Neural Activity based Biofeedback Therapy for Autism Spectrum Disorder through Wearable Wireless Textile EEG Monitoring System

Ahna Sahi a, Pratyush Rai *b, Sechang Oh b, Mouli Ramasamy b, Robert E. Harbaugh c, Vijay K. Varadan b, c, d

a Dept. Psychology, Sam Higginbottom Institute of Agriculture, Science and Technology, Allahabad, U.P. (India) 211007;
b Dept. of Electrical Engineering, University of Arkansas, Fayetteville, AR (USA) 72701;
c Department of Neurosurgery, College of Medicine, Pennsylvania State University, Hershey, PA (USA) 17033;
d Global Institute of Nanotechnology in Engineering and Medicine Inc., Fayetteville, AR (USA) 72701

ABSTRACT

Mu waves, also known as mu rhythms, comb or wicket rhythms are synchronized patterns of electrical activity involving large numbers of neurons, in the part of the brain that controls voluntary functions. Controlling, manipulating, or gaining greater awareness of these functions can be done through the process of Biofeedback. Biofeedback is a process that enables an individual to learn how to change voluntary movements for purposes of improving health and performance through the means of instruments such as EEG which rapidly and accurately ‘feedback’ information to the user. Biofeedback is used for therapeutic purpose for Autism Spectrum Disorder (ASD) by focusing on Mu waves for detecting anomalies in brain wave patterns of mirror neurons. Conventional EEG measurement systems use gel based gold cup electrodes, attached to the scalp with adhesive. It is obtrusive and wires sticking out of the electrodes to signal acquisition system make them impractical for use in sensitive subjects like infants and children with ASD. To remedy this, sensors can be incorporated with skull cap and baseball cap that are commonly used for infants and children. Feasibility of Textile based Sensor system has been investigated here. Textile based multi-electrode EEG, EOG and EMG monitoring system with embedded electronics for data acquisition and wireless transmission has been seamlessly integrated into fabric of these items for continuous detection of Mu waves. Textile electrodes were placed on positions C3, CZ, C4 according to 10-20 international system and their capability to detect Mu waves was tested. The system is ergonomic and can potentially be used for early diagnosis in infants and planning therapy for ASD patients.

Keywords: Mu waves, ASD, biofeedback, EEG, smart textile, bio-sensor, wireless, wearable sensor system

1. INTRODUCTION

Autism is a group of developmental brain disorders, collectively called Autism Spectrum Disorder (ASD). The Autism Spectrum or Autistic Spectrum describes a range of conditions classified as neurodevelopmental disorders in the fifth revision of the American Psychiatric Association’s Diagnostic and Statistical Manual of Mental Disorders 5th edition (DSM-5) [1]. The spectrum refers to the broad range of symptoms, skills, and levels of impairment, or disability, that children with ASD can have. It is a lifelong developmental disability that affects how a person communicates with, and relates to, other people. It also affects how they make sense of the world around them. It is a spectrum of condition, which means that, while all people with autism share certain difficulties, their condition will affect them in different ways. Some people with autism are able to live relatively independent lives but others may have accompanying learning disabilities and need a lifetime of specialist support. People with autism may also experience over or under sensitivity to sounds, touch, taste, smells, light, or colours. Under DSM-IV-TR, autism was characterized by delays or abnormal functioning before the age of three years in one or more of the following domains: (1) social interaction; (2) communication; and (3) restricted, repetitive, and stereotyped patterns of behavior, interests, and activities. [2]

1.1 Developmental course and prevalence rate:

Under DSM-5 criteria, individuals with ASD show symptoms from early childhood, even if those symptoms are not

*prai@email.uark.edu, phone 1 479 966-5525; www.uark.edu
recognized until later. Traditionally, autism is not diagnosed until age 2-3, when parents bring their children to medical attention, or when signs are detected on routine checkups or day care. The patterns of onset include early developmental delays or losses of social and language skills. Some children with ASD seem to develop normally around 18-24 month of age and then they stop gaining new skills, or they lose the skills they once had [2]. First symptoms of ASD frequently involve delayed language development, often accompanied by lack of social interest or unusual social interactions, odd play pattern, and unusual communication patterns. During the second year, odd and repetitive behaviors and the absence of typical play become more apparent.

1.2 Management:

The main goals of treatment or management are to lessen related deficits and family distress, to increase quality of life and functional independence. No single treatment program has been found to be successful in treating all individuals with ASD. Health professionals plan treatment to match the person's particular needs, their strengths, and difficulties.

In treating ASD in children it is important to begin the treatment early on in the disorder. It entails planning a treatment program to meet the child's needs, for both behavior and communication problems, involve parents and other primary caregivers. Early intervention focuses on teaching social skills, developing motor and communication skills, reducing problem behaviors (e.g., emotional outbursts, head banging, interrupting) and promoting positive behaviors (e.g., turn taking in social situations). Medication is sometimes used to improve attention span or reduce unwanted behaviors, such as hand flapping. However it is important to explore other ways of reducing these behaviors because some medications have harmful side effects, especially if taken over a long period of time. Psychological treatment, including behavioral interventions has been shown to improve the functioning of people with ASD.

Intensive, sustained special education programs and behavior therapy early in life can help children acquire self-care, social, and job skills. Available approaches include applied behavior analysis (ABA), Neurofeedback therapy, developmental models, structured teaching, speech and language therapy, social skills therapy, and occupational therapy. There is a long list of possible treatments for ASD, some of which have no evidence to show that they work. Effective treatment programs for ASD should include psychological treatment to address difficulties in behavior and attention and promote the development of language and communication and social skills [3].

2. MU WAVE

Mu waves have been studied since the 1930s, and are referred to as the wicket rhythm (Fig. 1) because the rounded EEG waves resemble croquet wickets. Mu waves are synchronized patterns of electrical activity involving large numbers of neurons, in the part of the brain that controls voluntary functions. These patterns as measured by electroencephalography (EEG), magnetoencephalography (MEG), or electrocorticography (ECoG) repeat at a frequency of 9–11 Hz and are most prominent when the body is physically at rest, meditating or sleeping [4]. Unlike the alpha wave, which occurs at a similar frequency over the resting visual cortex at the back of the scalp, the mu wave is found over the motor cortex, in the mid-section of 10:20 electrode configuration spanning from ear to ear.

![Fig. 1. Typical Mu-wave, Comb or Wicket rhythm](image)

Mu waves are suppressed when the person performs a motor action or visualizes performing a motor action. This suppression can also be explained as desynchronization of the mu wave by large numbers of neurons, especially mirror neurons, firing in synchrony. Mirror neurons are a class of neurons that are involved in abilities such as empathy and perception of other individual’s intentions. Researchers such as V. S. Ramachandran and colleagues have suggested that this indicates involvement of mirror neuron system in mu wave suppression [5].
In a typically developing individual, the mirror neuron system responds when he or she either watches someone perform a task or performs the task him- or herself. In individuals with autism, mirror neurons become active (and consequently mu waves are suppressed) only when the individual performs the task him- or herself [6]. These findings suggest that the mirror neuron system may not be non-functional in individuals with autism, but simply abnormal in its development. This information is significant to the present discussion because mu waves may be integrating different areas of mirror neuron activity in the brain [7]. Other studies have assessed attempts to consciously stimulate the mirror neuron system and suppress mu waves, using neurofeedback (a type of biofeedback given through computers that analyze real time recordings of brain activity, in this case EEGs of mu waves).

3. BIOFEEDBACK THERAPY

Neuro (Bio) feedback therapy is one of the upcoming treatments for ASD. Neurofeedback (NFB), also called neurotherapy or neurobiofeedback, is a type of biofeedback that measures brain waves to produce a signal that can be used as feedback on brain activity to teach self-regulation. It uses real time displays of electroencephalography (EEG) to illustrate brain activity and teach self-regulation. Biofeedback is commonly provided using video or sound, with positive feedback for desired brain activity and negative feedback for brain activity that is undesirable.

Biofeedback uses operant conditioning to alter brain waves so that a client’s brain can achieve more flexibility and stability. In addition, it can help decrease or prevent excessive arousal or anxiety and assist the client with attention and motivation. For families choosing home visits with dynamic counseling and play therapy, Biofeedback can be done in their home.

Many research studies have shown potential of biofeedback therapy for treatment and management of ASD by targeting various symptoms observed among ASD patients especially brain activity [8]. Some systems concentrate on enhancing the levels (power) of β waves, while suppressing level (power) of θ waves over frontal and central, midline cortical brain areas i.e. theta/beta protocol [9]. Some systems concentrate on reducing level (power) of δ waves, while increasing level (power) of α and β waves in the frontal brain area [10]. Similarly, enhancing mu-suppression by mirror neurons in the motor cortex can be used as operant conditioning for treating or managing ASD [5]. Most of these systems use conventional conductive gel based gold cup electrodes, while few of them use dry electrodes but only for open areas such forehead or require shaving the head. In this study, a wearable wireless textile EEG monitoring system has been presented for neural activity based biofeedback therapy for ASD. EOG and EMG monitoring has been incorporated in the system to detect eye motion, eyes close and open, jaw motion as additional factors for monitoring subject response. The system has been described in detail in the next section. The multi-lead EEG monitoring system is integrated into a mu-wave suppression based biofeedback therapy to enhance motor skills as shown in Fig. 2.
4. WEARABLE SYSTEM

The wearable system comprises of textile based nano-structures sensor electrode array for measurement of EEG signals in the motor cortex and the occipital lobe. The sensors are connected to amplifier- wireless transmitter module, which amplifies and relays the signals to the computer that is the CPU of the biofeedback system that initiates and loops the audio/video cues till the mu-wave attenuation is detected. Scoring algorithms can be installed in the CPU that can monitor the progress of the operant conditioning and overall progress of the ASD patient.

4.1 Textile based nanosensors:

EEG was acquired on the skin through textile based nanostructured electrodes. The challenge was to acquire EEG through the hair on the head. To serve this purpose, nano-structured conductive electrode with millimeter long pillars of conductive textile (Fig 3) were used. Nano-structured textile electrodes have electrode-skin contact comparable to or better than the Silver-Silver chloride electrodes [11]. These electrodes are textile based and can be seamlessly integrated in to wearable head gear such as cap, skull cap and head bands, thus providing a reusable system in form of a skull cap with wireless transmission.

![Image of wearable system](https://example.com/wearable-system.jpg)

**Fig. 3.** (a) Wearable nanostructures textile electrode based system with wireless EEG, EOG and EMG monitoring, (b) nanostructured textile electrode surface and (c) illustration of its interface with the scalp.

Data obtained from preliminary tests, performed with the nano-structured electrode at O2 position of a healthy subject, indicate that distinctive waveforms (Fig 4) can be identified. Low noise levels were observed due to good electrical contact of electrodes with the scalp, which is not achieved otherwise with plane textile electrodes.
Fig. 4. Two brain waves namely, alpha waves (obtained with eyes closed) associated with meditative state and beta waves (obtained with eyes open) associated with attentive state, distinguishable in the time domain.

4.2 Wireless Module for Data Acquisition and Transmission:

The analog EEG signals acquired through the electrodes need to be amplified, digitized and transmitted wirelessly. The overall schematic of the wireless module is as shown below in Fig 5.

Fig. 5. Overall schematic of the wireless module for EEG measurement

Amplifier

The amplifier which was a part of the wireless module consisted of 5 channels for the EEGs from 5 different locations over the scalp (C3, Cz, C4, O1, O2). The amplifier module amplifies and filters the raw EEG signals. The EEG signals are weak by nature and have to be amplified and filtered before data processing. Usually the un-processed EEG signals range from a few micro volts to milli volts. Transmitting these weak signals may cause the signal to be contaminated by noise and may degrade the signal to noise ratio at the receiver. Similarly, 50/60 Hz power line interference is also another factor which makes amplification necessary. Noise from the power line interference may cause impedance mismatch in the electrodes. To overcome this problem, an instrumentation amplifier with high common mode rejection ratio (CMMR) and high input impedance was used. Two more stages consisting of non-inverting amplifier and active low pass filter were used to amplify and filter the signals further to improve the signal quality and to improve the signal to noise ratio. The DC charge accumulated in the electrodes was removed in the second stage by high pass filter. The amplified and filtered signals were offset to 2V by setting virtual grounds of amplifiers with a voltage reference. The positive biased signals were for single supply of amplifier and the input range of the analog-to-digital (A/D) converter in the microcontroller. The gain and bandwidth of the amplifier module were tuned to 80 dB of gain and 0.3 to 35 Hz of bandwidth according to the American Academy of Sleep Medicine manual. Fig. 6 shows the schematic of the amplifier for EEG measurement.
The principal function of the transmitter was data processing and data transmission. In terms of the Nyquist-Shannon sampling theorem [12], 100 Hz sampling rate is adequate sampling rate to represent the EEG components ranging from 1 Hz to 38 Hz frequencies. Therefore, 100 Hz sampling rate was fixed to convert the amplified analog physical EEG signal to digitalized EEG signal. The transmitter mainly consists of a microprocessor and a Zigbee module. ATmega328P which has 8-bit RISC architecture was used. The microprocessor was equipped with a 10-bit resolution AD converter, and the AD converter digitizes the analog signals from the amplifier module. AD conversion was triggered by the generation of interrupt signals generated by the timer registers [13]. It was programmed in such a way that the conversion was triggered when the register value crosses zero. The interrupt signals were generated in specific intervals since the upper value of the timer register was preset. Thereupon periodic AD conversion is being facilitated by the interrupt generation in constant intervals. AD conversion resulted in the formation of sequential packets of data with code number, sampling rate, number of channels and data. The sampling rate was set to 100 Hz for each channel. The digitized signals were then sent to Zigbee module through Universal Asynchronous Receiver/Transmitter (UART).

A Zigbee module was used to communicate between the transmitter and the receiver unit. The frequency band of the Zigbee was the 2.4GHz ISM (Industrial, Scientific, and Medical) band. The whole module was powered by a 3.7V, 1800 mAh poly lithium battery. 3.7 V was boosted up to 5V to provide power to the microprocessor and amplifiers. The regulated 5V was again stepped down to 3.3 V for operation of the Zigbee module by a low-dropout regulator. Fig. 7 shows the flow chart of the algorithm implemented on the microcontroller [14].

4.3 Software interface for Neural Activity based Biofeedback:

The software was programmed on the computer side, essentially a laptop. This computer program was decoded into separate software modules to perform various functions. Key functions of the program were to display, to save, and to...
provide more reliable EEG data from an EEG data transmitted from the transmission module through wireless ZigBee communication. The transmitted EEG data from the transmission module was delivered by ZigBee protocol. Therefore, when the remote computer program was operational, a connection request was initiated from the transmission module, and the operation of delaying the request is termed as “listening” in this software module [13,15,16]. When the listing operation was performed by a connection request, a 49 transmission data capsulated by the protocol was delivered in a receive buffer on the remote computer. The receive buffer got filled every 1 sec, at that time; a data parse task was performed. The data parse task separated only EEG data from the data capsulation by the protocol and acquired basic information about measurement conditions such as the number of channels. The extracted EEG data from the capsulated data was saved on each display buffer with channel information.

Finally, the data was displayed on the computer screen. When EEG data was displayed, AR-PSD channels were activated according the user requirement. AR-PSD was formulated to calculate the auto regressive power spectral density in the specific wave regions’ of the EEG signal. Fast Fourier Transform (FFT) was performed in processing the EEG signals. This method was adapted to assist the feature extraction and signal classification procedures. Similarly, a protocol was framed to calculate the AR-PSD value over the frequency band (8-13 Hz) which always detected the maximum position in the prescribed band of frequency [15]. This method proves more suitable when compared to taking the average value in the particular frequency band which may also be inundated by noise signals. Therefore, only the maximum value or the peak was continuously detected which results in AR-PSD waveform of the desired frequency band.

A 500 milliseconds moving window FFT was initiated along with the audio/video cue. The AR-PSD was used to detect the presence of wavelets of interest and score them based on their peak amplitude and area under the curve. This result was use as the indicator of mu-wave level, which drives the decision algorithm to proceed to the next cue or repeat the current one.

4.4 : Multichannel EEG monitoring for detection of Mu waves by the Wearable Biofeedback system

Data from healthy subject was obtained by positioning electrodes at C3, Cz, C4, O1 and O2 according to the 10-20 electrode positioning for EEG signal acquisition. Data was recorded from electrode positions O1 and O2 while subject was asked to keep eyes open (idle case) and eyes closed meditating. The two AR PSD plots of EEG data from the above conditions were compared. It was observes (Fig. 8) that when subject’s eyes were closed, alpha waves are dominant such that AR PSD peak over alpha band (8-12Hz) had higher value than when the subject’s eyes were open (idle case). Positions O1 and O2 are optimum for detection of alpha waves, which is the key to classifying peaks in 8-12Hz band as alpha or mu wave [17].

Fig. 8. Comparing AR PSD plots of the O1 from healthy subject, when (a) eyes open and (b) eyes closed, for alpha waves alpha band (8-12Hz) has higher value.
Mu wave suppression occurs when the healthy subject observes a visual cue and think of imitating the actions or motions. Mu wave suppression can be identified when the amplitude of AR-PSD peak suppresses upon physical movement or intent to move physically [5]. Since the mu and alpha waves share the same bandwidth, it is important to differentiate between them. This was achieved by multi-channel EEG signal acquisition. EEG signals were acquired for healthy subject upon triggering of the visual cue of an activity (in this case a video of swimming actions) and the subject was asked to think of imitating the swimming action displayed. The AR-PSD plots of EEG, just before triggering the cue, from C3 and O1 in Fig. 9 show that while there was a peak in the 8-12Hz region of C3, there was no peak in the same region for EEG from O1. There are peaks observe in the beta wave region indicating the left hemisphere was active and subject was concentrating on the visual cue. Since occipital lobe position (O1 and O2) are considered the optimum position to scan for alpha waves, it can be said that the alpha waves were absent during that time. Hence, it can be said that the peak in C3 was mu wave and not alpha wave. Repetitions and more number of subjects will help us verify if such peaks are actually mu waves.

5. CONCLUSION

The wearable wireless textile EEG monitoring system, presented here, has been shown to detect mu-waves. As observed, the AR-PSD panel shows possible presence of Mu waves in the left hemisphere of the subject in this study. The mu wave appearance can be substantiated by repetitive testing that shows disappearance of the waves upon motion or intent of motion. Low amplitude of mu-wave can be justified by the fact that the subject in this study was healthy. Higher peaks can be seen in subjects with ASD where mu wave appearance and attenuation are stronger, and easy to capture because they appear upon movement rather than intent of motion. The wireless communication allows for the system to interface with personal computing devices such as PC, smartphones and PDAs, which can act as the CPU of the neural activity (biofeedback) based operant conditioning process. The biofeedback system presented here has the potential to be used for non-invasively monitor and help condition ASD subjects by using the mu-wave suppression conditioning therapy. The system is a mobile platform, which can be scaled to enable doctors and care givers to monitor more than one individual. The automated system can be used at home under parental guidance, while keeping the therapist updated at remote location through internet.
REFERENCES