coverage (Bhagchandani et al., 2018). The versatility of the EEG system enables the employment of various numbers of electrodes to produce a robust neocortical dynamic function measurement with each scalp cap as it can provide an estimation of over mass tissue volume containing around 1 billion neurons (Mosslah et al., 2019).

Generally, the channel employed can be a single or multichannel and incorporate up to 256 channels following a 10 to 20 systems arrangement. A continuous EEG or cEEG uses about 9 to 16 electrodes arranged accordingly following the standardised international 10 to 20 system as shown in Figure 2. This system employs 21 electrodes placed on the scalp surface with nasion and inion as a reference point (Mosslah et al., 2019). Nasion point is situated above the nose, on a par level with the eyes, whereas the lump of bone at the skull's foot is

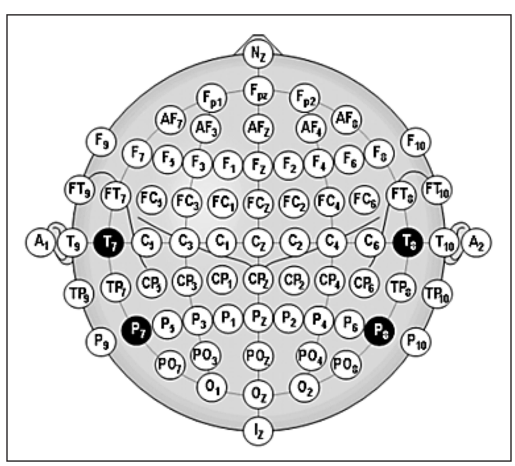

Figure 2. International 10-20 EEG system (Rojas et al., 2018)

between the midlines of the head. Additionally, the Queen Square System has also been applied to record the electrical potential of evoked potentials in clinical testing (Husain & Sinha, 2020).

The traditional EEG system was somewhat invasive and had to implement the penetrative electrodes through the brain, whereas the electrodes are now only applied on the scalp nowadays. Initially, EEG is less portable. Medical grade EEG devices have 16 or 32 channels on the headgear with amplifiers connected to these electrodes. Consumer-grade wearable EEG, on the other hand, only ranges from 2 channels to 14 channels. The two types of EEG follow the international 10-20 standard arrangement system (Mosslah et al., 2019). The decrease in electrodes is associated with a decrease in performance. However, studies show that the easy to set up wearable EEG device could outperform medical-grade EEG and detect artefacts. These artefacts such as muscle and eye blinking movements can be filtered out in pre-processing. Aside from that, the advancement of EEG allowed it to be wearable and wireless, allowing a correct measurement of imagined directional inputs and bodily movements of the user as there will be no constraints to movements. Examples of low to middle-cost EEG devices are Emotiv EPOC+, NeuroSky, MindWave, Ultracortex Mark IV EEG, Interaxon Muse, B-Alert X Series and ENT-Neuro EEG (Abujelala et al., 2016; Lin et al., 2018).

Structure of EEG System

Generally, the basic steps used in EEG signal processing involves retrieving the raw data and continues with the conditioning and amplification of data, as stated in Figure 3.

The raw data must go through pre-processing steps. First, the signal goes through a measuring rig or amplifier that include a high-pass filter, and then an analogue filter is preceded for low-pass filtering. A high-pass filter, for example, can eliminate a direct current (DC) component or a slow fluctuation. In contrast, undesirable high-frequency components can be removed by "conditioning" the data with a low-pass filter. It is then followed by information acquisition, which involves converting analogue data to digital data to retrieve analysable data using pre-programmed software. Signal processing is then done by passing the data through a filter for data filtering to remove any unwanted noise and suppress certain parts of the signal. Feature extraction then paves the way for the characterisation of signals into distinct frequency classification. Feature selection is an optional step before classification involving many features to specify the

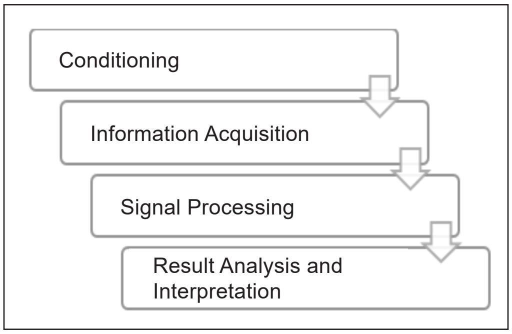

Figure 3. Basic processes in EEG signal processing

signals relevant to the study target. Lastly is frequency analysis and interpretation of results (Reyes et al., 2019).

EEG can process these data through several different programs. For example, there are linear techniques such as Independent Component Analysis (ICA), Eigenvector, Fast Fourier Transform (FFT), Autoregressive (AR), Wavelet Transform (TW), Wavelet Packet Decomposition (WPD), Principal Component Analysis (PCA). In contrast, the non-linear technique includes Fractal Dimension Analysis (FD), Hurst Exponent (H), Higher-Order Spectra (HOS) and Correlation Dimension (CD) (Reyes et al., 2019; Vaid et al., 2015). Additionally, past studies incorporated entropy and complexity measure, EMG signal integration in Brain-Computer-Interface EEG (BCI-EEG) system, computer-aided diagnostic (CAD) system, as well as Emotiv EPOC headphones system for imaginational colour image data (Maddirala & Shaik, 2018; Yu & Sim, 2016).

Benefits and Limitations

Among other modalities, EEG is very much non-invasive, painless, and safe for use even in young children (Casson et al., 2018). Due to its cost-effectivity, it is suitable for usage in large scale studies despite the amount of repetition used. The recorder is often portable, does not involve large types of machinery and is only needed to be applied on the scalp of the head like a cap. However, previous EEG is found to be bulkier with longer cables. Therefore, EEG has been revolutionised into wearable and portable EEG (Lau-Zhu et al., 2019). As it is a simple system, setting up for usage is also non-complex. Due to its versatility, it can be adjusted to a different number of channels with different electrodes installed within the region of interest, enabling researchers to control coverage area and increase data accuracy (Read & Innis, 2017). EEG also has exceptional temporal resolution and supports real-time resolution to track events within the brain at milliseconds. Despite the notable benefits, EEG also presents challenging limitations: poor spatial resolution, inability to penetrate deeper beyond the cortex and subcortical regions from which the signals are derived, to observe activation patterns (Casson et al., 2018). It causes the need to integrate other neurotechnology to provide extensive functional data, such as integrating EEG with fMRI. Not only that, but it also has high noise, and possible data loss may occur during the recording of high-intensity activity (Beres, 2017). Such activities include running or jumping (Hill, 2019).

TRENDS IN EEG STUDIES

The extensive use of EEG in neurological disease is majorly seen in epilepsy and seizures (Reyes et al., 2019). The brain undergoes paroxysm where electrical current changes abruptly, causing a spike in action potential due to excessive depolarization of neurons as shown in Figure 4, causing modified behaviours such as memory loss, convulsions, and continuous

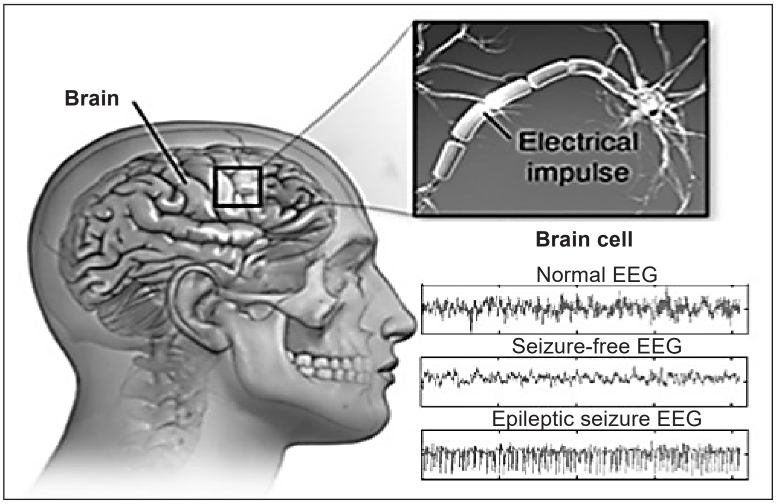

Figure 4. Electrical impulses in normal, epileptic and seizure brain (Siuly et al., 2016)

jerking due to muscle spasms, emotional disarray and may cause unconsciousness (Siuly et al., 2016). This occurrence results from an imbalance in neurotransmitters and brain wiring, causing incorrect signal transmission and distribution, disrupting hormonal release. In addressing this issue, interventions have been made using EEG, and with an increasing number of cases against time, improvements, and modification of EEG technology has continuously been made. Additionally, EEG also provides measures on the effectiveness of the intervention technique with the aid of pre-and post-treatment assessment (Reyes et al., 2019). Additionally, these advancements of technology have been providing means in products manufacturing that are useful and feasible to the community and allowing formulation and improvements of teaching and learning techniques in education.

EEG Techniques in Clinical and Rehabilitation Use

Reyes et al. (2019) explained that the technological evolution of EEG started with the focus on the early detection of epilepsy. This proposition provided accuracy and sensitivity of data acquisition technique at 64 to 81% and 65 to 81%, respectively, followed by a study focused on focal epilepsy via neural networks of the brain, giving only 47.4% of data sensitivity. Finally, Da Silva produced a newer proposition on reviewing MEG-EEG signal processing technique comparison to demonstrate the epileptic characteristics of the human brain (Deolindo et al., 2020). Later, the technique of EEG signal classification using cross-correlation and spectral power density, resulting in 99.81 to 100% data accuracy and sensitivity. Within the same year, a meta-analysis study was proposed to predict the best periods of medication uptake and reduction of doses and stop intake from reducing medical expenses of epileptic patients. These studies provided evidence for the feasibility of EEG as an important prognostic tool in the clinical field.

EEG Techniques Application in Neuromarketing

Interestingly, there are US-based neuromarketing companies that are constantly growing. These companies are AC Nielsen and Forbes Consulting Group. Nielsen has been outsourcing their services to other companies in market data science analytics (Lin et al., 2018). Consumer Neuroscience has expanded its footprint beyond various fields such as bioengineering, marketing, food technology and industrial designs. In neuromarketing and consumerism, it is important to study human responses towards certain items or products and advertisements (Plassmann et al., 2015). It is to ensure the ability to capture people's attention and engagement, which will provide larger opportunities for effective product and service sales.

Presently, Beta and Gama brainwaves oscillations have posed importance in predicting box office sales in movie productions by studying the EEG results during movie trailers viewings in studying consumer behaviours (Boksem & Smidts, 2015). Recent studies also took account of the Alpha waves activity in calculating neural activities related to sales of tickets and free recall of the movie storyline (Barnett & Cerf, 2017). The same techniques have been applied in direct studies of television-based marketing ads, enabling calculations of engagement index using a beta, alpha and theta waves. The EEG used in this study was dense-array EEG (Lin et al., 2018).

Potential Trends Forward

Rapid economic and technological growth demands the evolution of intervention techniques and tools to ensure better ways are produced for a better future. In the aspects of EEG in Neuromarketing, a huge potential can be seen with integrating Virtual Reality (VR) (Maples-Keller et al., 2017) and wearable EEG as it allows mimicking of real-life situations and environment to be used in studies (Lin et al., 2018). VR is currently being used in tourism and education (House et al., 2020). Virtual, augmented, and mixed reality has provided diversified and interactive teaching and learning environments to improve students' cognitive ability, especially in terms of information processing and storage and recalling acquired knowledge such as VSI Patient Education (VSI PE), as shown in Figure 5.

In Neuromarketing, VR was integrated with EEG in several studies, especially in 2020. However, it is still in trial studies. Therefore, it has not been used widely in the market, unlike in education, where virtual and augmented reality has been widely used to create immersive studying environments. It may be because VR itself is an expensive technology and requires knowledgeable professionals to create the VR 3D environment using software such as Unity3D or CRYENGINE and VR devices such as Oculus Rift, Playstation VR, HTC Vive and Samsung Gear attached to an EEG like in Figure 6.

Despite that, this mixed-reality convergence eases the process of incorporating computerised virtual graphic objects via 3D environment with ease at any selected location,

Figure 5. VSI PE on brain model (House et al., 2020)

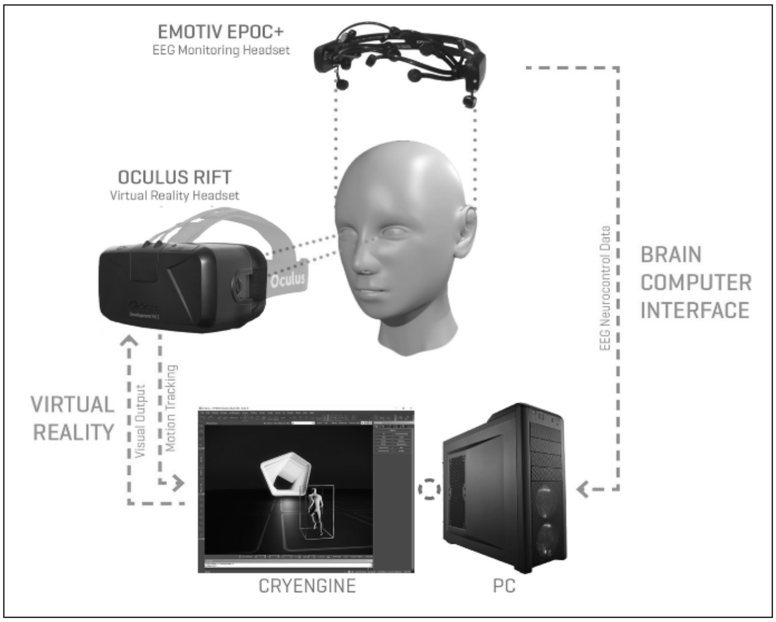

Figure 6. VR 3D environment (Doma, 2019)

be it in a lab, office and even outdoors. Liu and colleagues (2018) have also studied virtual reality in military training by making immersive battlefield environments and weapon production. Additionally, VR has been used to mimic the environment that can boost the health and well-being of military personnel (McIntosh et al., 2019). The same concept can be applied in marketing as it works by providing stimulation to the individual's emotional experience, elucidating reactions through emotional changes and brain activities. A recent study from 2016 to 2020 showed VR being the most effective in evoking emotional engagement by 31.03% compared to music at 24.14%, music videos and clips at 20.69%, and pictures at 3.45% (Suhaimi et al., 2020). Previous studies have also incorporated the use of virtual reality to remedy anxiety, which provided empirical evidence of its viability (Maples-Keller et al., 2017).

As the beneficial uses of VR are evident, coupling of VRs to EEG systems can provide vast insight to researchers in studying the effectiveness of intervention via brain activity signals imaging. Furthermore, there is a possible application of treatment intervention techniques for various psychiatric disorders to provide more extensive and personalised treatment for each type of disorder. Lastly, to study how human emotion is manipulated through virtual reality choices of various products in the market. The various benefits it carries makes it a viable technique and device to be applied in the future, not just in studies. Thus, the application of VR-EEG is possible in future innovations to ease studies and training in marketing and military, education, and ultimately healthcare.

CONCLUSIONS

The invention of EEG has paved the way for diagnosing and studying various neurological disorders and studying human cognitive processes. The signals of an EEG provide subjective sine signal patterns enabling the visualisation of changes in brain activity. The flexibility of an EEG system allows manipulation of techniques to best-fit study goals and allow better coverage of the brain area for accurate imaging with the manipulation of electrode number and position. The Revolution of EEG against time has caused EEG to be wearable, portable, and accessible to the masses, allowing extensive use of EEG in research and study, not just for the application in healthcare. Furthermore, the study of consumer neuroscience in neuromarketing has been found important and has received the attention of various business owners, managers, scientists, and technology designers as EEG pave the way for better and more effective marketing of products and services. Despite the innumerable benefits an EEG system possess, there are still limitations that have yet been tackled, warranting the opportunity to explore and improve a better performance in visualising brain functionality. Nevertheless, the vast benefits of EEG outweigh its limitations which can be addressed via multimodal integration**.**

ACKNOWLEDGEMENT

We would like to thank Universiti Sains Malaysia for the support given to complete the manuscript.

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