The Applications of Brain-Computer Interface in Elders

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Abstract. Brain-Computer Interface (BCI) is a system that is based upon a computer, collects signals from the brain, which are then analyzed and displayed by an output device. As a current-day popular trending technology, there is potential that BCI can help with the health of elders since this group of population is experiencing both physical and cognitive decline. BCI is mainly categorized into two parts: invasive and non-invasive BCI and each of them can be used in different contexts. Then the paper addressed the use of BCI in both physical rehabilitation and cognitive improvement, especially for the elderly population, how BCI can be applied for treatment, and analyzed BCI's advantages and disadvantages for being used. Finally, the paper addressed BCI from various societal perspectives, including ethical issues, societal issues, privacy and security, and informed consent for using BCI technology. This study explored the application of BCI technology in the management of neurological diseases such as Parkinson's disease and analyzed its role in motor rehabilitation, cognitive impairment intervention, and other aspects. It also analyzed issues that need to be addressed in terms of ethics, safety, and social impact of BCI. This study aims to promote the optimization and clinical application of BCI technology and provide a scientific basis for personalized neurorehabilitation in the future.

Keywords: Brain-Computer Interface (BCI); Neuroplasticity; Biomedical Engineering; Neuroscience; Biochemistry.

1. Introduction

As humans get older, the effects of aging will be more obvious on both physical and cognitive, and these aging effects have great impairments on their daily lives. In this busy century, elders' daughters or sons may not have enough time to take careful and complete care of them. Many elders need wheelchairs or walking sticks to help them walk. A lot of elders have weekly rehab appointments, but the rehab appointments don't have an obvious effect. From a cognitive perspective, the elders' cognitive ability has been declining as they age. Most elders experience memory decline, language ability decline and related cognitive disorders, for example, Parkinson's disease and Alzheimer's disease. These harmful effects in their daily lives can't be easily treated, or the treatments of these need a huge amount of cost. These problems arise in a lot of families. However, Brain-Computer Interface (BCI) technology has permeated into the treatment for those patients who are suffering from these declines, and it has some positive effects. For example, Xiao et al. (2018) designed a system utilizing BCI to support visual fixation with patients who have the Disorder of Consciousness (DOC); With the help of an electroencephalogram(EEG) and event-related potential (ERP), ten healthy elderly participants can control the wheelchair. Research has shown by using BCI experiment paradigms, the elders could manipulate the operation of a smart home. The BCI also helps with communication in everyday tasks and managing an exoskeleton to promote the power of the body's joints [1].

This paper is going to focus on BCI technology and its application to elders. First, it's going to have a brief introduction to BCI technology: different types of BCI technology, the components of BCI technology, and how it works. Then the second section will focus on BCI's motor and physical application or treatments on elders: how BCI works and is incorporated into this process and its positive and negative effects on elders. The third section will discuss BCI's cognitive application or treatments on elders. The fourth section is going to focus on BCI's effects on society and the ethical issues related to this technology, whether this could be widely used in daily life.

2. Principle of BCI

Brain computer Interface (BCI) provides a pathway for signal exchange between the brain and computer. Nowadays, it is more used to restore and enhance brain function, by using external stimuli such as the computer and nervous system [2].

BCI is classified based on its invasiveness: non-invasive BCI and invasive BCI. Non-invasive BCI collects intracranial messages with no need of cerebral intervention, such as EEG, magnetoencephalography (MEG), functional magnetic resonance imaging (fMRI) [2]. The non-invasive BCI costs less than invasive BCI and is more comfortable. For example, with electrodes attached to the patient's head, EEG could track and record brain wave patterns, and then signals are sent to the computer. Here is some equipment associated with BCI, as shown in Figure 1 [3].

Fig 1 The Equipment associated with non-invasive BCI [3].

Invasive BCI thought has disadvantages compared to non-invasive ones. The invasive BCI also has a lot of advantages, such as obtaining nerve information with a much better spatiotemporal accuracy; its signal-to-noise ratio (SNR) is higher, so it could resist noise interferences; its electrodes could be placed in the vicinity of the target area, which is very important for BCI to decode specific information [4].

2.1. BCI's Components

There are four main components of BCI: signal acquisition, processing, output, and feedback; these four components can be referred to in Figure 2. Signal acquisition is responsible for the identification and recording of neural information, which is an important factor of BCI, but it also needs taking into consideration many factors, such as invasiveness, resolution, fidelity, cost, usability, and safety[5]. Signal Processing undergoes several stages: digitization, transmission, preprocessing, feature extraction, pattern classification, and target command generation to operate external devices. The relevant technologies are spike sorting, signal filtering, blind source separation (BSS), timeline–frequency analysis, and classification algorithms[6]. The output component usually involves a robot's arm or physical thing to do the human's intended action by the information already processed through the former interface. The feedback element is that the computer informs the participant about its action and interpretation. All these four components are from a closed-loop from BCI[5].

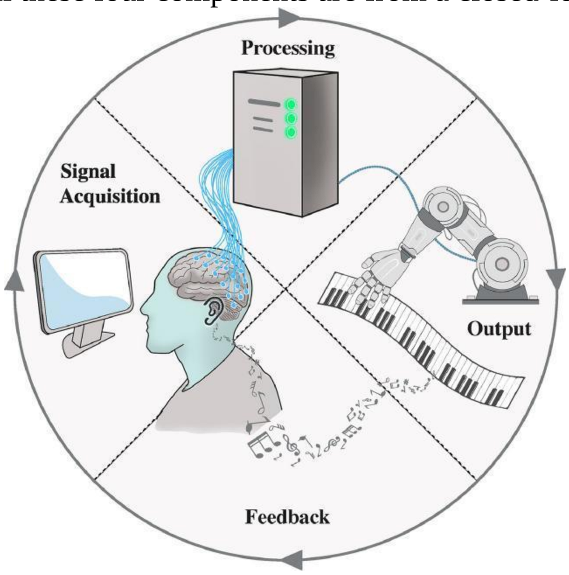

Fig 2 The general components of BCI [5].

BCI often needs a cap incorporating electronic components that can test cerebral action measurable on the scalp. A wearable BCI may be proper for gaining advantages of strengthened and virtual reality, gaming, or manipulating automated equipment. EEG is the most used approach by the majority of wearable BCIs to detect cerebral signals[7].

2.2. BCI's Application in Physical Rehab

Stroke is a very common disease associated with elderly people these days. According to statistics, at least 75 percent of strokes take place in people aged ≧65 years. It is known that the chance of getting a stroke increases by 2 times every ten years beyond 55 years old[7]. Currently, BCI technology is mostly focused on the post-stroke motor function recovery of the upper limbs. Over a decade ago, magnetoencephalography (MEG)-BCI-controlled hand orthosis began to be used for stroke rehabilitation, which was demonstrated by a study[8]. The study showed that the users got used to regulating the timing and power to manipulate an orthosis, this could demonstrate that, in coordination with a robot or orthosis which could deliver feedback, non-invasive BCIs could act as an effective technology.

Several controlled clinical trials concerning the effectiveness of the BCI-robotics indicated significant improvement in UE motors as far as the Fugl-Meyer Assessment (FMA) and Action Research Arm Test (ARAT) are concerned. The study indicated a significant improvement in FMA in stroke patients who were given BCI training with contingent orthotic feedback before physiotherapy [9]. BCI intervention also has a long-lasting impact, based on the study [10], related to chronic stroke subjects, there was an obvious increase in FMA after BCI-robotics therapy, then they were followed up in the next 6 months. The data demonstrated that the patients still kept their FMA score. In a study [11] about BCI-exoskeleton for elbow training, obvious improvement in FMA and ARAT scores and post-treatment movement quality in terms of motion kinematics, was demonstrated. A study [12] also demonstrated the efficacy of BCI-robotics to incorporate rehabilitation of gross and fine hand movements. The results showed that the participants with higher modulation of sensorimotor rhythms (SMR) reported better functional results and promoted finger extension ability.

These studies are all using BCI robots which are bulky and hard-bodied. These robots are costly, hard to control, and cannot be used in many contexts. In contrast, there are soft robots that are light and wearable and employ flexible-mounted actuators. There was a study [13], by using BCI-based soft robotic gloves for rehabilitation for stroke. This study demonstrated improvement in FMA and ARAT and provided evidence of a phenomenon of kinesthetic illusion in subjects.

2.3. Advantages and Disadvantages Associated with the Helping of BCI for Physical Rehabilitation

BCI is a trending technology in current days and will be incorporated into clinical uses in the future. It created a direct link or pathway between brain signals and computers. With the help of a robot or robot arms, it could display the signal or information it processed from the patient's brain. This is helpful for those who have difficulties moving or experience great motor impairment, especially for those elders. From various studies, the effect of BCI is visible. It has great potential for wider use and function restoration in the future. Scientists are still deepening this field and improving it.

However, BCI also has many disadvantages. Many BCI technology needs the help of a hard and huge robot or robot arm to help display the signal of the patient, and these robot arms are inconvenient and hard to move. It also has a huge cost and may cause obstacles to being incorporated daily. In addition, invasive BCI requires signal implantation. This involved potential risks such as infection and raised ethical issues.

2.4. Cognitive Improvement of BCI

BCI is usually focused on how to translate someone's brain signal for computer programs to interpret and display it. Many studies have focused on motor system incorporation with BCI. However, BCI's use on cognitive systems is also potential. They are more cooperative to conscious control, yielding better regulation of localized brain activity. A study [14], by experiment using functional Magnetic Resonance Imaging (fMRI) and Electrocorticography (ECoG), proved the continuing stimulation of the Dorsolateral Prefrontal Cortex (DLPFC), that this area could be controlled voluntarily. DLPFC may be useful for BCI applications. In cooperation with fMRI's accurate position, and brain cognitive system in BCI's wide application could be researched in the future. It could provide a new control method for those who have impairment on motor and expand the width of BCI's application in life at the same time.

Another study [15] by Munoz and colleagues, applied BCI technology in video games to train constant attention in ADHD patients, by a low-cost BCI system. However, such a system has not been used in clinics. Similarly, in another study [16] led by Lim and colleagues, a series of training games were developed, in which attentional levels were measured by EEG signals to evaluate exercise. It proved to be effective to promote attention levels in children with ADHD, by promoting parent-rated inattentive scores on the ADHD Rating Scale.

Among the elderly population, Lee and colleagues introduced a new game incorporating a memory training element [16]. The BCI training was shown to improve both attention and visuospatial and memory abilities with satisfactory usefulness and acceptability. The same authors then replicated the study on cohorts of healthy, predominantly Chinese-speaking elderly, to explore the universal property of the system and training program in different populations speaking different languages [17]. They confirmed the potential of BCI training in improvement of cognition in both English- and Chinese-speaking elderly, demonstrating its practicality and acceptability in different populations.

Gomez-Pilar and colleagues [18,19] developed a BCI system for training in Neurofeedback (NF) in healthy elders. There were 5 tasks with increasing difficulty levels. In these tasks, participants practiced logic and memory by studying, learning and training. The feedback was shown by an object moving on the screen controlled by motor imagery tasks. The test and EEG results have shown that, after 5 times of practice, the participants' cognitive abilities have developed, particularly changes in visual, language, and memory.

2.5. Advantages and Disadvantages Associated with the Helping of BCI for Cognitive Improvement

Concluding from the above studies, it could be addressed that BCI has great potential to be used in clinical or daily life in the future. As the studies show, it can help improve cognitive, language-speaking, visual, and memory abilities, especially among the elderly. BCI also has a lot of uses for different diseases, such as ADHD, elders with age-related cognitive decline, and patients with neurological disorders such as stroke.

However, BCI also has a lot of disadvantages. First, it still can't be currently used among a wide population, though researchers have demonstrated its ability and application in the help with ADHD patients, it still can't be used in clinical situations. Second, the use of BCI often requires a step of training and testing, which needs a lot of time and may not be suitable for those patients who need the treatments as soon as possible.

3. Discussion of Ethical and Societal Issues

Although in current days, BCI has been used in the medical field and other fields like entertainment, marketing, education, and defense industry, there are also ethical concerns related to it. First, is the user's safety related to BCI. There are potential health risks existing in both invasive and non-invasive BCI. User's health may be harmfully influenced by BCI either during long-term or afterwards immediately. Injuries to the user may contribute to many possibilities, such as the insertion of electrodes into the cerebral cortex, dislodgement of functional electrodes over time, malfunctioning of the power supply, and other intraoperative or postoperative complications. Attention should be paid that non-invasive BCI may have negative effects on neuroplasticity which is essential for youngsters.

Second are privacy and security related to BCI. There are several papers published recently demonstrating that brain data could be extracted with hostile intention or there could be a case of access without approval to the BCIs, bringing further effects on the autonomous action and liability.

Third is informed consent related to utilizing such technology. All risks must be analyzed in a way that is understandable to the user in the context of informed consent. From another study, it proved that both researchers and participants are responsible for identifying and investigating risks.

4. Conclusion

BCI is an improving and trending technology that can be applied and used in daily life. Both invasive and noninvasive BCI have their advantages and disadvantages. Non-invasive BCI does not require injury for electrodes to be injected into the skull, but invasive BCI is more precise at gathering brain information signals. The patient's brain signals are usually gathered by BCI and displayed by either a robot or a robot arm. This characteristic could help with the physical rehabilitation of old people. In addition, the brain-machine interface also could help patients with ADHD, stroke, or elders who experience memory or language decline, but these haven't been applied widely today.

In summary, the paper addressed the ethical and societal issues of BCI. The potential health risks, privacy and security, and informed consent need to be considered when applying BCI to participants.

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