**A Feasibility Study: Application Of Brain-Computer Interface In Augmentative And Alternative Communication For Non-Speaking Adolescents With Neurodevelopmental Disabilities**

**Background**

Neurodevelopmental disabilities (NDDs) are characterized by early childhood onset with cognitive, social, and motor impairments1. Autism, Rett syndrome, and communication disabilities are some of the conditions categorized under NDDs 1. Verbal communication impairment is one of the main challenges in some groups of NDDs 2. For instance, around 25% to 35% of the autistic population are not able to engage in effective spoken communication 3–5.

All people have a basic human right to have the resources and supports necessary to communicate their desires, thoughts, & feelings 7. Autistic individuals typically cannot effectively communicate their needs and desires. This can increase their feeling isolated and trigger a variety of emotional problems (e.g., depression) and self-injurious behaviors 8, especially in the non-speaking autistic population 9,10.

There are a variety of approaches (such as Didactic and naturalistic ABA, Pivot Response Treatment, Discrete Trial Training11) that benefit early childhood to elicit their speech12. However, evidence indicates the difficulty of teaching verbal communication to children after the age of five 13–16. Besides, there are few studies for teaching directly expressive verbal communication to the non-speaking autistic population based on a recent review, though there is substantial literature on teaching pre-verbal skills (e.g., joint attention, imitation) 13.

In this regard, technology-based Augmented and Alternative Communication (AAC) can be a better strategy for the non-speaking population. AAC benefits the non-speaking population with NDD to communicate their needs, thoughts, and desires17–19. A meta-analysis comparing different types of AAC applications (e.g., Picture Exchange [PE], Picture Exchange Communication Systems [PECS], Speech Generating Devices (SGD)), reported that both SGD and PECS are rated as effective in helping non-speaking people to communicate basic needs, wants and desires 19. It also reported that many in the non-speaking autistic population prefer using technology-based AAC for communicating19. Tech-based AAC compensates for some difficulties in speaking that older children and adolescents experience17–19 although the use of AAC is “severely understudied” for autistic adolescents and adults20–22, suggesting a real need for developing high-tech AAC considering each autistic person’s needs20. AACs have been less effective for older children and adults compared to preschoolers (5 and younger)23,24. AAC should be easy to use, with low cognitive demand, and address different needs of autistic adolescents 20,22. Currently, AAC applications, however, are not equitably accessible in terms of availability in rural areas, affordability for people with diverse socioeconomic status, and learnability25–27. To use of AAC devices effectively requires training for autistic individuals and extensive theoretical and practical experiences for teachers 12,25,27.

There are inherent limitations in the use of AAC applications for those who have the most significant learning needs, multiple disabilities, and/or motor skills problems 18,19,28,29 as well as those who have the least functional speech 23. Considering the potential of AAC, we aim to expand its modalities for the autistic population by adding brain-interface technology (BCI). BCI can translate brain signals into identifiable words, or/and audiovisual output. The AAC-BCI has been suggested as a beneficial approach for those with significant or multiple disabilities such as Rett syndrome 29 as it has short training times and a simple control task. Further, by direct translation of the brain signals to audio/visual output (or in other words—by direct, natural, neural control of assistive technologies 30), the limitations of traditional AAC devices such as the misattribution of motor movement of participants 31, can be resolved 30.

There has been growing interest in using electroencephalogram (EEG)- based BCI for a variety of conditions, (e.g., autism, aging, and physical disabilities) 32 and a variety of outcomes including rehabilitation (e.g., therapies to regain physical abilities), diagnosis (e.g., coma), recreation (e.g., gaming, art), assistive technology (e.g., communication, mobility) 33. Researchers 34 have found that EEG-based BCI with an accurate algorithm using machine learning (ML) could be influential in leading us to understand and help non-speaking people develop the capacity to effectively communicate their thoughts, feelings, and ideas. Further, BCI is easy to use and does not need training or using motor skills on part of the participants 26. The evidence indicates using a steady-state visually evoked potentials (SSVEP) paradigm in BCI can contribute to efficient, accurate communication 35. SSVEP can be applied to a variety of populations and conducted in a short time, without needing an overt response, with a high signal-to-noise ratio (SNR) and high information transfer rate (ITR) 35,36.

Based on a brief literature review (from 2015 to 2022), BCI studies were not found for Rett syndrome, however, in the autism field can be classified into two main categories – for identification and training purposes. For example, BCI can be used to identify signal patterns related to sound/music preferences 37 and the music consistent with autistic children’s moods for therapy purposes 38. Further, the signal patterns related to mental stress 39,40, interest level in a task, and mental workload in autistic children can be detected using BCI 41–44. Social joint attention of autistic children also can be detectable using the BCI technique 34. Among autistic children, training-purposed BCIs have been shown to improve attention using a BCI-based video game 45, social skills using neurofeedback training46, social joint attention 47–51, and learning to interpret emotional facial expressions and social skills52 and learning to drive for autistic adolescents 42.

Current studies indicate that using BCI can be useful and feasible in the autism population to improve social skills and teach specific tasks. However, there is no evidence of using BCI to expand AAC or improve communication for autistic people53. There is a variety of AAC-BCI used with other populations 26,54–60 and established literature on AAC for those with cognitive and literacy problems59 that could be enlightening for our project by adapting their principles and knowledge 59 for us with the autistic population.

An EEG-based BCI is popular to use because it is a non-invasive, safe, and more affordable technique compared to other devices and can facilitate accurate communication30. *We aim to explore the use of an EEG-based BCI in AAC (12 pictures in this study) for the Non-Speaking population with neurodevelopmental disabilities.* We will study the feasibility of BCI+AAC for non-speaking adolescents with neurodevelopmental disabilities who: (1) never have used AAC application; (2) previously could use AAC successfully but currently are not able to use it (e.g., Rett syndrome) due to losing their motor skills; (3) have significant and/or multiple disabilities (e.g., autism with significant intellectual disabilities).

**Aim**

The proposed study aims to explore the application of BCI-AAC with autistic youth and young adults. Brain signal patterns will be detected using an SSVEP-based BCI in response to visual stimuli (12 pictures) in the non-speaking autistic population. Recognized brain signal patterns from participants will subsequently be translated into audio output presented via a phone app or computer.

**Method**

*Participants*. We will recruit participants (N= 15, age = 12 -18) from disabilities related communities and organizations in MN. They may speak minimally or not be able to speak. For minimally speaking participants, word counts will be assessed based on a guideline to define the level of speech 13. Inclusion criteria: participants should have a formal diagnosis of either autism or neurodevelopmental disability. Those with secondary conditions of mild and moderate intellectual disabilities (ID) as well as those without ID will be included. Participants should already or previously have demonstrated an ability to use AAC as well as have normal vision or corrected normal vision (not less than 20/100 on a Snellen test). Photosensitivity assessment will be checked before enrolment in the study with visual light sensitivity questionnaire-8 (VLSQ-8). Exclusion criteria: participants who do not have the mentioned formal diagnoses, those with epilepsy history, those who have metallic cranial implants, and those with most significant ID will be excluded. Before starting recruitment, the IRB application will be submitted and once it is confirmed, the recruitment will be started. The consent (parent) and assent (youth with NDD) letters will be provided for those who declare their interest in the study voluntarily.

*Measures. The Peabody Picture Vocabulary Test, 5th Edition (PPVT-5)*61,62. This standardized norm-referenced instrument will be administered before experiment to measure receptive language of participants. Further, before each experiment, the comprehension of participants, or receptive attention, to each experiment picture will be checked by asking them to point out each picture by telling the name of the picture. The number of distinct words for minimally-speaking participants will be reported, which was recommended for a clear language phenotype of participants13. Overall, we will be able to have a phenotype of participants regarding the current levels of receptive language scores.

*Study Protocol*. *Task design and BCI modality:* A total of 12 pictures (i.e., AAC) will be selected for the task. In each trial, 4 pictures will randomly be presented on an LCD monitor in front of the subject and 4 LEDs placed in the top left (1), top right (2), down left (3), and down right (4), of the monitor. LEDs flicker with 8, 10, 12, and 15 Hz respectively. Subjects will be requested to select the output command (i.e., one of 4 pictures on the monitor) by paying attention to a sound that defines the number of the picture along with a visual cue (i.e., an arrow pointing at the picture). Each session will include 120 trials and each picture will be presented 10 times. Each trial time is equal to 7 seconds including 5 seconds picture presentation followed by a 2-second rest black/white screen (the total duration of each session will be 14 minutes). Overall, 3 sessions will be presented by inserting about a 5-minute break between sessions. The schematic task design and presentation are shown in Figure 1.

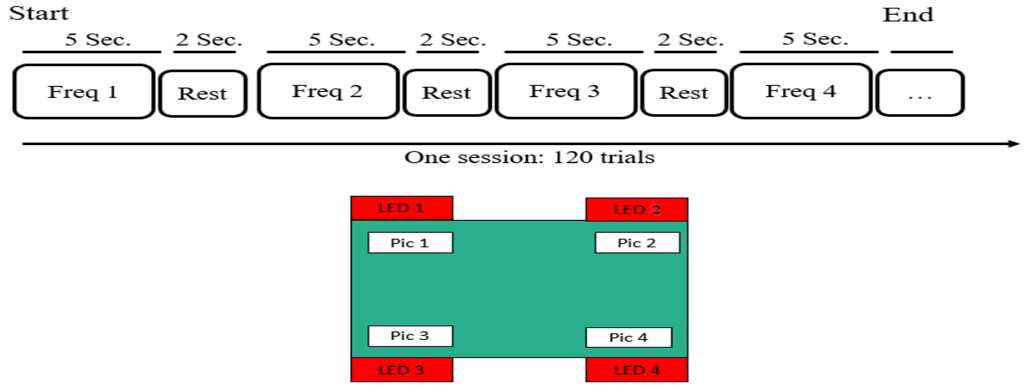


Figure 1: Schematic presentation of task.

*Data acquisition*: Eight channels of EEG signals will be acquired using a 10-20 standard system. Electrodes will be placed in occipital and parietal areas. The right ear and Fpz are dedicated to reference and ground electrodes respectively. Online notch (50 Hz) and bandpass filters (2-100 Hz) will be used. The frequency sampling frequency in this study is 512 Hz. The location of EEG electrodes is depicted in Figure 2. Synchronization pulses/trigger signals will be recorded simultaneously with EEG signals.

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| Figure 2: The location of EEG electrodes. | Figure 3: General block diagram of the experimental setup and data analysis. |

*Data analysis*. Firstly, EEG data will be preprocessed with a baseline correction and offline appropriate bandpass filters. Then the data of each trial will be extracted using triggers/ synchronization pulses. After the preprocessing, extracted signals of each trial will be analyzed with time, frequency, and time-frequency analysis. Informative features for each analysis will be used in the input table of machine learning methods. Machine learning methods (e.g., SVM, Decision tree, etc.) classify the signals and determine the output command. A general block diagram of the experimental setup and data analysis is illustrated in Figure 3. Further, the data from the PPVT-5 and the number of words for minimally-speaking participants will be reported and analyzed descriptively.

*Performance analysis*. Two well-known criteria will be measured for validation of the analysis. Accuracy (Acc) defines the fraction of corrected trials for all trials (Eq.1). Information transfer rate (ITR).  A general evaluation metric devised for BCI systems determines the amount of information that is conveyed by a system's output. ITR is equal to information transferred in bits per trial, N= number of targets, and P is equal to the classification accuracy. It is calculated by dividing the number of correct command classifications by the total number of classified commands (Eq.2). Both Acc and ITR will be reported for each participants function and for whole group of participants.

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| (Eq.1) |  |

*Timeline*



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