THE JOURNAL ON TECHNOLOGY AND PERSONS WITH DISABILITIES

Communicating with People with Profound Intellectual Disabilities Using Brain Computer Interface

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Abstract

People with profound Intellectual Disability (ID) have difficulties expressing their needs due to their limited communication skills. These skills are usually limited to gestures and vocalizations many of which so idiosyncratic that can only be interpreted correctly by their caregivers/parents often with a large gap between their interpretations. In this paper we explore the application of Brain Computer Interface (BCI) in designing a methodology to interpret the mental state of these individuals during interaction within their environment, focusing on the phenomenon of "surprise" in interaction. We report on our progress towards predicting the participants' reactions to expected and unexpected events by classifying their brain activities monitored by electroencephalography (EEG signals). This study takes a major step forward towards improving the communication skills with individuals with ID in particular with those outside their family circle.

Keywords

Intellectual Disabilities, Brain Computer Interfaces, Communication Systems, EEG signals.

Introduction

People with ID comprise a wide range of individuals with different cognitive abilities and while there are great individual differences, they can be categorized based on their communication skills. Introduced by McLean et al. and widely shared in the literature (James McLean and Lee Snyder-McLean) this population is categorized to the following three groups: *perlocutionary, Illocutionary* and *locutionary communicators.* Perlocutionary communicators are the individuals that do not intentionally signal other people but their intentional behavior has a meaning being interpreted by their parents and caregivers. Illocutionary communicators express a communicative intent by using different nonverbal forms of behaviors such as gestures and vocalization and *locutionary communicators* are able to use symbols to communicate their intentions and needs. These individuals use many idiosyncratic gestures and vocalization, which cannot be easily ruled out as unintentional (Iacono, Carter and Hook). Number of studies explored the modalities and functions of such behaviors that can be considered communication attempts but there are still ongoing researches on the issue of defining and recognizing intentionality in behavior and communication (Brady et al.; Carter and Iacono; Ogletree, Wetherby and Westling; Wetherby et al.; McLean et al.).

Several augmentative and alternative communication systems are designed to help the ID population communicate better (Ogletree et al.; Romski and Sevcik; Hourcade et al.). Figure 1 shows a typical communication system where a subjects' behavior is being observed and interpreted by the facilitator and then responded appropriately. These methods can be roughly divided to aided and unaided systems. One core principle of the intervention systems for perlocutionary communicators is to try to interpret the idiosyncratic behaviors as potential communication attempts and respond to it until those behaviors are being intentionally generated by the communicator to create the same response (Ogletree et al.; McLean et al.). Another core principle is to practice routines and then introduce unexpected changes in the routine to see the individual's reaction and provide opportunities for initiating a communication attempt. These methods rely heavily on the caregivers' and therapists' interpretation of the ID population behavior. Caregivers have to be attuned to correctly interpret the unconventional gestures and vocalizations and respond to it appropriately, given the multiple possible interpretations (Carter and Iacono) it is valuable to reduce the risk of mistaken interpretations.

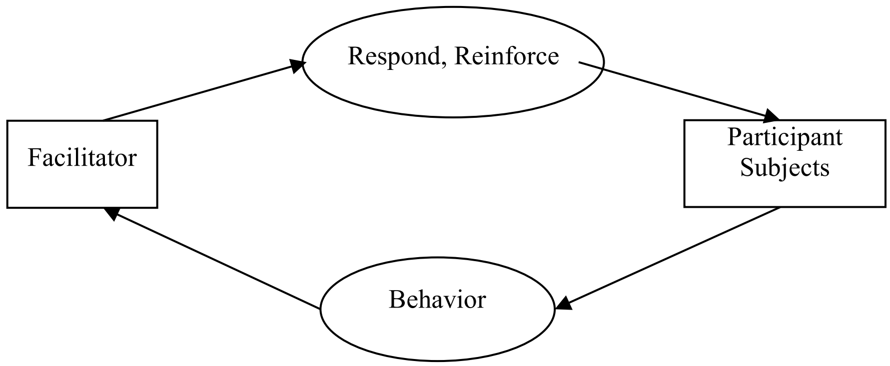

Fig. 1. Communication System.

Therefore, the focus of this study is to gain better understandings of the intentions of perlocutionary communicators by directly using their brain activations to identify the markers that signal intentional state during an interaction. We focus on "surprise", when one side observes an unexpected event. With cognitively typical individuals, one can recognize the behavioral correlates of mental state of surprise in their reaction; but with person with ID, idiosyncrasy of the behavior would hinder the correct interpretation their behavior and mental state. In addition, one would not know whether the practiced routines of teaching (e.g. symbolic communications) are actually working, if we cannot after all test, whether what follows after the subject points to some symbols is expected from their point of views.

Electrophysiological measures have been widely used and studied for individuals with ID, mainly for the purpose of medical diagnosis and treatments (Boyd, Harden and Patton). Many studies have also explored the EEG correlates of development of cognitive skills in young typical and atypical toddlers (Mundy, Card and Fox; Henderson et al.). Our study takes a different route and explores the effectiveness and usability of Brain Computer Interface (BCI) methods in communication with people with severe to profound ID using interactive environment and activities to record EEG signals corresponding to perceiving unexpected events in different situations. We train the classifiers based on recorded data to predict the moments that the person is surprised during interaction in order to show that using the classifiers to detect surprise would help the caregivers to better communicate with the individual with ID.

Case Report

The participant of the study was a 20 years old female diagnosed with Angelman Syndrome (AS). AS is a neuro-genetic disorder characterized by Severe/Profound Mental Retardation and epileptic seizures. AS was first recognized by Harry Angelman and is believed to be caused by the lack of maternal copy of the UBE-3A gene expression on chromosome 15 (Kishino, Lalande and Wagstaff) and is associated with unique behavioral and physical features (Dan). Some of these features present in our subject are profound mental disabilities, lack of speech, sialorrhea, hyperactivity, puppet-like gait, etc. She does not seem to have visual impairment and her motor skills are not perfect but good enough that she can reach and grab even very small objects (i.e. peanut) after few attempts. She has been (with some AAC intervention) taught to use a communication device called TANGO, but from our observation she was not able to use that device at all. She more likely sees the devices as a toy or an interesting/colorful box but she does not use it in any purposeful way. We believe that she cannot communicate intentionally although she makes many gestures and vocalizations that one cannot confidently rule out as not having communicative intents so we conclude that she is a higher functioning perlocutionary communicator.

Method

In this study, we have used the Emotiv Epoch EEG headset. It has 14 channels with the international 10-20 system placement (See Fig. 2). Given the condition of our participant, wireless connection and relatively easy setup were the main reasons for selecting this EEG headset. We conducted our experiments in a classroom setting where only the participant, authors and support specialist were present in the room.

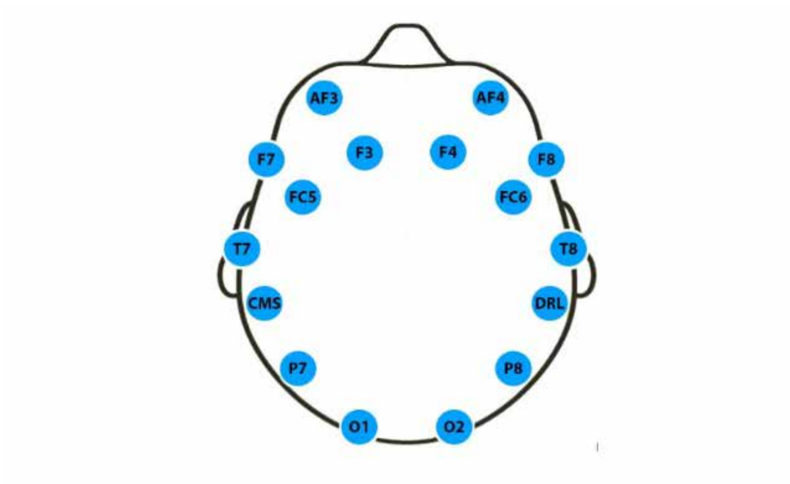

Fig. 2. Electrode placement on the scalp in EEG headset.

Brain-Computer Interface

"A brain computer interface (BCI) is a communication system in which messages or commands to the external world do not pass through the brain's normal output pathways of peripheral nerves and muscles" (Wolpaw et al.). So BCI systems have been developed to enable the users to control and communicate directly by controlling their brain activities when they cannot do it using brain's normal output pathways. Most BCI systems are based on variety of different electrophysiological signals such as Mu rhythm, P300 potentials and slow cortical potentials (Wolpaw et al.). Fig. 2 shows a schematic of a BCI system where EEG signals are processed for a specific BCI application. An important component of BCI systems, also shown in Figure 3, is the feedback of the system to the user. It means that both the user and the BCI should continually adapt to each other to guarantee a reasonable performance.

But the fact that the users must learn to intentionally manipulate their brain waves, with the purpose of communicating with their environment hampers the usability of these devices for people with ID. Our application needs a BCI system such that it does not require subject training and allows online detection of subject's mental state (Krusienski et al.). Our study follows the recent work on online predicting of mental state without subject training by (Wang, Guan and Zhang). In that study, participants were presented a sequence of portraits and the authors proposed a model to predict from the EEG signals if the person is looking at a familiar face (rare event) in a sequence of mostly unknown faces (prevalent event). Our approach includes predicting from the EEG recordings of the subject's brain, if in a routine of expected events, a situation is unexpected. We report the usability and efficiency of our method after formulating the problem in a form of machine learning classifier model and the communicative behavior of our subject.

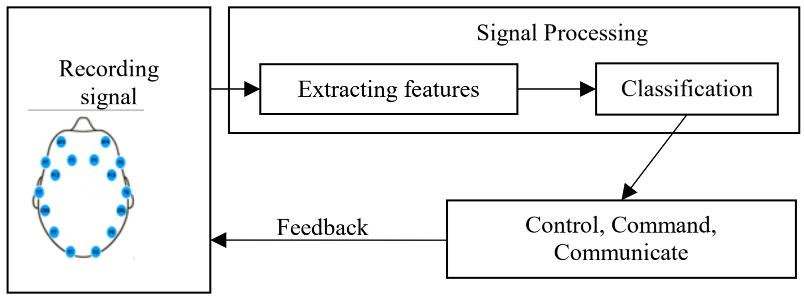

Fig. 3. Brain Computer interface.

Expected vs. Unexpected Events

Every time our subject heard the sound of the bag of snacks, she immediately moved her attention to where the sound came from; she got excited and started to salivate. So it was evident that she knew the sound and associated it with the coming snack (or a joyful experience). This is an example of expected and unexpected that has a very clear and obvious behavioral correlates. She expected to get a snack after hearing that sound or seeing the snack bag. But what if we give her a not very interesting toy? Would she ignore the toy because in this case the power of pursuing the goal is very strong?

One of the common communication interventions is to work with simple boards with two switches, where they get different rewards for pressing different buttons. The purpose of such interventions could be teaching cause and effect. But what we have not seen in the literature is methodologies to verify if these causal relationships are actually being learnt. We are using the notion of *Expected vs. Unexpected* to explore a practical example of such methodology, we call "expected" and "unexpected" to be two states of mind. Figure 4 shows how we modified the model shown in figure 1. Now the facilitator has access not only to the behavior but also to the estimated mental state of the subject.

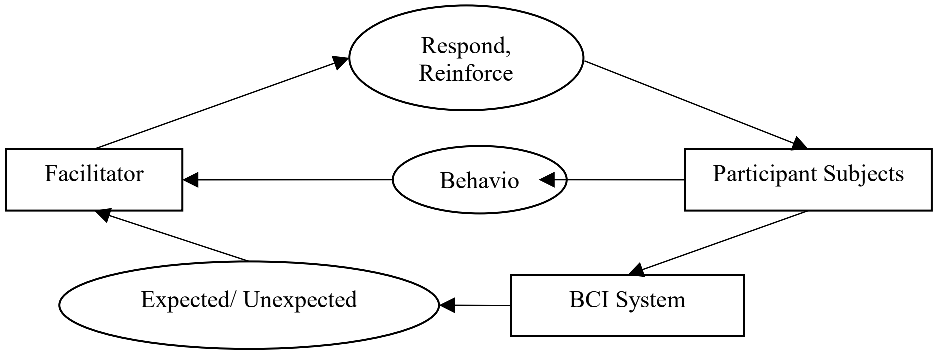

Fig. 4. Improved communication system using BCI system.

Results

In this study we have used a machine learning classification approach to map a set of inputs to a discrete set of classes. The inputs are the EEG signals from 14 channels and the two outputs classes are the expected and unexpected states/situations. We aim to predict at an instance during interaction if the subject is observing expected or unexpected event by using a training data set consisting of a set of EEG signals and the corresponding labels (e.g. expected and unexpected). We have used the classification method proposed in Lage-Castellanose et al. study (Lage-Castellanos et al.; Blankertz et al.). Due to The highly noisy signal from EEG, a low pass filter was applied on input signals prior to segmenting the EEG signals to 300 ms windows to extract the features from the raw EEG data using fast fourier transformation (Polat and Güneş). By using those features, we trained support vector machines classifier for two output classes consisting “expected” and “unexpected” (Krusienski et al.; Wang, Guan and Zhang).

For training and validating of the model, we created a training set consisting of several input signal-label pairs. To create this set, we considered only those activities that the behavioral correlates of unexpected situations are very visible in them (for example the snack bag task discussed earlier) to distinguish two outputs with confidence. We created a training set of size 80; 55 expected and 25 unexpected events and used cross validation to test the algorithm. Our model was able to predict the mental state in 69 % of the cases, which is much higher than the chance level cases.

Table 1. The reported benefit of the new communication framework.

	Session 1	*Session 2*	*Session 3*
Facilitator 1	1.5	1.7	2
Facilitator 2	1.7	2.1	2.2

In the next step, we performed the evaluation of the algorithm in a real-time communication setting as shown in figure 4, where a facilitator observes both the behavior and the models estimate of the subject's mental state while engaging in an interaction. Two facilitators worked three sessions of 20 minutes with the subject in this setting. We asked the facilitators to report on a scale how much they thought the new setting helped their interaction with the participant (1:no help to 3: significant help). Table 1 shows that employing the BCI system provided more information about the mental state of the subject, to the facilitators and they found that knowledge helpful.

Discussion and Conclusion

The goal of this study was to explore BCI techniques to facilitate communication between individuals with ID and others, as it would increase the independent living of these individuals. Vos et al. proposed a method to interpret the well-beings and emotional state of persons with ID using some physiological measures such as heart rate and breathing time. The person with ID is not aware or conscious that their well-being or mental state is being read using another device but the bottom line is that they are becoming more independent of their caregivers/parents as the only people that can read their inner states. It would also give them an opportunity to communicate with more people whom they do not know very well so they can generalize their communication skills.

In this paper we have discussed that Brain Computer Interface (BCI) can be a great area to explore for designing new communication systems for people with ID. Subject of our study was an individual with very limited capabilities in expressing her needs and feelings intentionally. Given the prevalence of idiosyncrasy in this population, we have discussed the need for communication devices that can help to estimate the intentions/mental state without using the behavioral correlates. An EEG based BCI model was presented for predicting the instances that the participant observes or experiences surprising or unexpected instances. Our model performed well when predicting these instances that supports our claim on how it can be used in communication intervention settings to inform the facilitator the subject's mental state. Future works will try to improve the performance of the model by exploring different classification and feature extractions algorithms as new algorithms are being proposed. Also considering other common and informative mental states would be a very interesting direction for future works.

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Journal on Technology and Persons with Disabilities

ISSN 2330-4216

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