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Application of brain-computer interface in the treatment of amyotrophic lateral sclerosis

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Abstract. Amyotrophic lateral sclerosis (ALS), also known as Lou Gehrig's disease and gradual freezing disease, is a rare disease. At present, it mainly relies on drug therapy and supportive therapy, but the therapeutic effect is not significant. With the progress of medical technology and computer science, brain-computer interface technology, also known as BCI, has been developed in recent years. Previous studies have shown that BCI can be used to help patients with dyskinesia recover and assist patients with brain injury to recover after operation. With further research, the central nervous system signal is transformed into the external environment's instruction. For patients with ALS and AD, it is possible to communicate with the outside world through BCI technology. This paper mainly discusses the application in the treatment of ALS to realize barrier-free communication between ALS patients and the outside world. This paper mainly introduces ALS, brain-computer interface technology, and case analysis and explores the application of brain-computer interface technology in the treatment of amyotrophic lateral sclerosis. The conclusion is that this treatment method is obviously superior to the traditional method, but it has not been widely popularized and needs further study.

Keywords: Amyotrophic lateral sclerosis, brain-machine Interfaces, treatment.

1. Introduction

Amyotrophic lateral sclerosis (ALS) is a rapidly progressive neurodegenerative disease that is characterized by the loss of upper motor neurons in the motor cortex and lower motor neurons in the brain stem and spinal cord. The respiratory system of patients is seriously affected, and the symptoms last for three to five years, and finally they die of respiratory failure. ALS patients will also be accompanied by cognitive and behavioral changes, making it more and more difficult to communicate with the outside world. At present, the mainstream treatment programs include drug therapy and supportive therapy. At present, the drugs approved for treatment include riluzole, edaravone, and sodium phenylbutyrate/taurine glycol, and the supportive treatment includes physical and occupational therapy, robotics, nutritional therapy, speech therapy, and ventilation equipment and AC equipment. With the in-depth study of brain-computer interface technology, the central nervous system signals are transformed into instructions, making it possible for patients with language and nerve disorders to communicate with the outside world. This paper discusses the combined application of computer science and medical technology and the therapeutic mechanism and effect of treating amyotrophic lateral sclerosis through the brain-computer interface. BCI technology provides an effective way for ALS patients and patients of the same type to resume language communication.

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2. Literature Review

The cured cases of brain-computer interface technology are reviewed as follows:

First, BCI is used to help people with severe dyskinesia, supporting biofeedback training for patients with epilepsy, stroke, or attention deficit hyperactivity disorder (ADHD) or controlling computer games. Every psychological activity, such as decision-making, planning to move, and mental arithmetic, is accompanied by the excitement and inhibition of distributed neural structure or network.

Second, BCI is used in the training of motor control for stroke recovery [1]. The subject was a 43-year-old woman, 10 months after stroke. She cannot make any fingers of the hand she is involved in produce isolated movements. Through hard work, she showed that the metacarpophalangeal joints of all four fingers and thumb were overstretched at the same time, and at the same time, she showed the flexion of the proximal interphalangeal joints and distal interphalangeal joints of all fingers. The combined intervention with BCI and FeS includes the experiment of trying finger movement and relaxation conditions or the experiment of imaginary finger movement and relaxation conditions. Training was conducted three times a week for three weeks (nine classes in total). After nine courses of BCI+FES intervention (three times a week), participants showed the recovery of isolated index finger extension.

Third, BCI is an auxiliary technology for patients with craniocerebral trauma. It controls the movement of the cursor through the collected signals of the electrooculogram, electromyogram, and electroencephalogram. More detailed information about the operation and setup process of the device is reported. Six adults, all of whom suffered from brain trauma or were thought to be in a coma, took part in a seven-month study. All participants can navigate the maze. Most participants can also use this device to type simple words. An increase in positive behavior and attention span was also observed.

Fourth, clinical application of BCI based on electroencephalogram (EEG). The patients with acute or subacute hemiplegia stroke were tested with the customized BMI system. Four patients participated in the study. The BMI system feeds back the amplitude of sensory motor rhythm extracted from scalp EEG in real time. On average, 120-200 hand exercise training tests were successfully conducted at the bedside for 3.3 days (ranging from 2 to 4 days) without any adverse effects.

Last, BCI is used for the recovery of neurological health in stroke patients. BCI initiated the treatment of neurological health from the head. Neurorehabilitation focuses on the interaction of movement, feeling, speech, cognition, and environment, and BCI is the hub of many fields.

3. Introduction to ALS Disease and its Traditional Treatment

3.1. Definition and symtoms

Amyotrophic lateral sclerosis is a delayed progressive neurodegenerative disease affecting motor neurons [2]. It is characterized by the loss of upper motor neurons in the motor cortex and lower motor neurons in the brain stem and spinal cord, which eventually affects respiratory function and leads to respiratory failure about 3 to 5 years after symptoms appear.

The early symptoms are clumsiness and weakness of one or both fingers, followed by small hand muscles. With the progress of the disease, muscle weakness and atrophy can involve the forearm, upper arm, and scapular muscles, then develop to the trunk and neck, and finally involve facial muscles and throat muscles. Medullary palsy will occur in the late stage. According to statistics, the disease mostly occurs in middle-aged men, and the patient died of respiratory failure after three to five years of symptoms.

3.2. Typical cases and traditional treatment

Former American baseball superstar Lou Gehrig died of this incurable disease. Later, it was learned that the root of Lou Gehrig's disease was genetic inheritance, and it was mainly manifested as amyotrophic lateral sclerosis. Because Lou Gehrig is the first well-known athlete suffering from this disease in sports, ALS is also called Lou Gehrig's disease. Another prominent figure is Stephen Hawking, the most famous physicist who suffered from this disease at the age of 21. He had only three fingers to move. The doctor had diagnosed that he would not live for three years but miraculously lived to 76 years old.

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Through consulting the data, the main treatment schemes include drug therapy and supportive therapy [3]. At present, the medicines approved for treatment include riluzole, edaravone, and sodium phenylbutyrate/taurine glycol, and the supportive treatment includes physical and occupational therapy, robotics, nutritional therapy, speech therapy, ventilation equipment, and AC equipment.

4. Introduction to Brain Machine Interface

4.1. Definition

Brain-computer interface (BCI) provides a method to develop the interaction between brain and computer. Communication is developed due to the neural response produced by sports or cognitive activities in the brain. The communication here includes muscular and non-muscular movements. These actions will generate brain activities or brain waves, which are directed to hardware devices to perform specific tasks. BCI was originally developed as a communication device for patients with neuromuscular diseases [4].

4.2. Wide application fields

BCI technology has realized that these interfaces can effectively convert the signals of the central nervous system into the commands of external devices and developed a well-known EEG, which is then used to understand the internal functions and neural communication of the brain with further research [5-6]. Besides recording and displaying brain activities, BCI also allows users to control programs such as video games, computing software, spellers, web browsers, and thought translation devices. It is also used for sensory simulation to break through the bottleneck of audio-visual media interaction. In the medical field, this technology has potential, and the active brain can bypass the sick body to perform functions or treat some brain diseases, such as motor neuron diseases, amyotrophic lateral sclerosis, spinal cord injury, Parkinson's disease, epilepsy, depression, blindness, deafness, and chronic pain. The expanded use may be neural interfaces to enhance human inherent abilities, such as memory and attention. In the field of brain science, the signal quality of EEG equipment is evaluated. It is also used in neurology and neurosurgery to make patients with nervous system disorders communicate with the external environment.

4.3. Mechanism

A typical BCI system includes a signal acquisition system, signal processing technology, and output equipment [7-8]. Signal acquisition can be carried out in three ways: invasive, non-invasive, and semi-invasive. Invasive techniques include obtaining signals by penetrating microelectrodes in the dura mater of the brain. In the semi-invasive method, the electrode is placed under the scalp, not in the gray matter. Noninvasive techniques include placing electrodes on the scalp without surgery. Some non-invasive techniques for recording brain signals are electroencephalography (EEG), magnetoencephalography (MEG), and magnetic resonance imaging. Non-invasive techniques are widely used in research because they are not easy to cause any damage to brain tissue.

5. Application in the Treatment of ALS Disease

5.1. Treatment methods

By transmitting signals from the brain directly to the machine, bypassing the injured spinal cord or surrounding motor neurons, BMI can restore the ability of paralyzed patients to directly interact with and manipulate the environment. BMI receives neural signals from the patient's brain, usually from surgically implanted electrodes. Then, the system decodes and sends these signals to a computer or an auxiliary device, allowing the patient to control the device only through brain activity [9].

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5.2. Specific case analysis

After consulting the literature, the patient was a woman who was 58 years old when she got informed consent in September 2015 [10]. She was diagnosed with advanced ALS in 2008 and was in a locked state, which required positive pressure mechanical ventilation through a tracheotomy. She is able to communicate by using eye movements (using an eye tracker) and blinking to indicate "yes" and "no," but she is completely paralyzed in other aspects (ALS Functional Rating Scale scores 2, which score dysfunction from 0 to 40, and the higher the score, the lower the degree of disability). Then the implantation of electrodes and devices, the determination of activated cortical areas, decoding and training, communication, and home use are carried out. Combined with the results of the literature, it can be seen that BMI has a significant therapeutic effect on ALS, and the user satisfaction has increased.

A young man named Li Ming (a pseudonym) gradually recovered part of his motor ability from his long-term paralysis through the treatment and rehabilitation of the brain-computer interface. Li Ming used to be an excellent athlete. An accident paralyzed him from the neck down. Over the years, he tried various treatments, but the results were not satisfactory. Just when he almost gave up hope, he came into contact with the brain-computer interface treatment and rehabilitation project. In this project, the microelectrode array is implanted into Li Ming's brain to monitor and analyze the movement intention of the brain in real time, so as to control the actions of external devices. After a series of rigorous evaluations and screenings, Li Mingcheng is the subject of this project. In the process of brain-computer interface therapy and rehabilitation, Li Ming experienced a process from initial adaptation to gradual proficiency. At first, it took him a long time to adapt to the interaction between the brain and the machine and control the actions of external devices. But with the passage of time, he gradually mastered the skills and was able to complete some simple movements, such as grasping and moving his arms. In this process, Li Ming also experienced many setbacks and difficulties. Sometimes, he will feel tired and helpless and even want to give up. However, with the encouragement of doctors and therapists, he persisted. After months of treatment and rehabilitation training, Li Ming has made remarkable progress. He can not only complete some basic actions of daily life, such as eating and drinking water, but also do some simple sports, such as walking and cycling. This is a huge breakthrough for him, and it also makes him regain the confidence and fun of life.

A case similar to Li Ming in the clinic is not an isolated case. Another Xiaohua (a pseudonym), a 12-year-old boy who lost the motor ability of his lower limbs because of a serious spinal cord injury, underwent successful brain-computer interface implantation after weeks of preparation. During the subsequent rehabilitation process, he utilized a brain-computer interface for training. By employing his imagination to move his legs and controlling a virtual leg model on a computer screen, under the guidance of doctors and therapists, he dedicated several hours each day to training. After several months of consistent practice and adjustment, Xiaohua began attempting control over real leg prostheses through brain-computer interface. Gradually adapting to the prosthesis, he achieved significant milestones such as standing up, walking and even running -- a great breakthrough for him. Witnessing this progress filled Xiaohua's family with immense happiness and moved them deeply. They expressed their emotions by stating: “We thought Xiaohua could never walk again, but now he can not only walk, but also regain the joy and confidence of life.”

5.3. Effects and limitations

With the continuous progress of technology and in-depth research, the application of brain-computer interfaces in rehabilitation departments will be more and more extensive. In the future, we are expected to see more personalized, efficient, and non-invasive brain-computer interface technology applied to clinical practice. This will bring better rehabilitation effects and quality of life to patients and also open up a new road for the development of rehabilitation medicine.

However, to realize this vision, we still need to solve many challenges. First of all, we need to further study and understand the neural mechanism and working principle of the brain in order to better analyze and utilize neural signals. Secondly, we need to develop more reliable, stable, and efficient brain-computer interface technology and equipment to meet clinical needs.

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Brain-computer interface technology is particularly important for patients with severe neuromuscular disabilities who can't communicate and/or control the environment by using the normal output channels of the brain (peripheral nerves and muscles) [11]. Although brain-computer interface is promising, there are relatively few published works supporting the translation from basic research to reliable and effective user communication choices. In other words, there is still a big gap between the possible functions provided by BCI technology and the functions provided by this technology at present. The main disadvantages of the system are relatively slow speed and high requirements for electrode caps and electrolyte gels. Nevertheless, the system may provide the last choice for those who have little or no other effective means of communication.

6. Conclusion

In this paper, the definition, typical symptoms, and characteristics in different stages of onset and the current mainstream treatment techniques of amyotrophic lateral sclerosis are systematically introduced. In addition, the definition, application fields, and mechanism of the brain-computer interface are introduced. Finally, the treatment methods and case analysis of the brain-computer interface for amyotrophic lateral sclerosis are expounded. Brain-computer interface (BCI) is an effective treatment for amyotrophic lateral sclerosis (ALS), but there are about 100 thousand people in the world who need treatment, and the instruments and equipment of BCI are expensive, so it will take some time to become the mainstream therapy. At present, BCI treatment and recovery of brain injury, ADS, and AD are all in the experimental stage, and the possibility of cure is evaluated. The popularization and perfection of BCI have broad prospects in the future. It is gratifying that it will be possible for ALS patients with terminal illness to communicate with the outside world, bringing good news to thousands of families.

BCI technology has the potential to revolutionize the relationship between human beings and themselves, external devices and other humans, thereby opening up new possibilities. In particular, its application in rehabilitation departments holds great value and promise. Despite being in the developmental stage, continuous scientific research and technological innovation will undoubtedly propel BCI towards revolutionary changes in the field of rehabilitation medicine. This advancement not only facilitates physical recovery and enhances quality of life for patients but also foster progress and development within the entire realm of rehabilitation medicine. Therefore, active exploration and study of BCI technology are imperative to bring positive outcomes to a larger patient population. Simultaneously, it is crucial to address ethical concerns as well as privacy and security issues associated with these technologies to ensure their responsible development.

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