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Exploring the clinical impact of brain computer interfaces (BCI) in stroke, epilepsy, and amyotrophic lateral sclerosis (ALS)

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Abstract. Brain Computer Interface (BCI) technology emerges as a transformative force in neuroscience, offering an innovative avenue to re-establish communication pathways between the brain and the external environment for neurological disorders precipitated by infections, genetic mutations, or heavy metal toxicity. This paper commences with a summation of noninvasive and invasive BCI, followed by an exploration of their applications in stroke, epilepsy, and Amyotrophic Lateral Sclerosis (ALS). Subsequently, the paper delves into the utilization of BCI technologies within the context of three major neurological disorders: stroke, epilepsy, and ALS. This paper illustrates how BCIs facilitate the restoration of motor functions, mitigate the frequency of epileptic seizures, and enhance the quality of life for ALS patients by reconstructing the neural pathways between the brain and either the body or assistive devices. Finally, this work synthesizes the key insights from the discussion and outline the prospective directions for BCI technology development, hinting at the expanding role of BCIs in neuroscience and medicine.

Keywords: BCI, neuron disease, stroke, epilepsy, ALS.

1. Introduction

Neuron disease has brought a massive amount of inconvenient for people's life. For example, stroke causes understanding difficulties and some language problems. Epilepsy will cause cognitive barrier and disabled. Paralysis leads abnormal reflection and muscle atrophy. Amyotrophic Lateral Sclerosis (ALS) leads limbs rigidification. This means some diseases will probably influence people's action capability. Generally, neuron diseases are caused by error conduction between synapse, abnormal secretion and wrong accumulation of proteins. By carrying out external devices is likely relieving these symptoms and increase people's living standard. Brain computer interface (BCI) is a typical example.

BCI divide in to two main types, which is non invasive BCI and invasive BCI. In term of non invasive BCI, it will probably be an alternative way for people to do motor actions and also make improvement in conscious regulation, since EEG is likely to participant with other tech to deduce out people's state. For the invasive BCI, it is important in using cognitive saying out word significantly. Apart from that, bionic eyes is a new developed technology which implant an artificial eyeball within a chips that can receive signals and conduct to retina cortex though optic nerves. Besides, participant needs to wear a glasses with cameras in it, which means the glasses can act as real eyes. This technology can help blind

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people seeing world clear again, but this tech have not use clinically yet. Nevertheless, although the basic concepts and mechanism of BCI is familiar, for the EEG, sometimes it divide into resting state which may cause different effects on disease and scientists are still analysis the effects after patients used BCI skills, it still not be general, so this paper will be focusing on stroke, epilepsy and ALS to summary patients improvement. As a result to conclude the potential and problems may need to fix in the future. This paper focus on how BCI helping disable patients. This paper first describe two types of BCI then put BCI in cases of Stoke, epilepsy, paralysis and ALS and compare the potential efficiency. Scientists' experiments and data will be concluded and figure out how to improve the problems.

2. The general features of two kinds of BCI

This paper will mainly focus on two kinds of BCI, which is non invasive BCI and invasive BCI. It is a newly developed technology which enhance the connection between neuron signals and signals of external devices. This technology is able to help disable people realize moving voluntarily. Non invasive BCI like Electroencephalography(EEG) which only needs recording some signals by external devices without surgery, which means it is less harmful and efficient but more errors due to distraction from environment. By contrast, invasive BCI needed to implant electrode deep in the brain with very precise resolution but the information only focus on a partial region of the brain instead of whole brain, and different people are likely having different rejection reaction after implanted. These two kind BCI is concluded in table 1.

Table 1. Common and difference between non invasive BCI and invasive BCI.

	Non invasive BCI	Invasive BCI
Function	Transport signals	Transport signals
location	Surface of brain (wear as cap)	Brain cortex/ Thalamus
Resolution	Easy disturbed	High and accurate
Surgery requirement	No need (less harmful)	need
Flexibility	Wear anytime and anywhere	Deep in brain
Aim population	Recovery trainers/ Mild cases patients/ Entertainments	Paralytic/ Long term needed/ Severe symptoms

2.1. Developing of non invasive BCI

For taking method with the fastest and least harmful, non invasive BCI will be chose. EEG is a typical example of non invasive BCI, which shows particular potential in a target region in brain as it represents the specific neuron activity between synapse [1]. By placing an electrode in the region that measured, EEG can record the neuron signals and regulate cortex activities. A specific use of EEG is in traumatic brain injury (TBI). TBI is a complex neuron disease which can cause swelling and pressure increased in brain [1]. However, the problem is that TBI will probably promote epilepsy occur, which called chronic epileptic phase [2]. This means EEG cables are suffered stronger tension from chronic phase and experiments may be stopped much earlier [2]. Anyway, biomarker provided by EEG is also essential for TBI since it is helpful for curing epilepsy after injury. During the recovery period of TBI, EEG is likely to be a tool to adjust patients' cognitive behaviour [2].

In terms of cognitive, non invasive BCI is also helpful for disorders of consciousness (DoCs) which is chronic neuron disease [3]. EEG cooperating with transcranial magnetic stimulation (TMS) will probably help to distinguish between consciousness and unconsciousness. TMS-EEG data will use in two conditions which are general anesthesia and deep brain injured patients like DoC patients. Explainable consciousness indicator(ECI) represent different states of consciousness while awareness. Scientists classified domain for high and low states for transfer learning, like table 2 [4].

The target domain means the region of participants tested in brain and source domain means conditions set when training for learners so it can use to calculate ECI and can draw out a correlation graph which shows NREM sleep shows low arousal and conscious but REM sleep shows low arousal

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but high conscious [4]. As source domain is different to target domain which adding DoC, the accuracy of arousal is 73.33 which is much lower than 89.91. Also, the accuracy in category of awareness of Ane and DoC is 88.62 that lower than 90.14 [4]. In conclusion, it seems that non invasive BCI can more precisely monitor patients' behaviour in target region through external devices but decrease if adding extra region that is not in target due to the data in table 2. Some specific non invasive BCI like EEG is able to cooperate with other models and calculations to deduce out the degree and state of conscious on normal person and patients like drawing a correlation graph.

Table 2. Classification Accuracy for single experiment in different conditions for resting state [4].

Target Domain	Source Domain	Arousal (accuracy ∓standard deviation)	Awareness
Ane	Ane	89.91∓8.01	90.14∓6.96
	Ane+ DoC	73.33∓14.25	88.62∓ 8.84
DoC	DoC	----	73.03∓17.26
	DoC+ Ane	86.04∓12.35	73.68∓ 15.42

2.2. Invasive BCI developing in disease

The two main function of invasive BCI is regulating behaviour of external devices and another one is to regulate brain activity. A famous example told that a monkey first play game with a metal straw. The neuron link device record what the neuron firing like staff the monkey learned and the reward, and it find that the monkey can finish the task independently without the help. This means it is able to analysis cognitive functions. This is figure out through psychological actions.

Invasive BCI is largely benefit for artificial controlling and recovery training, especially for stroke ans ALS patients who have lost motor ability. These patients have similar neuron signals like normal people. A system which composed of emotive Epoc Mind Controller (EPOC) robotic arm, and computer which need to create out visual stimuli first by MATLAB, then emotive EPOC collect the signals conduct between neurons from yes and transfer to computer [5]. At last, control robotic arm to write by match the patterns on the robotic arm. An experiment was carried out. Eight participants with normal visual horizon first begin with outline test without shield walking outside [5]. As a result, the highest accuracy is 100%, and even transfer rate is 26.5 bit/min[5]. Compared with high transfer rate information from BCI which is 27.15 bit/min, and is quite similar. In order to prevent randomly of the experiment, participants are asked to watch the shiny point in four of them then control the robotic arm to write down on the paper [5]. This means this system is able to provide for disabled person to write and made life more convenient. This mechanism is mainly by visual evoked potential(VEP) [5]. The accuracy of this five participants in second experiment is 96%. Comparing with non invasive BCI method EEG which have several factors may affect signals transduction and speed, such as the position and exact points of electrode that stick outside the brain. There is a possibility that the electrodes cannot get enough touch with scalp, so the signals will be weak and inaccurate. If it is in order to control limb, it will probably translate wrong cognitive and cause wrong action. This means this system is quite reliable and can help disable people to write something to some extent. The most important factor is the signals transported efficiently and precisely although it needs surgery and is likely to have rejection reaction.

3. BCI is playing roles in stroke

Stroke is not neuron disease actually but a kind of cerebrovascular disease. Stroke may cause by athetosis, which means the diameter of artery becomes narrower so the vessels are likely to be blocked. Another reason will probably be high blood pressure. As a result, the brain cannot receive enough blood with sufficient oxygen and nutrients, so the motor region on brain cortex may be less active and more harmful on basal ganglia, and this will lead injured in neuron aspects. Basal ganglia is a central component of motor circuit which sending signals from cortex to thalamus and back [6]. Movement disorder is a case in point. Due to different ages have different metabolism in brain, thalamus stroke patients will probably have sensory deficit and leading error contraction in muscles [6]. Brain is likely to receive wrong signals

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sent back because of movement disorder, although the structure of cerebellum is normal. Hemiplegia is one of the most common symptom of stroke, and recovery happened automatically, but it still influenced by several factors like brain plasticity and critical period [7]. Upper limb error function is also a major problem in recovery of stroke. After the pathway is deficit, the order cannot pass to upper muscles, so patients may have error feeling about weight, temperature, location and tactile sense. This means it will be a potential safety hazard for patients as they cannot crab stuff properly and may lead scald.

EEG is one kind of BCI technology and acupuncture is helping recovery of stroke by cooperating with EEG. Acupuncture is a kind of Chinese treatment, which is helpful for patients recover motor functions without medicine. High resolution of EEG allow to measure the effectiveness and efficient of electron acupuncture in short time interval [8]. This means scientists are able to observe the rhythm, amplitude and power of patients and analysis the situations. EEG can show the brain connectivity and show brain activity indirectly. Brain connectivity means the relativity between the signals. In 2017, during the treatment of acupuncture, the wave of α and β wave change by the measurement of phase synchronization [9]. This method is in order to see the changes of brain activity and network before, middle and late period after treating electron acupuncture. Most participants are between 18 and 80 years old who has weak hemiplegia in upper limbs with no cognitive barriers, stroke diagnosis by computerized tomography (CT) and magnetic resonance imaging (MRI), as well as no allergic and medicine treatment before. It is likely because patients among all ages will probably be more representative and shows different response after using this method due to the graph show on EEG. They were dividing into three groups. The first group is short term paralysis which last shorter than 2 month [8]. The second group is middle term paralysis which last between 2 and 6 months. The third group is long term slack paralysis which is longer than 6 month [8].

Patients are injected vertically with 2 hertz, 20 minutes in to acupoint of Shousanli, Hegu, and Quchi [8]. Scientists also need to delete electrooculogram (EOG) since it has impacts on EEG signals analysis due to low amplitude and easy to be disturbed. Pearson correlation coefficient is one of index of brain activity. As a precondition, higher relativity between two signals means higher Pearson correlation coefficient. As a result, people divide that the brain connection base on β wave into 3 groups. After calculating pearson coefficient and observing wave from computer, the first two groups have stronger connections than the third group before electron acupuncture treatment, and more significant stronger in late period. The most obvious result is in term of the third group, having stronger signal connection during and late treatment [8]. This mean it has more β waves. Another result is observed from direct transfer function (DTS) which is also a kind of representation of brain activity deducing from EEG signals and other graph general meanings are same as Pearson correlation coefficient but change into α waves. What's more, from computer people can observe that the number of α waves of the first two group decrease after electron treatment and comparing with the period before treatment, and the third group has stronger connection between signals. In conclusion, Pearson correlation and DTS is connecting to BCI network. These two results both illustrates that brain activity in both α and β part decrease but β part increase in third group [8]. Brain activity increase means motor cognitive and recovery is likely to make an improvement. EEG is acting as a transporting device which provide frequencies and signals for calculation, so it promotes electron acupuncture helping stroke patients recover. However, questions still appears in both EEG aspects. The time for patients to take on EEG may influence the α and β wave present on computer and influence the statics in following experiment.

4. BCI in the treatment of epilepsy

Epilepsy is a chronic neurological disorder characterized by abnormal electrical discharges from neurons, which disrupt neuronal conductivity. Although the clinical application of brain-computer interfaces (BCIs) for treating epilepsy is still in developmental stages, researchers have proposed various strategies and methodologies. Patients with drug-resistant epilepsy, which is unresponsive to at least two antiepileptic medications, often explore alternative interventions such as EEG.

BCIs have the potential to precisely localize the origin of epileptic activity in the brain through techniques like intracranial EEG (iEEG) and electrocorticography (ECoG). High-frequency oscillation

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(HFO) spikes may serve as useful biomarkers to identify seizure onset [10]. This capability enhances surgical interventions by allowing practitioners to visualize the location of abnormal electrical signals. However, several challenges persist; iEEG is an invasive procedure, which increases the risk of rejection reactions and complications, with these risks escalating as the duration of recording increases [10]. A study by Simasathien indicates that the likelihood of remaining seizure-free after surgery ranges between 30% and 80%, suggesting that current localization techniques may lack sufficient precision [10].

ECoG, which is positioned on the brain's cortical surface, records electrical signals that can penetrate deeper brain structures, thereby minimizing interference from surrounding barriers due to its proximity to the source of activity. However, the recording of seizures remains problematic, especially in operating rooms where patients typically receive anesthetic agents that may influence electrical signal readings. For instance, drugs such as remifentanil and alfentanil can unintentionally heighten seizure activity during recordings [10]. These pharmacological effects could potentially amplify normal brain regions, thereby obscuring signals indicative of seizure activity.

Despite these challenges, both iEEG and ECoG are valuable tools for identifying epileptogenic regions and optimizing surgical decisions. ECoG offers higher signal resolution with reduced risks, while iEEG provides critical localization, albeit with associated infection risks.

5. The Role of BCIs in assisting patients

ALS is categorized as a neurodegenerative disease, the pathogenesis of which remains poorly understood. Factors such as genetic mutations, hereditary components, and immune dysfunctions, alongside abnormal neuroglial secretion, contribute to its development. The progression of ALS typically begins with respiratory muscle involvement and gradually extends to affect voluntary motor control throughout the body, ultimately impairing the ability to perform daily activities.

BCIs can play a pivotal role in alleviating the hardships faced by ALS patients. These interfaces not only facilitate rehabilitation and recovery training but also assist non-verbal individuals in expressing their thoughts and needs. One innovative approach involves decoding linguistic imagery through electrical signals, enabling those with speech disabilities to communicate more effectively and even convey unspoken thoughts.

The auditory processing system is divided into two streams: the ventral and dorsal pathways. Within the ventral stream, the left superior temporal gyrus (STG) is essential for processing phonemes, whereas the left anterior STG is involved in word recognition [11]. In a study conducted by Brigham, Kumar, Deng, Nguyen, and Koizumi, participants wore EEG caps to record speech imagery while maintaining a fixed position of the chin. Visual prompts were displayed in front of them during auditory clicks to aid in rhythmic synchronization during the tasks. This setup allowed researchers to identify informative channels by analyzing periodicity and cortical activity related to voice imagery, ultimately employing discrete Fourier transform (DFT) to enhance understanding of the functions involved [11].

The findings highlight that channels within the motor cortex, Wernicke’s area, and Broca’s area exhibit heightened frequency activities when in close alignment with the auditory frequency spectrum. Elevated frequency correlates with extended imaging time, which likely increases data accuracy, including signals, currents, and voltage levels. Once transformed into a computer-readable format and decoded, the meaning of the conveyed language can be rendered with higher precision.

Although this technique is still evolving, it holds considerable promise for ALS patients, providing them with much-needed avenues for communication with their families. Nevertheless, challenges remain in employing endogenous BCIs like EEG for this imagery system compared to exogenous options, largely due to the need for a greater number of recording channels. Additionally, differences exist between endogenous and exogenous methods regarding the impact of repeated imagery on decoding accuracy [11].

6. Conclusion

This paper discuss application of BCI in three kind of disease, which is stroke, epilepsy and ALS respectively. Starting from non invasive and invasive BCI introduce general use and have a general

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comparison. The non invasive is less harmful but the invasive BCI with higher resolution. During the discussion about three neuron disease, paper mainly focus on how EEG is applied during treatment. Also involve some cutting edge technology, such as bionic eye and imagery language system. The common treatment for these three disease is using electrode controlling muscles appropriate, which means disable person can live by themselves, but the mechanism for why the disease happened is different, so BCI is likely to cooperate with some medicine to relieve symptoms like epilepsy. This means the amount of medicine use is concluded as variables. In conclusion, BCI will largely increase people's living standard whether for normal people or neuron disease patients. In the future, BCI may pay more efforts in vision and listening and expanding language system. This means people may realize other's thoughts through listening frequencies directly by wearing earphone instead of talking and ling.

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