



## Real Time Systembrain–Computer Interface (BCI)

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**Abstract:** *A brain computer interface (BCI) is a system that aims to create a direct communication channel between the brain & a computer, with the purpose of transmitting messages & commands. Brain–computer interface is a communication and control channel that does not depend on the brain’s normal output pathways of peripheral nerves and muscles. The Current BCI’s record electrophysiological signals using non-invasive or invasive methods. Non invasive BCI’s use scalp-recorded EEG rhythms or evoked potentials, while invasive BCI’s use single-unit activity recorded within cortex or EEG recorded subdurally. Stroke and traumatic brain injury (TBI) cause long-term, unilateral loss of motor control due to brain damage on the opposing (contralateral) side of the body.*

**Keywords:** *BCI, TBI, EEG, MMI, UCLA, DARPA, BMI*

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### I. INTRODUCTION

A brain–computer interface (BCI), often called a mind-machine interface (MMI), or sometimes called a direct neural interface or a brain–machine interface (BMI), is a direct communication pathway between the brain and an external device. The history of brain–computer interfaces (BCIs) starts with Hans Berger's discovery of the electrical activity of the human brain and the development of electroencephalography (EEG). In 1924 Berger was the first to record human brain activity by means of EEG. By analyzing EEG traces. The Research on BCIs began in the 1970s at the University of California Los Angeles (UCLA) under a grant from the National Science Foundation, followed by a contract from DARPA ( Defence Advanced Research Project Agency) and Current BCI’s record electrophysiological signals using non-invasive or invasive methods.

Any natural form of communication or control requires peripheral nerves and muscles. The process begins with the user’s intent. This intent triggers a complex process in which certain brain areas are activated, and hence signals are sent via

#### 1.1 BCI

The peripheral nervous system (specifically, the motor pathways) to the corresponding muscles, which in turn perform the movement necessary for the communication or control task. The activity resulting from this process is often called motor output or efferent output. Efferent means conveying impulses from the central to the peripheral nervous system and further to an effector (muscle). Afferent, in contrast, describes communication in the other direction, from the sensory receptors to the central nervous system. For motion control, the motor (efferent) pathway is essential. The sensory (afferent) pathway is particularly important for learning motor skills and dexterous tasks, such as typing or playing a musical instrument. A BCI offers an alternative to natural communication and control. A BCI is an artificial system that bypasses the body’s normal efferent pathways, which are the neuromuscular output channels [2]. Figure 1.1 illustrates this functionality. Instead of depending on peripheral nerves and muscles, a BCI directly measures brain activity associated with the user’s intent and translates the recorded brain activity into corresponding control signals for BCI applications. This translation involves signal processing and pattern recognition, which is typically done by a computer. Since the measured activity originates directly from the brain and not from the peripheral systems or muscles, the system is called a Brain–Computer Interface.

A BCI must have four components. It must record activity directly from the brain (invasively or non-invasively). It must provide feedback to the user, and must do so in realtime. Finally, the system must rely on intentional control. That is, the user must choose to perform a mental task whenever s/he wants to accomplish a goal with the BCI. Devices that only passively detect changes in brain activity that occur without any intent, such as EEG activity associated with workload, arousal, or sleep, are not BCIs.

Although most researchers accept the term “BCI” and its definition, other terms has been used to describe this special form of human–machine interface. Here are some definitions of BCIs found in BCI literature:

Wolpaw et al.: “A direct brain-computer interface is a device that provides the brain with a new, non-muscular communication and control channel”. [2].

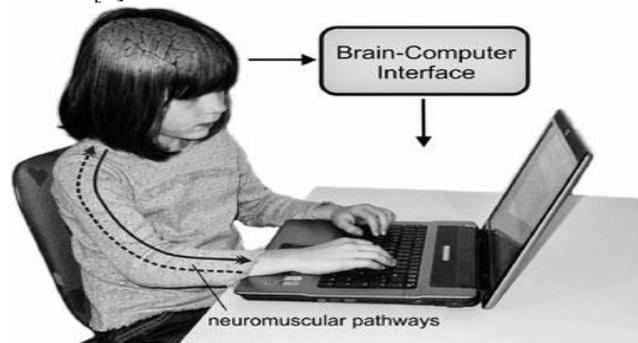


Fig. 1 A BCI bypasses the normal neuromuscular output channels

Donoghue et al.: “A major goal of a BMI (brain-machine interface) is to provide a command signal from the cortex. This command serves as a new functional output to control disabled body parts or physical devices, such as computers or robotic limbs” [3]

Levine et al.: “A direct brain interface (DBI) accepts voluntary commands directly from the human brain without requiring physical movement and can be used to operate a computer or other technologies.” [4]

Schwartz et al.: “Microelectrodes embedded chronically in the cerebral cortex hold promise for using neural activity to control devices with enough speed and agility to replace natural, animate movements in paralyzed individuals.

Known as cortical neural prostheses (CNPs), devices based on this technology are a subset of neural prosthetics, a larger category that includes stimulating, as well as recording, electrodes.” [5]

Brain–computer interfaces, brain–machine interfaces (BMIs), direct brain interfaces (DBIs), neuroprostheses – what is the difference? In fact, there is no difference between the first three terms. BCI, BMI, and DBI all describe the same system, and they are used as synonyms. “Neuroprosthesis,” however, is a more general term. Neuroprostheses (also called neural prostheses) are devices that cannot only receive output from the nervous system, but can also provide input. Moreover, they can interact with the peripheral and the central nervous systems. Figure 2 presents examples of neuroprostheses, such as cochlear implants (auditory neural prostheses) and retinal implants (visual neural prostheses). BCIs are a special category of neuroprostheses.

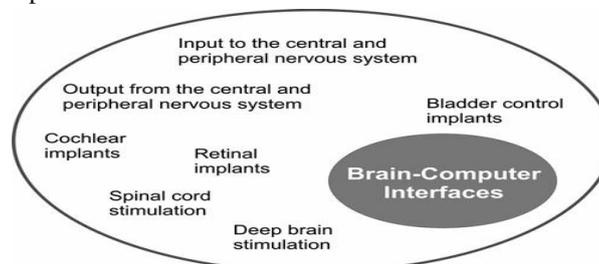


Fig. 2 Neuroprostheses can stimulate and/or measure activity from the central or peripheral nervous system. BCIs are a special subcategory that provides an artificial output channel from the central nervous system

## II. HOW DO BCIS WORK?

BCIs measure brain activity, process it, and produce control signals that reflect the user’s intent. To understand BCI operation better, one has to understand how brain activity can be measured and which brain signals can be utilized we focus on the most important recording methods and brain signals.

### 1.2.1 Measuring Brain Activity (Without Surgery)

Brain activity produces electrical and magnetic activity. Therefore, sensors can detect different types of changes in electrical or magnetic activity, at different times over different areas of the brain, to study brain activity. Most BCIs rely on electrical measures of brain activity, and rely on sensors placed over the head to measure this activity. Electroencephalography (EEG) refers to recording electrical activity from the scalp with electrodes. It is a very well established method, which has been used in clinical and research settings for decades. Figure 3 shows an EEG based BCI. EEG equipment is inexpensive, lightweight, and comparatively easy to apply. Temporal resolution, meaning the ability to detect changes within a certain time interval, is very good. However, the EEG is not without Disadvantages: The spatial (topographic) resolution and the frequency range are limited. The EEG is susceptible to so-called artifacts, which are contaminations in the EEG caused by other electrical activities. Examples are bioelectrical activities caused by eye movements or eye blinks (electrooculographic activity, EOG) and from muscles (electromyographic activity, EMG) close to the recording sites. External electromagnetic sources such as the power line can also contaminate the EEG.

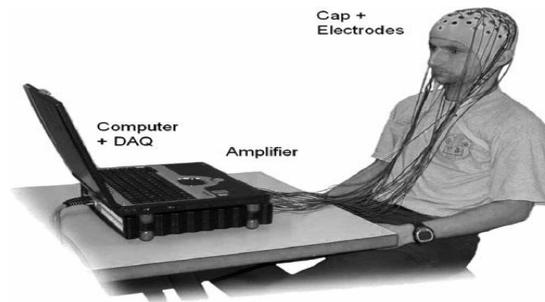


Fig. 3 A typical EEG based BCI consists of an electrode cap with electrodes, cables that transmit the signals from the electrodes to the bio-signal amplifier, a device that converts the brain signals from analog to digital format, and a computer that processes the data as well as controls and often even runs the BCI application

While most BCIs rely on sensors placed outside of the head to detect electrical activity, other types of sensors have been used as well [7]. Different oxygen levels of the blood result in different optical properties which can be measured by NIRS. All these methods have been used for brain-computer communication, but they all have drawbacks which make them impractical for most BCI applications: MEG and fMRI are very large devices and prohibitively expensive. NIRS and fMRI have poor temporal resolution, and NIRS is still in an early stage of development [7-9].

### 1.2.2 Measuring Brain Activity (With Surgery)

The techniques discussed in the last section are all non-invasive recording techniques. That is, there is no need to perform surgery or even break the skin. In contrast, invasive recording methods require surgery to implant the necessary sensors.

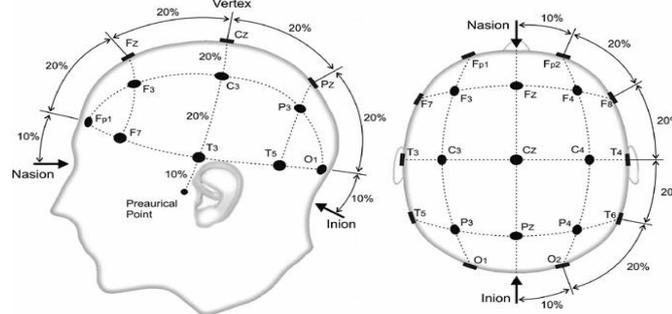


Fig. 4 The international 10-20 system: the left image shows the left side of the head, and the right side presents the view from above the head. The nasion is the intersection of the frontal and nasal bones at the bridge of the nose. The inion is a small bulge on the back of the skull just above the neck

This surgery includes opening the skull through a surgical procedure called a craniotomy and cutting the membranes that cover the brain. When the electrodes are placed on the surface of the cortex, the signal recorded from these electrodes is called the electrocorticogram (ECoG). ECoG does not damage any neurons because no electrodes penetrate the brain. The signal recorded from electrodes that penetrate brain tissue is called intracortical recording. Clearly, invasive methods have some advantages over non-invasive methods. However, these advantages come with the serious drawback of requiring surgery. Ethical, financial, and other considerations make neurosurgery impractical except for some users who need a BCI to communicate. Even then, some of these users may find that a noninvasive BCI meets their needs. It is also unclear whether both ECoG and intracortical recordings can provide safe and stable recording over years. Longterm stability may be especially problematic in the case of intracortical recordings. Electrodes implanted into the cortical tissue can cause tissue reactions that lead to deteriorating signal quality or even complete electrode failure. Research on invasive

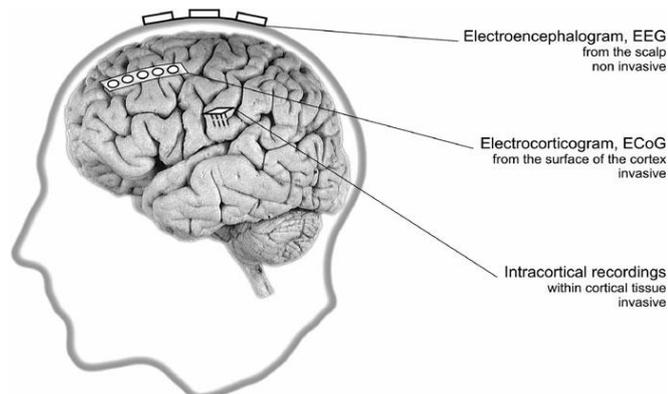


Fig. 5 Three different ways to detect the brain’s electrical activity: EEG, ECoG, and intracortical recordings

BCIs are difficult because of the cost and risk of neurosurgery. For ethical reasons, some invasive research efforts rely on patients who undergo neurosurgery for other reasons, such as treatment of epilepsy. Studies with these patients can be very informative, but it is impossible to study the effects of training and long term use because these patients typically have an ECoG system for only a few days before it is removed.

### 1.2.3 BCI Performance

The performance of a BCI can be measured in various ways [12]. A simple measure is classification performance (also termed classification accuracy or classification rate). It is the ratio of the number of correctly classified trials (successful attempts to perform the required mental tasks) and the total number of trials. The error rate is also easy to calculate, since it is just the ratio of incorrectly classified trials and the total number of trials.

Although classification or error rates are easy to calculate, application dependent measures are often more meaningful. For instance, in a mental typewriting application the user is supposed to write a particular sentence by performing a sequence of mental tasks. Again, classification performance could be calculated, but the number of letters per minute the users can convey is a more appropriate measure. Letters per minute is an application dependent measure that assesses (indirectly) not only the classification performance but also the time that was necessary to perform the required tasks. A more general performance measure is the so-called information transfer rate (ITR) [13]. It depends on the number of different brain patterns (classes) used, the time the BCI needs to classify these brain patterns, and the classification accuracy. ITR is measured in bits per minute. Since ITR depends on the number of brain patterns that can be reliably and quickly detected and classified by a BCI, the information transfer rate depends on the mental strategy employed. There are a few papers that report BCIs with a high ITR, ranging from 30 bits/min [14, 15] to slightly above 60 bits/min [16] and, most recently, over 90 bits per minute [17]. Such performance, however, is not typical for most users in real world settings. In fact, these record values are often obtained under laboratory conditions by individual healthy subjects who are the top performing subjects in a lab. In addition, high ITRs are usually reported when people only use a BCI for short periods. Of course, it is interesting to push the limits and learn the best possible performance of current BCI technology, but it is no less important to estimate realistic performance in more practical settings. Unfortunately, there is currently no study available that investigates the average information transfer rate for various BCI systems over a larger user population and over a longer time period so that a general estimate of average BCI performance can be derived. The closest such study is the excellent work by Kübler and Birbaumer [18]. Furthermore, a minority of subjects exhibit little or no control [11, 15, 19, ]. The reason is not clear, but even long sustained training cannot improve performance for those subjects. In any case, a BCI provides an alternative communication channel, but this channel is slow. It certainly does not provide high-speed interaction. It cannot compete with natural communication (such as speaking or writing) or traditional man-machine interfaces in terms of ITR. However, it has important applications for the most severely disabled. There are also new emerging applications for less severely disabled or even healthy people, as detailed in the next section.

## III. PHYSICAL MECHANISMS

- I. EEGs require electrodes attached to the scalp with sticky gel
- II. Require physical connection to the machine

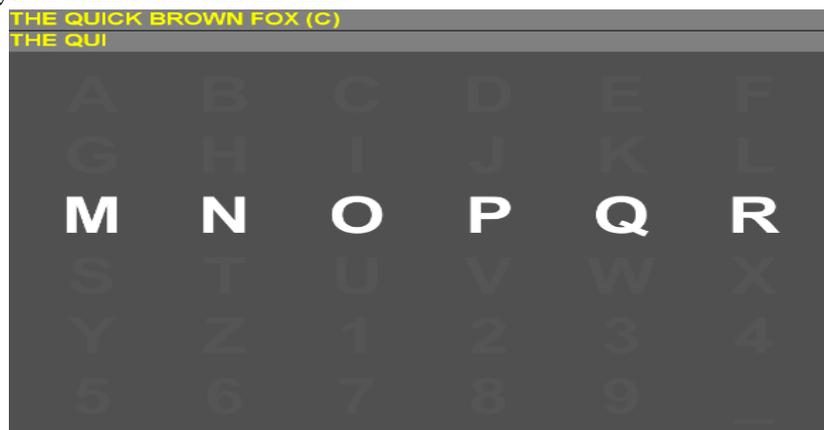


Fig. 7: P300 speller with 6x6 matrix showing one of the rows illuminated.

- BCI systems can be categorized as noninvasive when sensors are placed on the scalp, electrical potentials produced by the brain which is called Electroencephalography (EEG).
- The magnetic fields with a technique called Magneto-encephalography (MEG).
- Semi invasive when electrodes are placed on the exposed surface of the brain in a practice called Electrocochography (ECoG).
- BCI systems are invasive, when microelectrode arrays are placed directly into the cortex.
- Recent developments in brain-computer interface (BCI) technology, however, open the door to making these dreams come true. Brain-Machine Interfaces (BMI) is devices that allow interaction between living neuronal tissue and artificial effectors.

- In addition to electroencephalography (EEG) and invasive electrophysiological methods, these include Magnetoencephalography (MEG), Positron Emission Tomography (PET), Functional Magnetic Resonance Imaging (fMRI) and optical Imaging Functional Near Infrared Spectroscopy (fNIRS).

### 1.3.1 Clinical Application Used in BCI

- The main purpose of BCI research and development is the expectation that BCI technology will be valuable for those whose severe neuromuscular disabilities prevent them from using conventional augmentative communication methods. These individuals include many with advanced Amyotrophic Lateral Sclerosis (ALS), brainstem stroke and severe cerebral palsy.
- A variety of neurological diseases such as motor neuron diseases, spinal cord injury, stroke encephalitis or traumatic brain injury may lead to severe motor paralysis which may also include speech.
- We will refer to only those diseases that have been repeatedly reported in the BCI literature, i.e., Amyotrophic Lateral Sclerosis (ALS), high spinal cord injury and stroke all three diseases have quite different effects on the brain.
- BCI literature, i.e., Amyotrophic Lateral Sclerosis (ALS), high spinal cord injury and stroke all three diseases have quite different effects on the brain.
- Patients may have only a few muscles to control artificial for communicating their needs and wishes and interacting with their environment.
- We refer to the locked-in state if some residual voluntary muscular movement, such as eye or lip movement, is still possible people who lost all voluntary muscular movement are referred to as being in the complete locked-in state. In the realm of BCI use, it is of particular importance how and how much the brain is affected by disease.
- Successful BCI operation requires that the user acquire and maintain a new skill, a skill that consists not of muscle control rather of control of EEG or single-unit activity.
- Current BCI's differ in how the neural activity of the brain is recorded, how subjects (humans and animals) are trained, how the signals are translated into device commands and which application is provided to the user.

## IV. METHODOLOGY

### 1.4.1 Noninvasive Recording Methods for BCI

- Noninvasive BCI's use scalp recorded EEG rhythms or evoked potentials.
- Increased neural activity is accomplished by locally increased glucose metabolism, resulting in increased glucose and oxygen consumption. As a consequence of glucose consumption, cranial arteries dilate, allowing for increased blood flow that results in hyperoxygenation of the active tissue.

### 1.4.2 Blood Signals Recorded from the Scalp

In a Noninvasive BCI, participants are presented with stimuli or are required to perform specific mental tasks while the electrical activity of their brains is being recorded by EEG.

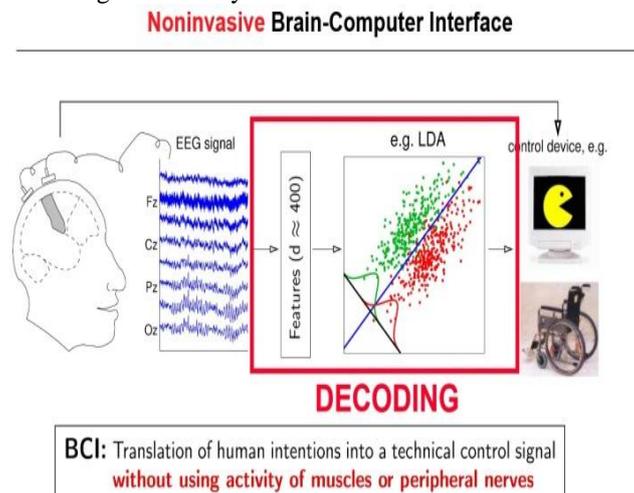


Fig 4. Generic noninvasive BCI setup: signals are recorded, e.g., with EEG, meaningful features are extracted and subsequently classified. Finally, a signal is extracted from the classifier that provides the control signal for some device or machine

### 1.4.3 The Magnetic Activity of the Brain

- The magnetic field generated by electrical brain activity can be measured by means of Magnetoencephalography (MEG). To date, this method is used only in laboratory settings and is consequently not suitable for a BCI for communication and control in the patient's home environment.

### 1.4.4 The Blood Oxygen Level Dependent Resonance (BOLD)

- Local concentration of deoxygenated haemoglobin in brain tissue depends on neuronal activity and metabolism and changes can be measured with functional magnetic resonance imaging (fMRI).

#### **1.4.5 Near Infrared Spectroscopy (NIRS) as a Recording Method for BCI**

- The NIRS-BCI is portable and could thus be used in a patient's home environment. Ratio of oxygenated to deoxygenated haemoglobin is expected to increase in active brain areas and is measured with NIRS.

#### **1.4.6 Invasive Recording Methods for BCI**

- Invasive recording methods either measure the neural activity of the brain on the cortical surface (electroencephalography, ECoG) or intracortically from within the (motor) cortex.
- These methods have strong advantages in terms of signal quality and dimensionality. However, they require surgery and the issues of longterm stability of implants and protection from infection arise.

#### **1.5.7 Brain Signals Recorded from the Surface of the Cortex (ECoG)**

- The electrocorticogram (ECoG) uses epidural or subdural electrode grids or strips to record the electrical activity of the cortex. It is an invasive procedure that requires craniotomy for implementation of electrodes is required (strips instead of grids) because strips may be inserted via a small hole in the scalp.
- Commonly, ECoG is used to localize seizure activity in patients with epilepsy before they undergo surgery.

### **V. STUDY DESIGN**

#### **Brain Signals Recorded from within the Cortex**

Intracortical signal acquisition can be realized with single, few or multiple electrodes (arrays) that capture the action potentials of individual neurons. Electrode tips have to be in close proximity to the signal source and the arrays have to be stable over a long period of time. A One patient was able to move a cursor on a computer screen to select presented items by modulating his action-potential firing rate, it was demonstrated that hand movements could be estimated from local field potentials. The Multielectrode arrays for intracortical recording are still to be improved for clinical application. They have been used in animals with stable recordings for up to two years. Several groups use multielectrode recordings to detect activation patterns related to movement execution in animals.

### **VI. RISKS & BENEFITS**

- It is important to note that the above applications will be limited to the noninvasive EEG based systems due to their comparatively low risk and cost.
- EEG's are non-invasive & do not involve any x-rays, radiation, or injections.
- EEG's have been used for many years & are considered very safe.
- The electrodes record activity without producing any sensation. Slight redness may occur in the locations where the electrodes were placed, but this will wear off after a few hours.
- However, there may be risks depending on your specific medical condition.
- The research will benefit our knowledge about the function of the human brain.
- EEG allow researchers to follow electrical impulses across the surface of the brain & observe changes over split seconds of time.
- An EEG can show what state a person is in asleep, awake, anaesthetized because the characteristic pattern of current differ for each of these states.
- One important use of EEG's has been to show how long it takes the brain to process various stimuli.
- A major drawback of EEG's, however, is that they cannot show us the structures & anatomy of the brain or really tell us which specific regions of the brain do what.

### **VII. FUTURE WORK**

- Improving physical methods for gathering EEGs
- Improving generalization
- Improving knowledge of how to interpret waves

### **VIII. CONCLUSION**

Based on therapist discussions, numerous improvements to the design are planned. Currently, a laptop processes the EEG signals to be used for orthosis movement. We plan to miniaturize the processing unit onto a micro-computer to give complete portability and allow patients to go beyond rehabilitation and use the device as a replacement of hand function in daily life.

BCI research over the last 20 years has focused on developing communication and control technologies for people suffering from severe neuromuscular disorders that can lead to complete paralysis or the locked-in state. The objective is to provide these users with basic assistive devices. Although the bandwidth of presentdays BCIs is very limited, BCIs are of utmost importance for people suffering from complete locked-in syndrome, because BCIs are their only effective means of communication and control.

In addition, we would like to expand the system's ability to adapt to spatially nonstationary signals. Implementing adaptive spatial filters or an adaptive classifier that finds the strongest correlated channel automatically and continuously would improve robustness in signal strength for a long-term out-patient orthotic. More importantly, spatial and temporal filters that remove artifacts from eye blinks, EMG, and breathing, are essential to the device performance outside of a research setting.

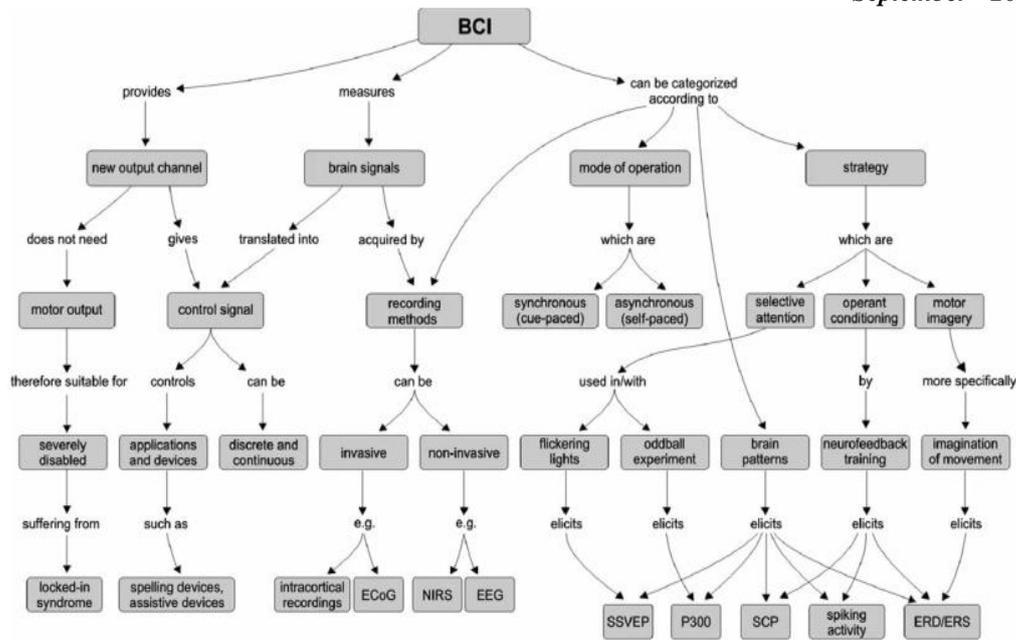


Fig. 10 Brain-computer interface concept-map

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