Introduction of BCI spellers based on P300 and Comparison between different BCI speller models

Tianyu Zhang, Wenqi Luo, Shulun Dong

Introduction

A brain-computer interface is an emerging communication system consisting of both hardware and software aimed to connect human brain and external devices. It brings great convenience to severely disabled people like ALS patients with degeneration of motor neurons. A long period of ALS will introduce amyotrophic lateral sclerosis (ALS) causing a locked-in syndrome (LIS). In a more general explanation, patients suffering from such disease could only perceive while could not to interact with the world. A BCI-driven spellerI system offers locked-in people a plausible way to interact with surroundings without the involvement of peripheral nerves and muscles. It recognizes some patterns of brain signals and interprets it into command by 4 core steps: signal acquisition, preprocessing or signal enhancement, feature extraction, classification and control interface. [1]. Compared to different algorithms applied to each stage of BCI, our group shows more interests in practical real-life applications, typically BCI spellers. BCI speller, especially P300-based BCIs, have been proven sufficiently suitable for ALS patients in the early and middle stages of the disease. [2]

To give further introduction on BCI spellers based on P300, we need to introduce P300 first from the following two aspects: what it is and what it does in out brain. P300 wave is an event related potential (ERP) component elicited in the process of decision making. Event related potential is the measured brain response that is the direct result of a specific sensory, cognitive, or motor event. [3] ERPs are usually measured by means of EEG or MEG. One example of ERP besides P300 is N170. N170 is a another typical component of ERP that reflects the neural processing of recognizing faces. Unlike P300, it evokes negative potentials every time it is elicited. When potentials evoked by images of faces are compared to those elicited by other visual stimuli, the potential from images of faces shows increased negativity around 130ms - 200ms after the stimulus presentation. P300 wave is also an ERP component, considered to be an endogenous potential, since occurrence of P300 doesn't associate with the physical attributes of a stimulus, but only with one's reaction to it. For instance, consider the stimulus to be a beam of light. It doesn't matter how strong the light is,what P300 only considers is a person's reaction to that beam of light. In other words, P300 reflects processes involved in stimulus evaluation or categorization.

One important experiment that involved P300 is the oddball paradigm. Oddball paradigm is an experimental design used within psychology and cognitive researches. Presentations of sequences of repetitive stimuli are interrupted by another stimulus. Then the reaction of the participant to this 'oddball' stimulus is recorded. Usually, the oddball paradigm is divided into a visual oddball paradigm and auditory oddball paradigm, using either visual stimuli or auditory stimuli. In ERP researches, it has been found that an ERP across parietal-central area of the skull that usually occurs around 300 ms after the stimulus presentation is larger after the 'oddball' stimulus. P300 wave will only occur if the subject is actively engaged in the task of detecting targets.[4]

When we record P300 by EEG, it surfaces as a positive deflection in voltage with delay between stimulus and response at roughly 250 to 500 ms. [5] As mentioned in the introduction of oddball paradigm, the signal is typically measured strongly by electrodes covering parietal and central lobe, which in the 10-20 system are represented by C2,C3,C4,P2,P3 and P4. P300 is also consisted of two subcomponents, usually named P3a and P3b. P3a has positive amplitude that displays maximum amplitude has a peak latency in the range of 250-280 ms. While P3b usually peeks at around 300 ms and differs upon the task in the range of 250-500 ms.

2. Farwell-Donchin paradigm

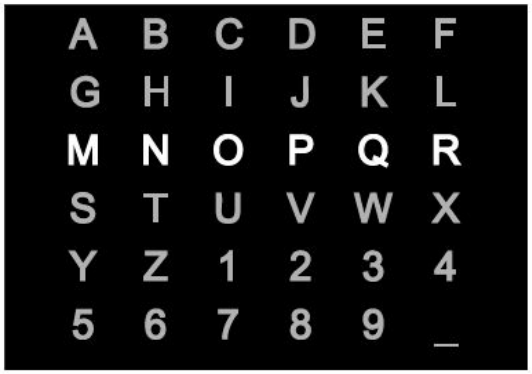
The first model of BCI speller we are going to introduce is Farwell-Donchin paradigm, probably one of the most known BCI speller model. [6] Such a system or paradigm can be used as a communication aid by individuals who cannot use motor system for communication (ALS patients). The panel consists a 26 letters of alphabet, also with several other symbols and commands (such as space, backspace), and it is displayed on a computer screen which works as the keyboard or the 'word input' device. To type using this paradigm, participants need to focus attention successively on the characters the participant wishes to communicate. For instance, if I would like to type word 'Apple', I would need to focus on the letter 'A' successively until the system successfully typed the letter 'A' and then I can start typing the next letter 'p'. The computer detects the character participant thinks online (real time). The system would repeatedly flash rows and columns of the 6x6 matrix. Remember the oddball paradigm that we have introduced in the introduction part. If we keep our focus on the letter 'A', then we put ourselves in a oddball paradigm where letter 'A' is the target stimuli. Whenever the row or the column that letter 'A' is flashed, it would elicit P300. By detecting those P300 signals, the system then predicts which row and which column the character participant thinks is in. The method this experiment uses to keep participants focus on the letter is to ask participants count the number of times the letter has been flashed.

In this experiment, we need to assume that only the rows and columns containing the chosen letter will elicit P300 signals. However, detection of P300 clearly requires signal averaging, which depends on the presentation of many stimulus. The effectiveness of this procedure as a communication channel depends on the degree to which the message can be communicated with a small number of trials using an efficient, cost-effective, online detector of P300 signal. Therefore, it would be important to determine how many trials it needed for the system to recognize the character at different levels of accuracy. The model has selected the length of time for each flash and the latency between flashes to optimize the accuracy of prediction of each character.

Results for this paradigm is really good considering the paradigm is first proposed or written in article by 1988. From the results of 4 different participants in the experiment, the mean time required to achieve 80% accuracy of determination of 1 stimulus out of 36 was 20.9 second. For 95% accuracy, the mean time required was 26.0 second. (Different accuracy here would affect number of trials the system has to run to make sure which character the participants are thinking) The study perfectly answers the question that if P300 can be employed as a switch by means of which the subject can toggle a choice. From the result and methods the study get, the answer is clearly a yes and it’s surprising that people can type a letter at about 25 seconds just by thinking it. However, the utility of a communication channel based on the P300 depends on the signal-to-noise ratio. The detection and measurement of P300 requires signal averaging. Therefore, it was conceivable that while P300 can in principle serve as a switch, its reliability under usual signal-to-noise conditions would have been insufficient for actual use.

The model or paradigm was well built and despite that it needs 26 seconds to type a single letter. Even if there were studies that showed P300 can be used in decision making, applying it to a speller is on another level. In the following parts, we are going to introduce other models on BCi speller which increase the accuracy and typing speed of this one by optimizing algorithms and distribution of the communication panel. (where participants can focus on the letter)

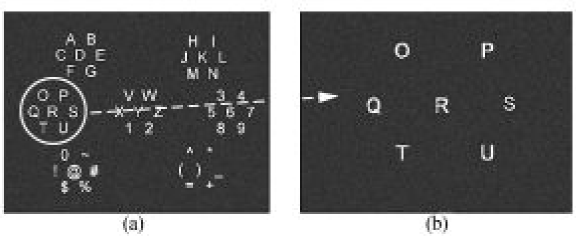
(Original P300 speller)



(Adapted from Farwell-Donchin paradigm)

3. Region-based P300 speller

This speller is based on the P300 speller designed by Farwell-Donchin in 1988 (Farwell-Donchin paradigm).[7] In Farwell-Donchin paradigm, a 6x6 matrix of letters and numbers is displayed and the participant is asked to focus on a target character while rows and columns of characters flash. In this article, it is shown that there is a human perceptual error in Farwell-Donchin paradigm and a new region-based paradigm is introduced to eliminate such error. Using results from the new experiment, it's shown that region-based paradigm has several advantages compared to the Farwell-Donchin paradigm and achieves better accuracy.



(Proposed region-based paradigm)

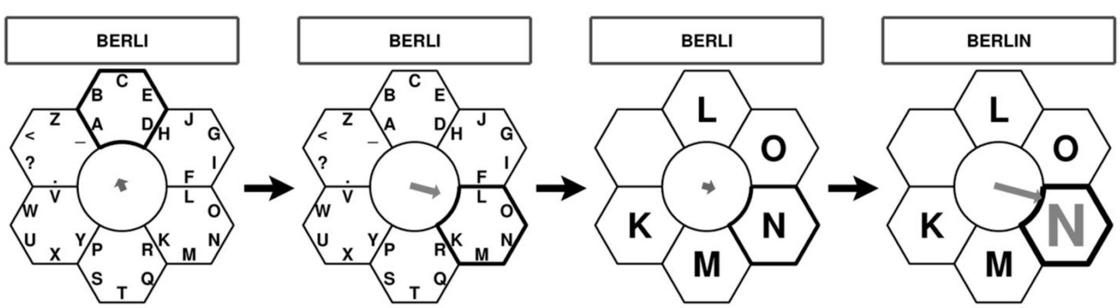
The idea of new paradigm (region-based) is to have several regions flashed instead of just flashing rows and columns. The choice of character is done on two levels. (as shown in the picture) In the first level, the characters are placed into 7 clusters in different parts of the screen. Similarly, the participant is asked to focus on a specific character within a cluster while a cluster of characters flashes randomly. Then, using detection of P300, the detected group are distributed into another 7 regions. In second level, similarly to what was done in the first level, different regions are flashed while the participant concentrates on one of the regions. Using P300, the system returns the character. From the new system or paradigm, we can see number of characters or commands that can be reached increases from 36 to 49.

The article shows that almost half the error cases during character detection occured when the row/column adjacent to the target row/column was detected. The result can be attributed to a shift in the subject’s attention, where the subject is unable to focus precisely on the target letter and flashing adjacent rows and columns would also elicit P300 signals.

The only way to show that the error decreased was to look at the overall results comparing Farwell-Donchin paradigm and region-based paradigm, which from the result we can see the number of errors occured in region-based paradigm is half of number of errors occured in Farwell-Donchin paradigm.

4. The Hex-o-Spell

Traditional spellers have many limitations including limited peripheral acuity and difficulties for users to identify targets. They have low degrees of freedom in communication. The Hex-o-Spell, working as a kind of mental typewriter by detecting the spatio-spectral changes of the EEG, offers an optimal solution to the problems mentioned above. It combines a central circle with six hexagon, each of them consisting five letters and one blank space representing backstep. Users of this speller can use motor imagery to choose their desired symbols. The central arrow points to one of hexagons, which represent a quintet of alphanumerical symbols. Then the chosen hexagon will be expanded to the another six hexagons and users can continue repeating the same process. The next character can be inferred given the previous symbol. Typing errors in the process can be corrected by using backspace of the mental typewriter. Control is based on the feedback from the system, which is a continuing- updating-state process. Generally, based on the experiment mentioned in this article, the average number of characters typed in a minute by each participant is between 2.3 and 5 characters for one subject and between 4.6 and 7.6 characters for the other.[8] This kind of speller can map a large vocabulary to the display symbols in the hexagons.



(Hex-o spell interface[8])

5. Comparison between different models

The region-based paradigm is developed based on Farwell-Donchin paradigm. In addition to higher accuracy of region-based paradigm, it had several other advantages compared to Farwell-Donchin. The number of characters that could be typed in the system is increased from 36 characters to 49 characters, providing more flexibility to participants when they are spelling a word. The oddball probability, by calculation of the article, which was ⅙ when flashing a row/column in Farwell-Donchin, was reduced to 1/7 in the new paradigm. It is also shown that this lower probability results in a higher amplitude in P300. [9]. Therefore, the P300 amplitude is larger and detection of P300 signals is easier in the new paradigm, which results that a smaller number of flashings is required for a successful P300 detection, which would lead to a faster P300 speller.

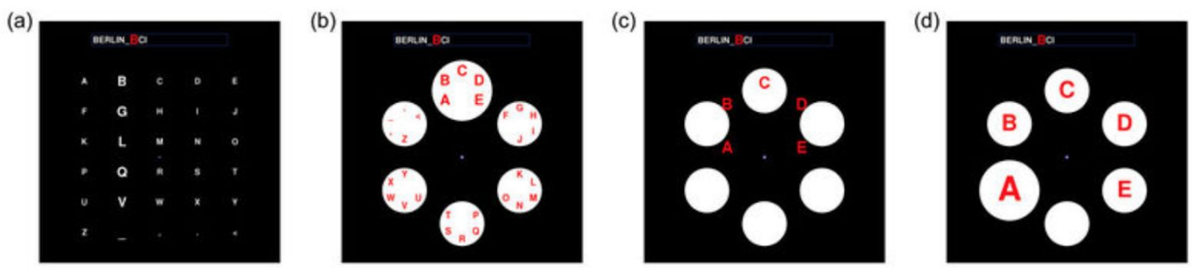
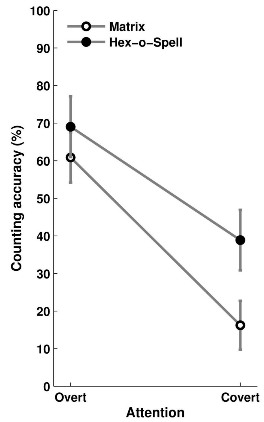


Figure 2

Screenshots of the two visual spellers. The current word was indicated in the box above the speller, and the current symbol was highlighted, (a) Symbol matrix. The column containing the target symbol **"B"** is intensified. (b) Hex-o-Spell, group level. The group containing the target symbol **"B"** (group "ABCDE") is intensified, (c) Transition phase. In a short animation, the symbols of the selected group are expanded onto the other discs. (d) Symbol level. The nontarget disc with the symbol "A" is intensified. The empty disc at the bottom is intended as a backdoor for returning to the group level in case the wrong group was selected.

Generally speaking, communication with BCIs share lots of common uneliminatable issues including noisy inputs and variability of signals. However, compared to Farwell-Donchin paradigm, the Hex-o-spell outperforms the matrix speller. It shows more excellent ability of stabilizing dynamics in noisy inputs and reducing the variability in the recorded data. The process mainly depends on several large symbols displayed in hexagons, which effectively avoid the problems of crowding and declining spatial acuity. Meanwhile, the Hex-o-Spell demonstrates higher accuracy for both overt attention and for convert attention.[10]



(Comparison of the counting accuracy)

From another perspective to summarize the difference, the Hex-o-Spell prevents interference by intensification of the target while during the process of the the Matrix speller, the targets will be repeatedly intensified successively.

6.Discussion

From what we have learned in class, we discovered and are amazed by the power of BCI, especially how different BCI projects or algorithms could be applied to our real life scenarios. From the auto-braking system to the mechanic hand controlled by brain, every BCI project has a way to help different people, either healthy or ALS patients. BCI speller can help people who lose their ability to move their fingers to type like normal people, just a little slower.

Starting with the first generation of BCI speller, even back in 1988, the Farwell-Donchin paradigm is able to let people type a character with 95% of accuracy in 26 seconds. Several different upgrades were made after the first generation. One model is the region-based paradigm, which increases the number of characters that can be typed and increased the typing efficiency. There are other BCI speller models which use mechanics other than P300, such as motor imagery, SSVEP and other models. Nowadays, the typing speed using BCI speller can reach to more than 5 characters per minute. With the help of dictionaries and building connection between characters, people who are not able to move their fingers can type several words in a minute.

One interesting extension to these studies would be to apply such technologies and algorithms to Chinese, helping people who can’t move to type in Chinese. We know that there are more than thousands of Chinese characters and it would be impossible to do it in the same way like existing BCI speller does. We think that if we apply pinyin to express Chinese characters (Pinyin is one way of expressing Chinese characters. However, several different characters can have same pinyin in Chinese). First we use similar methods in existing BCI spellers to let participants specify the pinyin of the character they are thinking about. Then we pop up a new level with all Chinese characters that have this pinyin. Participants then use similar methods to choose between these characters to specify the particular character. Also with the help of dictionaries and certain association between different characters. I believe one can type several Chinese characters in a minute.

BCI spellers are still developing over time. Within 30 years, the system has multiplied the typing speed several times compared to the first generation, Farwell-Donchin paradigm. There is still a long way to go. By integrating new algorithms and new methods other than P300, We believe the efficiency of BCI speller can be almost as good as the typing by a healthy human.

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