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Application of Brain-Computer Interface in the Treatment of Mental Illness

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Abstract: Traditional psychological treatment methods often require a long time and have limited effects. Researchers have begun to explore the combination of brain-computer interface (BCI) technology and mental health, providing new possibilities for the treatment and rehabilitation of mental illnesses. This paper reviews the advantages, existing risks, and challenges of BCI technology in mental health treatment, and prospects the future development of research on BCI and mental health.

Keywords: Brain-computer interface; Mental health; Psychotherapy

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1. Introduction

In the context of the continuous integration of medicine and technology, the field of mental illness treatment is ushering in opportunities for revolutionary breakthroughs, with BCI technology being a key driver. Mental illnesses, such as depression, anxiety disorders, and schizophrenia, have long plagued a large number of people worldwide, seriously affecting patients' quality of life and physical and mental health. Traditional treatment methods often face dilemmas such as limited efficacy, obvious side effects, and poor adaptability to individual differences when dealing with complex and diverse mental illnesses. With the rapid development of the times, humanity is entering a new era, and high-tech is increasingly entering public view. Among the many booming technologies, BCI has attracted much attention. This paper will discuss the applications of invasive and semi-invasive BCI, summarize existing technologies, and elaborate on their differences [1]. Meanwhile, combined with the current intractable, high-incidence, and high-recurrence mental illnesses in China, it will prospect the possibility of integrating BCI with mental illness treatment.

2. Brain-computer interface

Among the numerous research fields of BCI, one is closely related and continuously promotes its development.

Mental health is currently receiving much attention. As an important part of an individual's physical and mental health, mental health is the foundation for a person's healthy and all-round development, affecting all aspects of people's lives. Whether BCI technology can be used to detect or improve some mental illnesses is a new research direction today. BCI technology can be divided into the following types:

2.1. Invasive technology

Invasive technology can analyze signals from individual neurons in the brain and is implemented through surgical procedures. The entire process involves removing part of the skull, implanting electrodes into the brain, and then replacing the removed skull. Since the brain has no internal pain receptors, the recording process does not cause pain, but the surgery and recovery process may bring risks such as pain and infection. The advantage of invasive recording is that it can record millisecond-level action potentials, applicable to invasive recording in humans and animals [2].

2.1.1. Signal recording

(1) Extracellular recording: As a common invasive technique, it can be operated on animal brains to record detailed patterns of individual neurons. Microelectrodes made of tungsten or platinum-iridium alloy with a tip size of less than 10 microns are inserted into the target brain structure. During this process, the depth of the microelectrode is continuously adjusted to ensure it reaches a cell body to record voltage fluctuations caused by cellular action potentials [3].

(2) Multi-electrode arrays: To ensure the effectiveness of collection and acquire more neurons, microelectrodes should be arranged in a mesh structure to form multi-electrode arrays, which are closely related to BCI. The most common types of implanted arrays in this process are microwires, silicon-based, and flexible microelectrode arrays [4]. Multi-electrode arrays detect action potentials using the same phenomenon as single-electrode recording: when an action potential is generated, sodium ions rapidly influx into the cell, causing significant voltage changes in the extracellular space. Compared with traditional single-electrode systems, multi-electrode arrays are superior mainly in their higher spatial resolution, and their ability to record dozens of neurons simultaneously makes it possible to extract complex types of information [5].

2.1.2. Application of invasive BCI in humans

Hochberg et al. and Donoghue et al. conducted an experiment in which a sensor called BrainGate, containing an electrode array of 100 silicon microelectrodes, was implanted into the arm-related area of the primary motor cortex of a quadriplegic patient. The key issue explored in this experiment was whether motor intention could still regulate cortical activity three years after spinal cord injury and loss of hand movement.

The researchers found that some neurons could be activated by imaginary activities, such as bending and stretching of the wrist or elbow, and opening and closing of the hand.

2.1.3. Summary

For invasive BCI to be practical, it should meet the needs of long-term use by subjects. Currently, risk control and postoperative recovery of invasive BCI technology are issues that require continuous attention and optimization.

2.2. Semi-invasive technology

The aforementioned invasive BCI requires implanting electrodes inside the brain. Although this method can record brain signals more efficiently and clearly, it has significant risks and ethical issues. To better address such risks, researchers should study the specific use of BCI that does not penetrate the brain surface. Such BCI is called semi-invasive BCI [6].

2.2.1. Human BCI based on electrocorticographic signals (ECoG)

(1) ECoG cursor control based on motor imagery: One week after epilepsy focus surgery, electrodes are implanted under or on the dura mater of the patient in preparation for surgery. Different types of movements and motor imagery (e.g., movements of the hand, tongue, leg, or foot) are performed. The recorded ECoG data are then screened to identify electrodes and frequency bands with the highest correlation with the executed movements or motor imagery [7,8].

(2) Two-dimensional cursor control: The previous one-dimensional cursor control results were expanded to two-dimensional by Schalk, Ojemann, and colleagues (2008). Five patients participated in the study, in which 26–64 subdural electrodes were placed in the parietal, frontal, and temporal regions of the cerebral cortex, including the sensorimotor cortex. The study included three stages: (a) screening using motor tasks to identify suitable BCI features; (b) one-dimensional cursor control; (c) two-dimensional cursor control [9,10].

Figure 1 below fully shows the performance of the five participants. Control performance improved during 12–36 minutes of training. All five subjects successfully learned to control the cursor, achieving the appropriate goals, with an average hit rate of 53–73% [11].

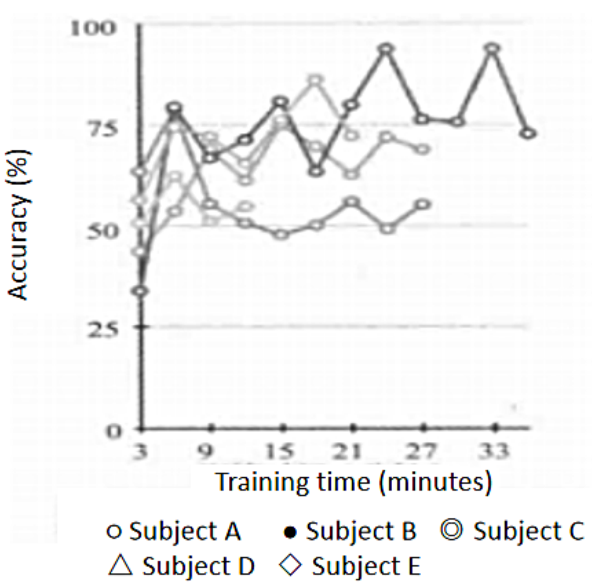

Figure 1. Two-dimensional cursor control using ECoG (Introduction to Brain-Computer Interface).

Long-term stability of ECoG-based BCI: Signal quality may decline during the immune process. Therefore, ECoG is considered a better choice for long-term use. During testing, a relatively stable state should be maintained to conduct experiments, continuously adjust parameter information, and ensure the validity of parameter values [12].

2.2.2. BCI based on peripheral nerve signals

This type of BCI does not record from the motor cortex and is relatively less invasive. This method is more suitable for controlling prosthetic arms and hands because although some motor and sensory nerve functions degenerate after amputation, many nerve fibers can still maintain their original functions. For amputees, nerve activity can be recorded through motor nerve fibers, which function to control some muscles of the residual limb.

Stimulation is used to provide feedback on the motor functions of these fibers, forming a natural closed loop for the prosthetic device to ensure effective control. During this period, other issues need to be checked to ensure the effectiveness of motor nerve fiber application [13].

2.2.3. Summary

Semi-invasive BCI reduces the training time required for users. Different semi-invasive BCIs have different functions and scopes of application, and users can choose according to their needs.

3. Mental health and mental illnesses

This section will discuss the meanings of mental health and mental illnesses, focus on common, high-incidence, and high-recurrence mental illnesses in current society, and discuss their treatment methods to find the possibility of combining with BCI technology.

3.1. Mental health

Mental health is relative; absolute mental health does not exist. Everyone lies somewhere on a continuous line between relatively healthy and unhealthy, and everyone's mental health status is constantly adjusting, not static.

3.2. Currently common intractable and high-incidence mental illnesses

Mental illnesses are caused by the combined action of internal and external factors on the human body, leading to damage to brain function, which is detrimental to the integrity of brain function and disrupts the internal and external environments [14].

3.2.1. Depression

(1) Core symptoms: Depression is generally characterized by low mood, slow thinking, and physical symptoms such as sleep disorders, loss of appetite, and physical discomfort.

(2) Treatment: Current main treatment methods include medication, psychological therapy, and physical therapy (repetitive transcranial magnetic stimulation).

3.2.2. Anxiety disorders

(1) Core symptoms: Emotional symptom includes patients feeling restless, tense, anxious, afraid, and worried. Physical symptoms include overexcitement of the autonomic nervous system when patients are nervous, such as rapid heartbeat, shortness of breath, sweating, and trembling. These diseases have one thing in common, prominent anxiety symptoms.

(2) Treatment: The main treatment methods are medication and psychological therapy, combined with traditional Chinese medicine psychological therapy to reduce the occurrence of anxiety disorders.

3.2.3. Obsessive-compulsive disorder (OCD)

OCD is a relatively refractory disease in psychiatry, with a lifetime prevalence rate of 2.4% in China.

(1) Characteristics of OCD: Problems arise from the patient's own thoughts, not affected by external factors; there is an idea or action that the patient tries to resist but to no avail; the idea of performing an action makes the patient uncomfortable, but not completing the action causes anxiety; ideas and impulses keep recurring.

(2) Treatment: Mainly psychological therapy combined with clinical treatment. For severe cases, patients may choose modified electroconvulsive therapy and transcranial magnetic stimulation according to actual conditions [15].

3.3. Summary

Currently, the three high-incidence mental illnesses in China include anxiety disorders, depression, and OCD, which have high recurrence rates and are prone to repeated attacks, making the cure process difficult. At present, these mental illnesses mainly rely on medication and psychological therapy, which can alleviate patients' pain to a certain extent but still cannot avoid repeated attacks. This is related to the current social living environment and prompts us to think, are there other better treatment methods to help patients get rid of their predicament?

4. Possibility of BCI in treating mental illnesses

As mentioned earlier, physical therapies such as transcranial magnetic stimulation and repetitive transcranial magnetic stimulation are used in the treatment of these diseases. For the human brain, one should understand the positions of the four brain lobes, which are the frontal lobe, parietal lobe, temporal lobe, and occipital lobe as shown in the **Figure 2**.

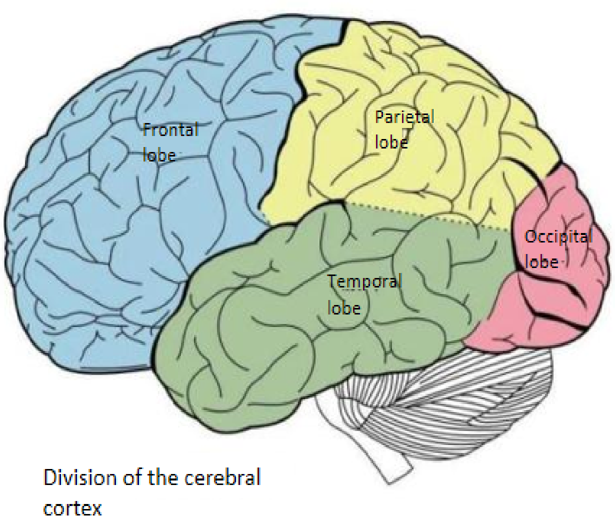

Figure 2. Cerebral cortex parcellation.

Studies have shown that the amygdala, located in the dorsomedial part of the anterior temporal lobe, slightly anterior to the hippocampus and the apex of the inferior horn of the lateral ventricle, has the function of regulating or controlling emotions. Simply put, the amygdala in the human brain is responsible for controlling emotions.

Neurons here reduce the manifestation of negative emotions in the human body to ensure that people are in a calm and rational state. Once this area has problems, negative emotions will become more obvious, affecting people's mental state and gradually leading to diseases.

On November 15, 2023, at Shanghai Mental Health Center, a therapeutic electrode was successfully implanted in a patient with OCD. This was the first functional neurosurgery performed in a psychiatric hospital in mainland China. The neurosurgery team from Huashan Hospital was responsible for accurately implanting the electrode into the double targets of the nucleus accumbens and anterior limb of the internal capsule of the patient Tian Yi, and the rapid effect is currently awaited.

In the treatment of mental illnesses, although progress has been made in methods such as intracranial stimulation to treat diseases and restore intracerebral functional parameters, the effects are only temporary. Can one implant these BCIs into patients' brains to achieve rehabilitation through brain regulation? The aforementioned semi-invasive BCI is safer than invasive BCI, with higher spatial resolution, better signal-to-noise ratio, wider frequency range, more convenient parameter adjustment, and shorter training time. Further study invasive BCI on the existing basis can obtain more accurate and clear data, and its application scope will be wider.

5. Conclusion

In summary, the exploration of BCI technology in the field of mental illness treatment helps solve current problems. Since BCI still has some ethical issues, and technologies to reduce infection risks need continuous development, these problems require us to continuously solve and overcome. Perhaps one day in the future, with more advanced technologies, different BCIs should be applied in different fields to better benefit all mankind.

Disclosure statement

The authors declare no conflict of interest.

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