

Cognitive Rehabilitation and EEG Analysis: A Review



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Abstract: Cognition is the capacity of the brain to register and decipher data dependent on information and experience. A portion of the subjective aptitudes are processing, memory and retention, logic and reasoning, attention and so forth. The subjective abilities begin to grow directly from the hour of birth of a person. There are situations where these advancements don't happen at the opportune time or in a proficient manner, which prompts scholarly disorders. The most commonly found intellectual disorders in children are attention deficit hyperactivity disorder (ADHD), epilepsy, encephalitis, autism spectrum disorder (ASD) and speech disorders. There are cognitive tasks and retraining intended for each sort of cognitive issue. These are planned so as to improve the cognitive degrees of the children who experience the ill effects of cognitive issues, for an improvement in their everyday lives. This paper gives an overview of some of the existing techniques for the improvement of cognitive levels along with the techniques of EEG analysis. The activities in the brain can be traced with the help of an electroencephalogram (EEG). Cognitive levels can also be studied with the help of EEG. The study that involves cognition requires careful pre-processing, feature extraction and appropriate analysis. The processed EEG information is analysed utilizing various techniques which can extensively be ordered into time domain, time frequency domain, frequency domain, non-linear methods and artificial neural network methods. Out of every one of these strategies, the frequency domain techniques and time-frequency strategies are most popularly used.

Keywords: Analysis, Brain, Cognition, Electroencephalography (EEG), Rehabilitation

I. INTRODUCTION

Brain is a part of the central nervous system located in the skull of the body.

Its primary functions are to receive, organize and distribute information to the rest of the body. Various parts of the brain include the Cerebrum, Cerebellum, the brain stem, etc. The cerebral hemisphere consists of various fissures called lobes with different essential functions.

There are 4 lobes namely frontal (speech and language, motor skills, memories, understanding and reacting to feelings, forming personalities, reward seeking behavior and motivation), temporal (primary auditory perception, balance, hearing and other sensory information), parietal (processing sensory information from various parts of the body, sense of touch, manipulation of objects, detection of numbers and orientation of the objects encountered) and occipital (receiving, processing and interpreting sensory information and visual activities and color differentiation).

Cognitive impairments in children can range from colossal intellectual deficits leading to severe dysfunctioning of the brain to mild impairments which lead to specific dysfunctioning of operations. Cognitive retraining is a method which is used to help children improve their lifestyle. Cognitive levels can be studied using Electroencephalography (EEG) and different cognitive disorders show different variations in EEG waveforms and this has been studied by experts in detail to understand the cause of such disorders and how they affect the development of the brain. The waveform can be studied using various EEG analysis methods which are discussed below. In this paper, the common cognitive disorders in children along with specific cognitive retraining methods have been discussed. Along with this, analysis of EEG waveforms have been discussed in detail.

II. MATERIALS AND METHODS

The action of acquiring knowledge using one's mental abilities, sense and experience is known as cognition. It also comprises how one uses and channelizes this acquired information in day to day activities. Cognition cannot be classified as a singular entity but it comprises various different aspects and it becomes an arduous task to map each and every process to the brain. It is very important to know the functioning of all the lobes in the brain to understand cognition and the various parameters associated with it.

2.1 Cognitive Disorders And Tasks

It is a group of neurological health disorders that affect learning, memory, perception and problem-solving abilities of a person. The normal functioning of the lobes in the brain is affected and the magnitude of impact depends on the type of disorder.

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It impairs cognitive functions in an individual to such an extent that normal functioning and performance of day to day activities become almost impossible without retraining and medication leading an almost normal life.

It is a widely accepted fact that the younger a person is, the higher their neuroplasticity is or in simpler terms, the ability of one's brain to rewire itself is higher in children than in adults.[1] And hence various noninvasive techniques especially the ones that fall under cognitive retraining are given high importance to help children with various learning disorders and other brain injuries overcome their disabilities and help them lead a near to normal life.

Cognitive retraining involves performance of certain repetitive activities which target a certain cognitive ability which in turn will improve the performance of the activity by the child over a period of time. Multiple techniques and their effectiveness are discussed below and are classified with respect to various disorders.[2]

2.1.1 Attention Deficit Hyperactivity Disorder

A person suffering from ADHD has many developmental problems with respect to the brain and neural activities (It is a neurodevelopmental disorder) such as learning disabilities, speech disabilities, behavioral disabilities, lack of motor coordination etc. Children suffering from ADHD often face difficulties in paying attention and get distracted by trivial matters or for no reason at all. They sometimes also display a serious compulsive disorder and temper issues. Some children also display restlessness and are observed to be active at all times and hence the name. Being overly active which is also known as hyperactivity, impulsive actions, making careless mistakes regularly, does not make eye contact when spoken to, does not follow instructions, have difficulties in organizing schoolwork or any other task or activity, does not cope with change very easily, misplace objects and belongings, display a trait of forgetfulness in performing daily activities etc[24]. There are various symptoms of hyperactivity and impulsiveness such as talking non-stop even when not expected to, mood syndromes, constantly correcting people's mistakes or blurting out answers of questions directed at other people, interrupting other people's conversation, anxiety etc. ADHD is a very complex disorder which has its roots in genetic variations. But it also entails certain environmental risks which are not a part of the symptoms generally shown in a person suffering from ADHD but these risks affect various other parts of the brain disturbing the structure and functionality of the brain in turn affect various other higher order functions and cognition. There are multiple reasons as to why cognitive retraining is the most preferred mode of treatment for children with ADHD. Firstly, they are designed in such a way that specifically targets the cognitive deficits in children with the disorder and in turn helping them perform these tasks and lead a more independent life. Secondly, cognitive tasks are noninvasive in nature and are hence not considered dangerous and can often be performed in homes or in places where the child feels comfortable the most. Lastly, these treatment methods don't cause any side effects and are at least considered to be partially effective when compared to various other treatment methods. Working

memory is the main target for application and impact of cognitive rehabilitation. It is considered to also affect various other cognitive levels in the brain and also help predict performance in that particular area. Many studies have shown that video games and tasks have helped alleviate hyperactivity and improve working memory but many have failed to replicate the same results and hence the effectiveness of such tasks is considered to be inconclusive[25].

2.1.2 Autism Spectrum Disorder

It is a group of disorders which is neurological in nature and classified as a developmental disorder which is seen in people from childhood and lasts for a lifetime. People with ASD generally face difficulty in communicating and interacting with people, display repetitive behaviors, express restricted interests, and often face enormous obstacles while attempting to function normally at school. New and improved ways of retraining such children with the disorder such as eye tracking mechanisms and other software solutions mainly because of the improvement in awareness by the general public are being developed. There are three primary objectives considered before designing these tasks which are based on the interaction between the child with ASD and the therapist. Firstly, it is to design a game system that targets the affected areas of the child with ASD. Secondly, to assess the interaction between the child with ASD and other people over the course of time and lastly to establish a mechanism which allows experts to compare the progress of the trainee over a period of time. Various software applications have been developed for cognitive rehabilitation and these applications can be divided into three broad categories namely mixed realities, Robotic games and dedicated applications. Mixed realities often include virtual reality elements and include them in the real world. Various studies show that positive results have been obtained when trainees are exposed to repetitive training in a secure environment. Children with ASD have a hard time in recognizing facial expressions and Augmented Reality (AR) help them overcome such difficulty. These games improve the creative and imagination skills of such children and assist them in discovering new skill sets. Such games are very flexible and help trainees face real life social situations and assist them in coming up with appropriate solutions, thus, helping them develop their social skills in the process. Robotic toys help develop the motor skills of children and also help them develop their social skills since some toys are designed to respond and communicate[26]. Although significant improvement is noticed in children with ASD, it is also important to know that robots do not entail human emotions and interaction with a human companion is very important in the development of social skills of the child.

2.1.3. epilepsy

One of the most common neurological disorders in the world is epilepsy. Epilepsy is a chronic disorder which is non-communicable. Epilepsy is associated with seizures. Seizures are defined as abnormalities in the electrical activity of the brain, due to which a person might show behavioral change, lose consciousness, or show changes in terms of movements. Occurrence of one single seizure attack does not signify epilepsy.

Be that as it may, on the off chance that various repetitive seizures are observed, one may say that the person suffers from epilepsy. People suffering from epilepsy show a decline in more than one cognitive abilities.

But memory and attention are the most common. Epileptic patients are usually prone to sleep disorders as well. This causes problems in concentration in a longer run. Depending on the specific area of cognitive problem, a physician suggests various medications and cognitive tasks. Studies have shown that when children with epilepsy are well informed about their condition they respond to medication and therapy in a much better way.[3] Cognitive training could be done in a way such that it treats a particular aspect of memory or tries to improve memory of a person in general. This depends upon the patient's condition. The most frequently reported memory problems in epileptic patients are forgetting names, loss of property, etc. Memory training for epileptic patients has few general rules which hold good for improving the memory of a healthy population, such as repeating words, giving more time and attention while learning, sorting and learning etc. Two approaches are used for memory training usually. The first approach is repeating the cognitive tasks for an improved memory over a period of time. And the second approach is by opting for mnemonic strategies. Mnemonic is also known as memory aid. Mnemonic devices include rhymes, songs, poems, images and other tools. [4] Cognitive rehabilitation in the field of epilepsy was introduced over a decade ago. It has gained popularity over the years. And some studies show that the compensatory methods improve the memory of patients. Cognitive rehabilitation for epileptic patients is an effective way of improving their day to day lives but these tasks need to be performed under supervision. [3]

2.1.4. encephalitis

Encephalitis is an acute inflammation of the brain. Symptoms include confusion, photosensitivity, headache, seizures etc. A person's cognitive abilities fall down permanently or for a very long time due to encephalitis. The most commonly reported cognitive problems include memory loss, speed of thinking, problem solving abilities etc. Out of these problems, most patients suffer from severe memory loss. In some cases, patients cannot even remember how to talk.[2] Cognitive exercises cause the brain to stimulate resulting in more neurons to fire which improves the brain functionality. Brain exercise is ultimately causing the brain to rewire itself, this is known as neuroplasticity. Cognitive tasks that have shown efficient results in the treatment of encephalitis are repeating words and numbers, rhythm matching, picture recall etc. These tasks improve the attention and concentration of individuals suffering from encephalitis. Also, problem solving abilities can be taken care of with the help of cognitive tasks.[6]

2.1.5. speech disorders

A speech disorder is a communication disorder that affects a person's ability to produce sounds that create words. Speech and language are a primary source of communication and when this gets affected, complexity in the child's development increases. Few cognitive tasks are suggested to overcome difficulties faced by children who suffer from speech disorders. The doctor first checks for various parameters before assigning the tasks. The parameters include a spell check, pronunciation, memory test etc. Some

serious games have been developed by project intelligence companies for social and cognitive competence. The games include speech drills, 3D game environments, Visual games, Virtual games, mobile games to develop social and communication skills. Virtual games help in fluency of speech. These games have helped overcome the difficulties faced by therapists to communicate with children suffering from speech disorders giving continuous assessment of the child's progress. [5]

2.1.6. dementia

Dementia is a collection of various disabilities which affect one or more cognitive functionalities of the brain such as memory loss and judgment. This disorder is mainly seen in elderly people. Since the person's cognitive abilities are drastically affected, they find difficulties in performing day-to-day activities. Some of the side effects of this disorder is display of multiple personalities, hallucinations etc. Childhood dementia is a very rare case of genetic disease. There is a lack of awareness of this disease because of its rarity. Dementia is a neurocognitive disorder which significantly degrades the quality of life of those who suffer from it. Dementia can cause the downfall of various cognitive abilities of an individual. Cognitive therapy is one of the many treatment plans for dementia. Studies show that cognitive tasks can help in delaying the cognitive abilities of a person suffering from early stage dementia. Simple tasks are usually prescribed to patients suffering from later stages of dementia such as, simple calculations, storytelling, reading aloud, playing musical instruments, dancing etc. [7]Cognitive training is one of the most popular therapies for treatment of dementia. Cognitive therapy can be passive where the patient is asked to listen to music, or it could be active where the patient is asked to play various simple cognitive games. The most popular form of active cognitive therapy is 'brain exercise using workbooks'. These workbooks come with different difficulty levels and cognitive tasks such as, memory games, games that require attention, games that require reasoning etc. [8]

III. ELECTROENCEPHALOGRAPHY AND ITS ANALYSIS

EEG is a procedure that records the electrical activity of the brain and this record is called encephalography. There are mainly 4 major frequency bands in the EEG waveform that is of high importance for measuring cognitive levels. These are Delta (Less than 4Hz, amplitude 20-200 microvolts), Theta(5-7Hz, amplitude is less than 45 microvolts), Alpha (8-13Hz, amplitude is between 14-45 microvolts), Beta (14-30Hz, amplitude is 2-20 microvolts).[9] EEG signals are popularly used to study brain of healthy individuals and of those who suffer from certain cognitive disorder. For example, for children with ADHD, the frontal lobe is of primary interest. Their EEG reading consisted mainly of Front thalamic non optimal functioning which is compared with standard frontal theta wave (FTW) parameters and a deviation in the frontal theta waves in the right hemisphere is observed. Children who suffer from right hemisphere FTW have difficulties in nonverbal performance, performing executive functions, regulation and control.[10]



For children suffering from epilepsy, their EEG activity shows abnormal changes at the time of seizures. Some people with epilepsy show unusual activity in their brain at all times.

These abnormalities are often seen as spikes which are called Interictal Epileptiform Discharges (IEDs) and they are clearly visible with or without disturbing the background waves. Various factors determine whether a patient will show IEDs during an EEG such as location and frequency of the attack. Even the timing of the attack is of significant importance during measuring these IEDs. Usually 50% of epileptic patients show IEDs in their first EEG test.[11] For children suffering from Encephalitis (Herpes simplex encephalitis), their EEG shows certain abnormalities such as periodic sharp waves or amplitude of the slow waves or focal waves get attenuated and seizures. The seizures may or may not be present.[12] Children who suffer from Autism Spectrum Disorder (ASD) often get seizures which can be screened using EEG.[13] MATLAB/ EEGLAB is commonly used for EEG analysis. There are various techniques for analysis. The most commonly used techniques are Power Spectrum Density (PSD), Wavelet Transform, Fourier Transform, Fast Fourier Transform. Various feature extraction methods are used such as Independent Component Analysis (ICA), Principal Component Analysis (PCA), and Linear Discriminant Analysis (LDA). Analysis is usually done to isolate different frequency bands of EEG.



Figure 1: EEG Analysis process

3.1. frequency domain analysis

Frequency is defined as the number of occurrences of a particular event. If a signal is represented in terms of its frequency and corresponding characteristics, then this kind of representation is known as Frequency Domain analysis. The most commonly used Frequency Domain Analysis is Power Spectrum Density analysis.[14]

3.1.1. power spectrum density analysis

One of the most important aspects of digital signal processing is the power spectral analysis. Power Spectrum Density measures the power of each individual component of the waveform and displays it in the form of a spectrum which explains how the energy of the waveform is distributed. PSD is commonly used to study the local stationary behavior and to depict the time evolving nature of an EEG signal.[15] It either represents frequency content of the EEG signal or the distribution of signal power over the frequencies. Some parameters derived are total power, spectral band power, median and spectral edge frequencies. This helps in distinguishing between awareness and responsiveness. The expression of the PSD as a component of the frequency P(f) can be got from the time series y(n) by utilizing the periodogram expression in equations (1) and (2)

$$P(f) = 1/Ts | \sum_{k=0}^{N-1} y(k) e^{-j2\pi f k Ts} |^2 \tag{1}$$

$$= 1/NTs | Y(F) |^2 \tag{2}$$

where Ts is the sampling period, N is the number of samples, and Y (f) is the discrete time Fourier transform of y(n).[16] This method is often employed to understand the EEG of those who suffer from ADHD.[17]

3.1.2. FOURIER TRANSFORM

Fourier transform is a mathematical tool used for the conversion of any time dependent signal into frequency domain. Fourier transform is widely used for analyzing biological time series like EEG signals. EEG is the measurement of fluctuation of voltage across the scalp. In Fourier analysis, the EEG signal is broken down into sinusoidal fragments which ultimately calculate the amplitude and frequency of each fragment. Thus, EEG is used for the quantification of data. Fast Fourier transform (FFT) is the most commonly used Fourier analysis algorithm used for EEG analysis. PSD is likewise realistic in two stages from the FFT of the auto-correlation Ryy (k) of the signal, where Ryy (k) is computed by the accompanying expression in equation (3)

$$Ryy(k) = 1/N \sum_{i=0}^{N-k-1} y(i) y^*(i+k) \tag{3}$$

where * is the complex conjugate. Thus, PSD can be expressed using equation (4)

$$P(f) = (Ts \sum_{k=-N}^N Ryy(k) e^{-j2\pi f k Ts}) \tag{4}$$

FFT-based methods are broadly diffused, for their simple relevance, computational speed, and direct translation of the outcomes. [16] A number of studies suggest the use of FFT for analysis of EEG of people who suffer from ASD.[18]

3.2. TIME DOMAIN ANALYSIS

3.2.1. LINEAR PREDICTION METHOD

This method is widely used for detecting seizures in epileptic patients. The most commonly observed symptom in epileptic patients is seizures which is basically occurrence of spikes in the EEG signals due to unusual brain activity. This linear prediction method employs a mathematical model where the future values of a discrete time signal is predicted linearly using certain functions of the available previous sample. This method is also called linear predictive coding. If x(n) is a random process where N are the most recent samples, called prediction order. The equation (5) can be used to compute linear prediction of the signal of interest [20]

$$x^n_r = - \sum_{i=0}^N N(a)_{N,i} x(n-i) \tag{5}$$

This method usually uses a low pass filter and in MATLAB, it uses an FIR filter. This method often throws errors which can be calculated by finding the difference between the predicted values and their respective exact values. Linear prediction method always assumes that the EEG signal is stationary but when there are spikes in the signal, the signal is no longer stationary which will give rise to the increase in prediction error. This helps in determining the location of the spikes in the signal. The time domain analysis techniques are generally seen to be used for comprehending EEG of epileptic patients.[19]



3.3. TIME FREQUENCY ANALYSIS

3.3.1. Wavelets

EEG signals are non-stationary by nature. However, in order to analyze these signals they are assumed to be stationary for short intervals. In time-frequency analysis, the EEG signals are treated as Gaussian curves. Gaussian and non-Gaussian parameters are calculated for analyzing EEG. The mean and covariance are calculated from the Gaussian curve. And the non-Gaussian parameters such as skewness, kurtosis, negentropy etc are also calculated. EEG is observed during sleep, wakefulness and rapid eye blinking. The most commonly used technique under time-frequency analysis is the wavelet transform. Wavelet transform uses the Morlet window. Important information can be obtained from the gap between time and frequency component. The main aim of wavelet transform is to create this gap efficiently. The Morlet window focuses on the time with respect to the sampling period of the EEG. The continuous wavelet transform is used for analyzing the change of frequency over time. This popular technique is often used to study neural signals of those who are epileptic or those who have Alzheimer. In continuous wavelet transformation, a given signal of finite energy is projected into different bands which can be represented as shown in equation (6) [21].

$$\gamma(s, \tau) = \int f(t) \psi_{s, \tau}^*(t) dt \tag{6}$$

Discrete wavelet transform is applied to discrete data to produce discrete dataset outputs. It can be represented by the equation (7) where i and k are real valued integers [21].

$$\psi_{i, k}(t) = 2^{-0.5} \psi(2^{-i}t - k) \tag{7}$$

3.4. FEATURE EXTRACTION

A feature is a clear characteristic measurement, transform, component extracted from the waveform. Feature extraction is performed immediately after pre-processing the EEG signals, Feature extraction is a very important process before EEG analysis since it helps the clinicians focus on the important and necessary aspects of the EEG waveform. There are various feature extraction methods and few of them such as independent component analysis (ICA), principle component (PCA) and linear discriminant analysis (LDA) are discussed below. ICA is used to linearly separate two or more mixed sources of EEG and to spare out the data from the artifacts. To perform ICA, the multiple sources of EEG waveforms obtained from various positions in the 10-20 systems must be uncorrelated. This must be done to restore the initial structure of the waveform after applying ICA. This is usually done using a processor called a whitening of data. It is to be noted that ICA can only be used for separating linearly mixed sources. Suppose there are c independent scalar source signals $x_i(t)$ for $i=1, \dots, c$ where t is a time index ranging from $1 < t < T$. The multivariate density function is represented using equation (8) [22].

$$p(x(t)) = \prod_{i=1}^c p(x_i(t)) \tag{8}$$

PCA is a very well-known linear transformation for efficient lower dimensional representation of the data. It is a very useful tool in data processing. It is used to find the principal component of each waveform or source and then the feature function is extracted from the corresponding EEG signal. PCA basically converts a large number of correlated variables into a small number of uncorrelated variables, which are called principal components. The covariance method is the most predominantly used method to find principal components. In this method, the main focus is on representing d -dimensional data in a lower dimension which will reduce the degree of freedom and reduce the space and time complexities. This is first done by computing mean vector μ and $d \times d$ covariance matrix for the full data set. The eigenvectors and eigenvalues are sorted in decreasing order. The largest k such eigenvectors are chosen. From $k \times k$ matrix A , whose columns consist of the k eigenvectors are represented as shown in (9) [22].

$$x' = A^t(x - \mu) \tag{9}$$

LDA is a type of feature extraction method which is used to reduce the dimensionality (reduce the number of variables) in the collection data set.

IV. DISCUSSION

In children with ADHD, a significant change in alpha and theta waves and no change are observed in beta waves. Power Spectral Density is one of the simplest techniques used for analysis and hence performed for most disorders. The only drawback of this method is that it cannot isolate the time or duration of the occurrence of frequency of wave of interest. EEG is a kind of data that measures voltage over time. The simplest method to break it down to its constituent frequencies is by applying a fast Fourier transform (FFT). It decomposes linear differential equations that do not contain non-sinusoidal sources and breaks them into component equations that consist of sinusoidal waves which in turn makes it easier to study the EEG waveforms since the characteristics of the sinusoidal waves do not change over time. FFT has the ability to discriminate between children with ASD and those without. FFT is most useful in analyzing sleep disorders since it has the capability to differentiate various slow waves. FFT cannot be used to analyze short EEG signals. Also, it is not useful to analyze epileptic seizures in EEG signals because it cannot localize the spikes. Time domain is not frequently employed in EEG analysis because the point of interest in an EEG waveform is usually a particular frequency component. Time domain analysis is usually done for detecting seizures in epileptic patients since it shows the time and duration of wave abnormalities and it becomes easier to identify the causes. Wavelet transform is most popularly used for analyzing EEG of patients with epilepsy and Alzheimer's disease. Wavelet transform is an efficient way to locate transient features in both time and frequency domain. Over the years, experts have developed various activities to improve the lifestyle conditions of people with cognitive disorders and even though improvements have been observed, no drastic changes have been seen and its effectiveness is yet to be proven.



V. CONCLUSIONS

The role of cognition in memory and learning and its importance was discussed in this paper. Although there are many cognitive disorders that exist, six most prevalent ones were discussed namely ADHD, ASD, Dementia, Epilepsy, Encephalitis and Speech disorders. Basics of EEG and the characteristics of various frequency bands were discussed. Children suffering from the above mentioned syndromes often show variations in their EEG and the primary characteristics of such EEG waveforms are also covered. Various retraining methods for children suffering from cognitive disorders are also discussed in this paper. Most of these techniques are very similar in nature because it involves improving the performance of a child in the fields of logical reasoning, memory and behavioral skills. The efficiency of such methods are still yet to be proven although slight improvements are seen in children which is mentioned in several surveys but it is still not enough to arrive at a fixed answer. To study the EEG characteristics, analysis is very important and these steps are covered in detail in the second half of the paper. A multitude of techniques are discussed for the analysis of EEG which are classified into three main categories namely time domain, frequency domain and time frequency domain. It is not possible to discern the best possible method to perform analysis since each method is suitable for different kinds of waveforms and disorders and each of them have their respective shortcomings. It's always better to understand which technique is the most optimum one that can be applied to a specific disorder.

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Engineering.

Yashodhara Bora is a student from the department of Medical Electronics of Dayananda Sagar College of Engineering. Throughout the course of her under-graduation she got the opportunity to comprehend the theoretical aspects of her interest which lies in Biomedical Signal Processing, Biomedical Imaging, Biomaterials, Biomedical Instrumentation and Neural



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Sonal Priyadarshan is a student at Dayananda Sagar College of Engineering pursuing Bachelor of Engineering in Medical Electronics. She has had the privilege to showcase her interest in both medical and electronics such as Human Anatomy and Physiology, Biomedical Signal processing, Neural Engineering, Biomedical Design, Control Systems, Digital and

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