Usability Evaluation of Brain Computer Interface for Deployment to the General Public.

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ABSTRACT:

The prospect of using our minds to directly communicate with a device is an attractive and fascinating idea. Many paradigms have been developed to investigate this, with the ultimate goal of creating a brain computer interface (BCI) system which is functional for all users regardless of individual variation. Several of these paradigms including steady state visual evoked potential (SSVEP), visual evoked potential (VEP) and event related potential (ERP)as well as traditionally used sensing methods such as electroencephalography (EEG), magnetoencephalography (MEG) and electrocorticography (ECoG), are explained and analysed to determine their merit. Specific problems with each procedure are highlighted and further discussion regarding common issues in the field, such as extensive training times and usability, are debated to determine the present state of BCI. Evaluations resulted in the conclusion that BCI is not yet ready for public use as its many unsolved problems outweigh its possible advantages.

Author Keywords

BCI; SSVEP; VEP; EEG; Usability; Universality; ECoG; ERP.

INTRODUCTION:

A brain computer interface (BCI) is a conduit which allows direct communication between an individual's mind and an electronic device. Initially developed to assist those with physical or communicative disabilities such as amyotrophic lateral sclerosis (ALS) and cerebral palsy [1], it is now being applied to a more general audience. The basic concept of BCI is to capture the electrical impulses of the human brain under specific functioning and classify those impulses so that output commands to a device can be established. Figure 1 shows the simplified model and fundamental principle of most BCI systems. Over years of research and development this basic concept has evolved and there are now several popular BCI paradigms in use.

Regardless of the BCI paradigm however, there has always been the central goal of developing a BCI system which would not discriminate against users and allow universality of use. As of yet, this has not been achieved and BCI is mostly still in its experimental stages as it suffers from numerous difficulties. Because of this, it is estimated that roughly 20% of the population cannot operate current BCI systems effectively, making them "BCI illiterate" [3]. To progress towards its goal of universality of use, BCI must address the problems which hinder its development as an interaction medium.

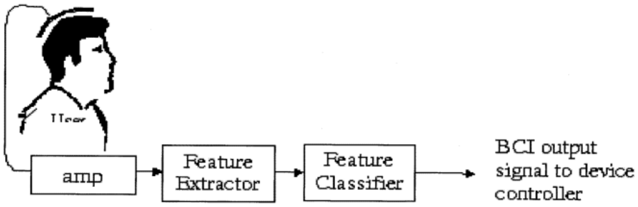

Figure 1: Basic model of a BCI system [2]

The following details an analysis and discussion on paradigm specific problems with BCI and also more general complications experienced throughout the field. An explanation and assessment of common paradigm associated problems is argued in section one and is followed by discussion on more general problems in section two. Throughout these sections, the universality and usability of BCI will be evaluated with regards to the practicality of deploying current BCI systems for everyday use.

SECTION 1: APPROACHES TO BCI

On a broad scope, the foundation of all BCI paradigms can be classified into two main categories. These are invasive and non-invasive BCI. As it implies, an invasive approach to BCI usually involves surgery or implants and is not currently popular among users. Conversely, non-invasive BCI commonly uses an electrode montage and electroencephalography (EEG) or magnetoencephalography (MEG) to detect the electrical impulses of the brain. The former detects the electrical current passing through a neuron when it fires and the latter, the magnetic field generated by the current. Figure 2 shows the possible placement sites of electrodes for EEG sensing. The following paradigms can use either an invasive or non-invasive detection technique but generally, non-invasive procedures are preferred. For any of these paradigms to be effective however, they must permit a high level of usability so that BCI is a viable choice for interacting with electrical devices. Each paradigm has its own disadvantages which often outweigh the possible benefit the system may provide. Two BCI methodologies, (SSVEP and ERP), are discussed and an insight into an invasive detection scheme (ECoG) is given.

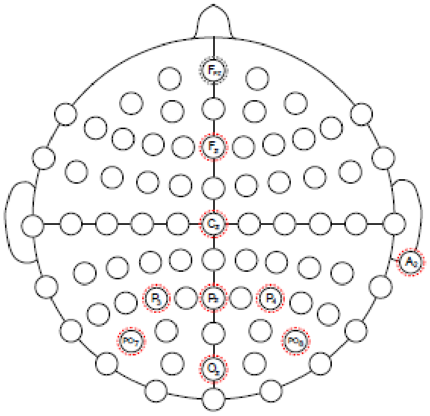

Figure 2: Possible electrode placement sites for EEG [5].

SSVEP & VEP:

One of the most common forms of BCI is steady state visual evoked potential (SSVEP). This is in the same branch as visual evoked potential (VEP) but the distinction between the two should be noted. Current cataloguing states that if the frequency of the stimulus is higher than 6Hz, then the form of EEG monitoring is that of SSVEP. Where by the brain is in a continued state of excitability. A frequency of lower than 2Hz will give rise to VEP [1]. This paradigm is based on the fact that the human brain will display electrical activity when the eyes are stimulated with a continuous visual cue. Usually this is in the form of a flashing LED or specific parts of a screen flashing at different frequencies. The electrical impulses produced by the brain will be of the same frequency or a multiple of the frequency of the cue. In this way a target area of the screen can be selected or a specific action mapped to a particular frequency [4]. Figure 3 shows the summary of the process.

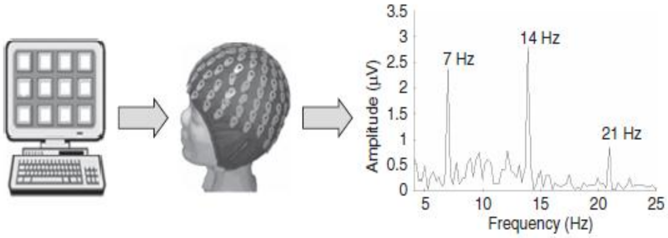

Figure 3: General process of SSVEP [4]. Visual stimulation at known frequencies are sensed and used to infer user intent.

VEP and SSVEP have been in development since 1970 and are still at the forefront of BCI systems. The advantages of this paradigm include easy system configuration, little user training, and a high information transfer rate (ITR) [4]. Of course these traits are system specific and can vary slightly between one implementation of the paradigm to the next. It can be applied as both an invasive (through the use of ECoG) and non-invasive (through EEG) system and produces promising results for both. Studies show that SSVEP alone can give a high accuracy rate of up to 76.9% [3]. All of these are desirable traits in a BCI system and improve general usability.

The most notable disadvantage with SSVEP and VEP is that these paradigms are closely coupled with visual perception. Any difficulties experienced in receiving the visual stimuli will adversely affect the BCI system. With this in mind, it is concerning to find that some users discover the flashing LED or screen used to provide the visual stimulus, distracting. A small portion of these users find it so discomforting that they are not able to operate the system at all [5]. Because of this, a certain percentage of the population may not be able to successfully use a VEP or SSVEP based system hindering the universality of the paradigm. The frequency used for stimulating the user is also of major concern as a correct frequency and threshold must be found else feature extraction becomes difficult. Different frequencies are usually trialled on an individual to obtain the subject specific optimal parameters [4].

ERP:

Whereas VEP and SSVEP are consistent with a regularly occurring visual stimulus, an event related potential (ERP) can be triggered by merely perceiving a stimulus. This could be anything from hearing a particular sound to seeing a static object. Even more impressively, ERP can also be activated by simply thinking of a particular activity [11]. Consider imagining an action such as extending and flexing one’s leg. Doing this causes certain areas of the brain to show more activity than others. Not surprisingly, for the example given, the motor cortex is highly stimulated while areas such as the occipital lobe show less activity. These impulses are regarded as ERP and can be further classified as being event-related synchronisation (ERS) or event-related desynchronisation (ERD). The distinction being that the former is associated with an amplitude enhancement in the frequency band of interest and the latter associated with decreased amplitude in the frequency band [11]. By recording the EEG data associated with thinking about an action, future brain impulses which are similar can be categorised and linked to that action.

ERP can be thought of as a more abstract interaction paradigm compared to SSVEP. A clear advantage is that ERP does not necessarily need a visual cue. Even when it does, the cue does not need to be constantly given for ERP whereas it usually does for SSVEP. It allows the user more freedom when interacting with the system as they can simply visualise an event. This is a huge advantage as visualisation is not constrained via real world limitations enabling the possibility of more complex commands to be issued and mapped [8]. Similar to SSVEP, ERP can be both invasive and non-invasive making it an attractive paradigm.

The major disadvantage of ERP is that it may vary more between users as compared to SSVEP. Individuals associate and relate images and sounds differently from one another as biological variation shapes the neurology of an individual’s brain uniquely. Therefore a certain cue may trigger slightly different electrical impulses between different users. This shows contrast to paradigms such as SSVEP as it is based on a more standard physiological responses to a stimulus which does not differ as greatly between individuals [4].

ECoG:

The previous two paradigms are more commonly non-invasive forms of BCI relying on EEG to record readings. However invasive forms have also been experimented with and can be applied to SSVEP and ERP. Of particular interest is the use of electrocorticographic signals (ECoG) as an interface rather than EEG. In this sensing method, an electrode array is placed directly onto the surface of the brain to allow monitoring of brain impulses. Similar to basic underlying concept used for EEG detection; brain impulses are recorded and associated with a particular stimulus. Eventually as more data is collected and the system adapts, the use of ECoG allows a direct command link to a device. These types of experiments have been primarily completed on primates and tests show that ECoG is a more receptive and accurate sensing procedure for feature extraction as compared to EEG. Detection rates can reach higher levels than with non-invasive detection and wireless recording of neural activity via ECoG can give an accuracy rate of roughly 70% [6].

An invasive BCI method through the use of ECoG instead of EEG typically allows for a higher ITR and a greater degree of accuracy. Signals from the brain are much stronger without dampening from the scalp and there is less interference from the external environment. Localisation of the signal is also more accurate as the signal origin is now millimetres away from the electrode sensor as compared to centimetres away in EEG based systems. Electrical noise from sources such as eye movement and muscle activity are also lessened permitting a clearer signal to be recorded [7]. All these factors combine to give a stronger and better signal through the use of ECoG which is desirable for the correct functioning of a BCI system.

The most concerning disadvantage of this paradigm is the most obvious. For the use of ECoG, the user must have direct brain-electrode contacts. This is usually achieved through a craniotomy which is the process of removing a section of the skull to gain access to the brain. Most tests and experiments with this paradigm have been completed using primates or lab rats as tests subjects with very few attempts having been completed on live humans [6]. The major reason behind this is the fact that an invasive procedure such as ECoG has yet to show a large enough improvement over non-invasive techniques used for BCI to compensate for its need for surgery. It does not guarantee a 100% signal detection rate and so is not heavily considered for general use. Even those who are disabled and have more to gain through BCI usually refuse such procedures and instead endure the comparatively extended training times associated with systems which rely on lesser detection methods.

SECTION 2: GENERAL DIFFICULTIES WITH BCI

The issues so far discussed are system and paradigm specific. Although they do impact on the usability of BCI, more general problems which effect BCI universally prevent it from being practically deployed for use by the wider population. These problems include; false recognition, extensive training times, hardware and software limitations (such as signal acquisition and classification) and conventional concerns with human computer interactions (HCI). The HCI based difficulties can be further sub-divided into the following categories: efficiency of use, effectiveness, memorability, learnability of the program, safety and user satisfaction [8]. The following section will discuss these problems and how they are preventing BCI from becoming a practical interaction medium.

FALSE RECOGNITION:

To improve the universality of BCI, much research has been focused on allowing all users to initiate commands with their minds. The main drive has always been to capture this activation regardless of biological variation between individuals. Many approaches such as a hybrid recognition system have been tested to improve this aspect of BCI [3]. However, it is equally just as important to ensure that no false positives are registered as this would just as severely affect usability. It has been found that this is best achieved by recording a user’s reaction to several mental tasks. These tasks can range from simple mental multiplication to visualisation of rotating an object. The most discriminatory mental task can then be found for the particular user and used for future activations. Studies have shown that completing this process can yield a 0% false positive reading while still maintaining a high true positive reading of greater than 70% [9]. Tuning a system towards a user in this way would allow it to function effectively and improve user experience and usability. However, a balance should be struck between a BCI system which is too sensitive to user inputs and one that is not sensitive enough. This problem of incorrect or absent recognition limits the use of BCI interfaces and hinders overall usability. It is one of the main bottlenecks which prevents BCI technology from leaving the laboratories and has yet to be solved in entirety.

TRAINGING TIMES:

The time it takes to adapt to a new system is also of concern for BCI. Users will be less willing to familiarise themselves with a new system if the training period is too long or complex. Often, the training associated with BCI is described as tedious and repetitive as users are forced to stare at a screen or visualise a motion for an extended period of time [8]. Some systems even only show results after weeks of trial and calibration [11]. This is not the case for most BCI systems but is also not too uncommon. The extended training times linked to BCI is not surprising as BCI was initially developed to assist physically disabled individuals with communication. For these individuals, an extensive training time is of less concern as the benefits for them are much greater when compared to physically abled users. To move BCI to the general populace, the training and calibration stage of BCI must be shortened or made intuitive. Attempts at this have been made and have targeted the gamer sub-set of the population as they are generally more accepting of a new interaction paradigm if it will give them a more immersive and rewarding experience [10]. The eager acceptance of new technology in the gaming community is evident in their adoption of the Nintendo Wiimote and Microsoft Kinect. Figure 4 shows an experimental BCI game named “Bacteria Hunt” which requires little to no training time and has been developed to test the usability of BCI systems on gamers. At its current stage however, BCI still requires system specific training times which are often not short enough to be acceptable to the public or even to sub sets of the population, such as gamers, who are more willing to experiment with new interfaces.

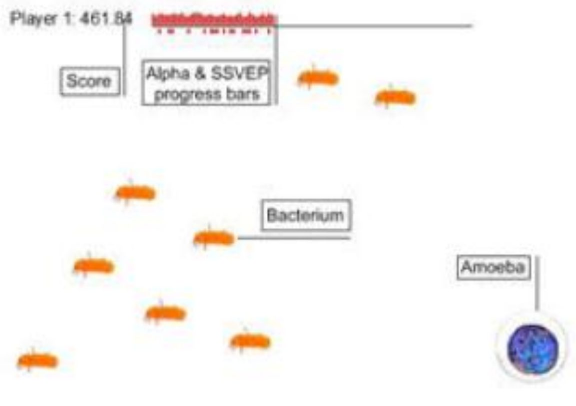

Figure 4: Bacteria Hunt. A game where users control the amoeba and mentally move it to consume bacterium [10].

TECHNOLOGICAL SHORTFALLS:

There are also limitations with the hardware and software aspects of BCI. For hardware, the precise detection of the brain’s electrical impulses is what holds BCI back. BCI based systems are subject to the particular sensory equipment used for monitoring. The usual electrode montage used for EEG and diagnostic equipment used for MEG has a large impact on the quality and usability of the BCI system. If detection and signal acquisition is not adequate then the entire system will fail. Of the two broad forms of signal acquisition (invasive and non-invasive), it is apparent that a non-invasive form is more preferable to an invasive form for general deployment. This rules out ECoG and leaves EEG and MEG as possible choices. EEG detection seems to be the more viable option for BCI commercialisation as compared to MEG which necessitates the use of large equipment (such as the superconducting quantum interface device (SQUID)) not readily available to the public. However, EEG still requires an electrode cap to be worn or electrodes to be placed directly onto a shaven scalp [5]. This is often uncomfortable and unsightly and shaving a user’s head is usually not an option for casual use of a BCI system. Because the ability for detection is restrained by the power of the hardware presently available, BCI distribution must be accompanied by the use of cumbersome headgear at best. This is not an appealing feature of BCI and is another reason which inhibits its release to the public.

On the software side of the problem is the need for a reliable and universal detection and categorisation algorithm. Many studies have attempted to create an optimal or perfect algorithm to improve these areas [2, 11] but find problems in customising an algorithm which suit all individuals. This is extremely difficult as an individual’s neurological mapping is unique and only rough averages can be taken into account when creating an algorithm. There are however algorithms which will tailor themselves to a specific user to improve usability of a BCI system [5]. Sadly these algorithms usually require the user to practice on the system for an extended period of time before they become fully effective. This only adds to the previously discussed problem of extensive user training time and impacts negatively on overall usability. Therefore, until better software can be developed to recognise and classify a user’s brain signals in a fast and reliable manner, BCI universality will not reach a stage where it is suitable for anything other than experimental or occasional use.

HCI BASED ISSUES:

Conventional trepidations with regular HCI also apply to BCI. There is a need for BCI systems to be appealing while still maintaining functionality for it to be adopted as an interaction paradigm. Efficiency and effectiveness of use is closely linked to the particular design of a system and is presently measured through ITR or the detection accuracy. Most non-invasive BCI techniques however only yield an ITR of 5-25bits/min at best [1]. Technology has not yet reached a point where BCI interaction can even match the efficiency of other interaction paradigms such as a keyboard and mouse, let alone come close to surpassing these paradigms. Learnability and memorability are also lacking for BCI. In part, this is due to the fact that a particular mapping or recognition scheme may be effective on one individual, yet result in sub-optimal recognition in another. This will adversely affect learnability and memorability as a particular system or command could be more difficult to master for one user compared to another. Safety with respects to HCI is more concerned with error handling rather than the physical safety of the system. Usually this is measured as the noise, (generated via external forces or by muscle movement) [11], to signal ratio and insures the system is functioning correctly regardless of the unwanted signals it is sensing. This aspect of HCI for BCI is progressing well as detection accuracy can reach up to 80% and continues to reach higher levels with newly developed systems [3]. However, until it reaches a level nearing 100%, it will not be ready for commercialisation to the public. Finally, satisfaction will depend on a combination of the factors already described. A responsive, efficient, functional system able to handle errors well will decrease user frustration and improve the BCI experience. This will ensure that this last criterion of satisfaction is achieved for the user.

Currently, not much research has been completed to incorporate HCI usability tactics into BCI but this must be addressed for BCI to move from a purely experimental interface system into one which can be used by the populace. Commercialisation for different user markets will ultimately determine how these aspects of HCI are handled as each target group will have their own wants and needs. Once the underlying technology for sensing and categorising is at a sufficiently effective stage, standard principles for HCI can be applied to allow universality of BCI.

CONCLUSION & SUMMARY:

A BCI offers a new and exciting interaction medium with vast possibilities only constrained via the boundaries of own minds. At its existing state however, it can be concluded that BCI is not yet ready for deployment to the general public for everyday use. The state of usability and universality has not reached a level higher enough for it to be used as an effective communication pathway. The various paradigms (SSVEP, VEP, ERP) and forms of sensing (EEG, MEG, ECoG) discussed have their distinctive limitations and disadvantages which make them unsuitable for an all-purpose distribution. Even for specific groups of the population such as gamers, where BCI is a more alluring prospect and paradigm specific issues are better tolerated, it is still hindered by collective problems affecting the entire field. These general problems with impulse sensing, impulse categorisation and extensive training times impact negatively on the universality of BCI and will need to be solved before BCI can move from its testing stages to a place in the home environment. Once initial improvements have been made to the foundations of the interface, more specific HCI design principle can be applied to enhance system use and advance usability.

FUTURE WORK:

Future research should look at alternative applications of BCI to further it from simply being a complementary input device to developing it as a standalone platform for interaction and communication. Integration of more advanced sensing equipment and novel feature cataloguing schemes should be investigated to advance the field in a desirable direction. Also, new possible target audiences should be investigated as BCI offers a unique way to interact with devices and should not be constrained to only assisting those with physical disabilities. Its application to other fields could revolutionise our relationship with computing and has the potential to greatly improve human-computer efficiency.

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