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Evaluation and Treatment of Major Depressive Disorder Based on EEG Technology

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Abstract:

Major depressive disorders (MDD) is a common mental disease that affects patients' life quality and functioning and traditional diagnostic methods have errors so that new technological tools are urgently needed to improve the accuracy of diagnosis. The aim of the study is to investigate the application of electroencephalography (EEG) technology and to analyze the potential in the evaluation and treatment of patients with MDD. EEG technology can effectively identify specific frequency bands to patients, combining with the analysis of frontal alpha asymmetry (FAA), which could provide a new way in diagnosis of MDD. Meanwhile, deep brain electrical stimulation (DBS) technology offers new opportunities for targeted treatment. Studies have shown that EEG technology can improve the diagnostic accuracy of MDD. Additionally, the stimulation feedback mechanism of DBS technology in different brain regions provides new ideas for the treatment of Treatment-Resistant Depression (TRD). This study provides a scientific basis for the evaluation and treatment of MDD, and exhibits the future application of EEG and DBS technologies in the field of psychiatric disorders which may change the treatment paradigm for MDD patients.

Keywords: EEG; MDD; FAA; biomarkers; DBS.

1. Introduction

MDD is a severe mental disorder which is one of the leading mood disease. According to incomplete statistics, depression has affected over 200 million people worldwide [1]. The severity of this issue is further highlighted by the World Health Organization (WHO). Up to 2018, WHO has ranked MDD as the third most burdensome disease, and predicts it will overtake other diseases to become the first by 2030 [2].

MDD typically manifests in two main aspects: emotional dysregulation and behavioral abnormalities. These include mood disturbances, sleep disorders, inappropriate guilt, and other related symptoms. People with MDD will suffer from serious physical and psychological damage due to the symptoms,

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resulting in secondary diseases, such as hypertension, memory loss, cognitive impairment, which are often accompanied by a series of psychological problems such as anxiety [3]. For the causative factors of MDD, the American Psychiatric Association (APA) says that it is related to age, life stress, childhood experiences, and personality traits. Moreover, women are more than twice more likely to develop the disease than men under the same factors.

Brain-Computer Interfaces (BCIs), an emerging technology developed in recent years, have been applied in military operations, rehabilitation therapy, and daily life due to their unique ability to enable thought-based control. It typically consists of three main components: a control module, a modulation module, and a recognition module, which together form a closed-loop system. By collecting electroencephalogram (EEG) signals from the brain and decoding them, it can effectively identify the abnormal growth or decay of various types of signals to achieve diagnosis. And through the signal recoding technology can be achieved to control the stimulation controller and thus achieve the role of regulating the brain. Based on the above principles, this technology can effectively identify the characteristic EEG signals of depression and achieve auxiliary disease treatment through modulation [4]. This study will explore various methods of MDD recognition and effective treatment strategies by examining the application of EEG technology in the context of depression.

2. Evaluation and Treatment of Major Depressive Disorder Based on EEG Technology

2.1 Technical diagnosis

2.1.1 Diagnostic assessment of MDD by FAA

EEG frequency bands can be categorized into five types: δ (Delta), θ (Theta), α (Alpha), β (Beta), and γ (Gamma). Different types of frequency bands are not only different in the size of the simple frequency, but in the size of the changes in their energy, all of which can show the active state of the brain. For example, when a person is sleepy, theta wave and alpha wave activity will be significantly increased, while beta wave is often closely related to thinking, attention and tension. Therefore, for patients with MDD, the EEG frequency bands will be abnormally elevated or lowered when compared with normal EEG, and this chapter will expand on this phenomenon.

Kang et al. transformed the asymmetric features of the left and right brain in four frequency bands (δ, θ, α, and β) into matrix images and input them into a convolutional neural network for classification [5]. According to the statistical comparison of the two groups of data in terms of accuracy, sensitivity, and specificity, it was found that the asymmetry matrix images in the α-band all achieved an accuracy rate of more than 97.5%, and the α-band was more prominent in all aspects when viewed from other frequency bands. Thus frontal alpha asymmetry (FAA) has a close correlation with the diagnostic evaluation of MDD.

Vinne et al. investigated the relationship between Frontal Alpha Asymmetry (FAA) and depression, taking into account multiple patient-related factors such as age, gender, and severity of symptoms [6]. This study proposed a significant tripartite relationship (gender x age x severity of findings) as part of the modeling study, and to determine the stability of the model, prospective analyses were also performed in the Gordon/Quinn dataset and a more liberal $p < 0.10$ criterion was used. It was evident from the meta-analysis of the data that there was a significant disparity between male and female data for patients with MDD who were older than 53 years of age. Therefore, the study variables of gender (male, female), age (whether <53 years) and frontal alpha asymmetry difference (FAA, in μV) were used as criteria to make a more intuitive plot of the data.

For MDD patients aged ≥53 years, there is a significant difference compared to the control group, as shown in Fig. 1. Interestingly, the results show opposite patterns for males and females. In males, the right frontal cortical activity is greater than the left, while in females, the left frontal cortical activity is greater than the right [6].

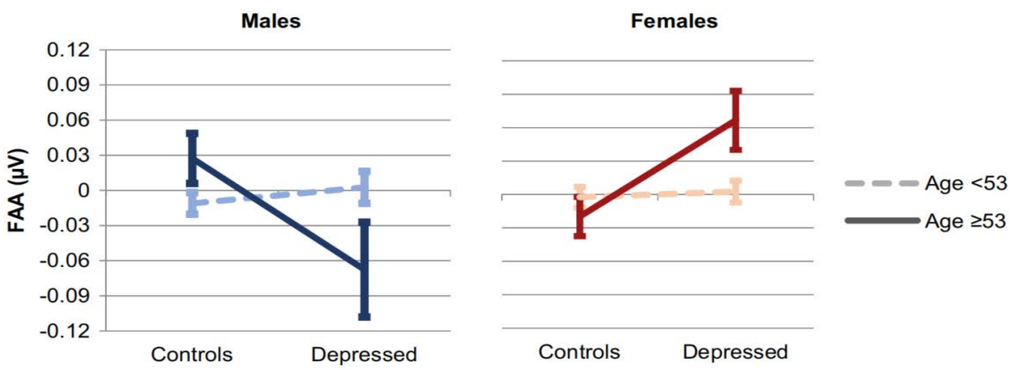

Fig. 1 The differences in frontal alpha asymmetry (FAA) between controls and patients with major depressive disorder, males and females, < 53 and ≥ 53 years of age, respectively. Positive values of FAA indicate that the right frontal is greater than the left frontal, and negative values indicate the opposite [6].

The study by Nikita et al. used gender and age as important factors in the study, indicating that FAA is internally significantly differentiated for patients with MDD, giving relevant reference factors in the input to assess whether a patient has MDD or not. In order to exclude the influence of a series of antidepressant medication factors, Liu et al. studied the FAA profile of unmedicated depressed patients to investigate whether it can be used as a neurophysiological marker for effective identification of depression, and used repeated measures to compare the frontal alpha band differences between the MDD group and the HC group in the rsEEG, and corrected the degrees of freedom and p-values using the Greenhouse-Geisser method of measurements [5]. The study concluded that, in contrast to the control group, MDD patients exhibited consistently lower Power Spectral Density (PSD) values in the right hemisphere electrodes compared to the left hemisphere electrodes.

2.1.2 Diagnosis based on EEG biomarkers deep learning analysis

EEG is a widely used neuroscientific method that collects brain tissue signals via scalp-placed devices. These signals, such as EEG band signals, is then decoded and analyzed using deep learning techniques. The goal is to identify specific biomarkers that can directly indicate MDD, thereby improving the accuracy of diagnosing major depression.

Hu et al. investigated emotion regulation and control abnormalities in MDD using event-related potentials (ERPs). They analyzed three emotional expression cues (fear, happiness, sadness) and two dot positions (emotionally coherent and incoherent memory) in MDD and HC groups. The study concluded that MDD patients showed stronger reactions to negative emotions, particularly sadness. Interestingly, fearful emotions elicited responses with low amplitude and short latency, while sad emotions produced responses with high amplitude and long latency. This pattern suggests a significant deficit in emotional processing. Further research found that initial attentional control was particularly affected by the sad emotion, but not the other two emotions. The study revealed a temporal pattern in emotional processing for MDD patients. At 100 ms post-stimulus, negative emotions activated a wide range of brain regions. By 200 ms, brain regions specifically associated with negative emotions showed high activation. Additionally, the P300 component was found to be involved in categorizing different emotional effects in MDD [7].

The experimental results suggest that psychological control forms the basis for maintaining attentional control. Furthermore, studies can effectively identify relevant biomarkers for MDD based on two factors: the specific response of MDD patients to sadness, and the degree of activation in different brain regions of MDD patients as measured by various potentials. Li et al. came to similar conclusions in their analysis of the ERPs, which demonstrated the feasibility of a new approach to diagnose MDD [8].

Modern neuroscience highly values the combination of EEG and its frequency bands. The unique role of different frequency bands in responding to human behaviors can be further explored. This exploration can build upon the established relationship between MDD patients and emotions, as well as the brain wave signals associated with emotional responses.

Related studies have been conducted on the correlation between theta waves and MDD, Jennifer et al. believe that the combination of Condition x Time x Group (Condition x Time x Group category) is important. After studied the

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theta waves before and after waking up from sleep in the MDD group compared with the normal group, they found that there is a significant decrease in theta wave activity in the morning in patients with MDD, whereas there is no change in the normal group through the Selective slow-wave disruption procedure (SWD), as shown in Fig. 2 [9].

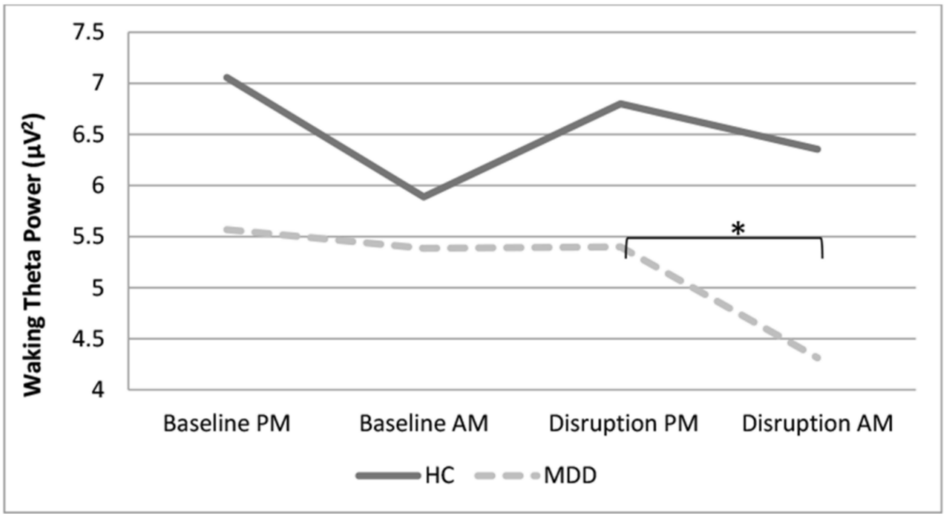

Fig. 2 Table of EEG Theta activity before and after waking up from sleep [9]

Further studies on adolescents with major depression aimed to verify the consistency of these findings across age groups. Compared to healthy controls (HC), adolescents with major depression exhibited a decrease in occipital theta wave power in the evening and an increase in frontal theta wave power in the morning [10].

Analysis of the data and patients' conditions revealed a correlation between frontal wave energy and depression severity. Higher frontal wave energy was associated with more severe depression in the morning. Conversely, more severe depression was observed in the evening when frontal wave energy was lower. These findings suggest a potential positive correlation between depression severity and frontal theta wave energy.

The research discussed above leads to several conclusions. Firstly, the overall energy of theta waves, as well as energy changes in different brain regions, can help identify MDD patients and assess the severity of their condition. Secondly, further research on theta waves and attempts to regulate their distribution and proportion could form the basis for future studies. These studies could focus on improving MDD identification and developing new treatment approaches.

In recent years, scientists have paid more and more attention to the study of the correlation between β and γ frequency bands and depression, and numerous related studies have found that the β and γ waves in the brain waves of MDD patients will be higher than those of normal people, taking Liu et al.'s study of EO (Eyes-Open) as well as EC (Eyes-Closed) in depressed patients as an example, which found that β and γ energies were generally elevated in the MDD group ($p < 0.01$) and suggested that β and γ energies are the first potential biomarkers for the diagnosis of MDD [11].

2.2 Technical Treatment

2.2.1 Therapeutic effects of DBS on different regions of the brain in patients with MDD

Patients with major depressive disorder (MDD) often struggle to achieve substantial improvement through medication and psychotherapy alone. In medical terms, this population is defined as having Treatment-Resistant Depression (TRD).Deep brain stimulation (DBS), as a reliable treatment for people with TRD, has been put into clinical research by a wide range of medical communities. Sun et al. evaluated patients who underwent deep brain stimulation of the subthalamic nucleus (STN-DBS) using three assessment scales: HAMA, HAMD, and possibly another scale specific to depression. The scores decreased by 63%, 67%, and 79% respectively, compared to the pre-treatment period [12]. This experiment shows that DBS treatment technique has improved results for patients with depressive tendencies. Scangos et al. conducted a DBS treatment study on a 36-year-old woman with severe intractable MDD by implanting and electrically stimulating 10 stereo EEG electrodes into the patient's orbitofrontal cortex (OFC), amygdala (AMY), hippocampus (HPC), ventral capsule/ventral striatum (VC/VS), and subgenual cingulate girdle (SGC), which showed that within and across brain regions regions with different stimulation targets having different clinical effects [13].

The study demonstrates that stimulating the same region in the right and left hemispheres can elicit different emotional responses. Moreover, different parts within the same region can also produce varied responses. This complexity suggests that emotional control is not governed by a single brain area, but rather involves intricate interactions among multiple regions. By and large, it can be seen that the stimulation of the right VC/VS as well as the left AMY is a significant positive emotional reveal, which is a similar conclusion in other research reports [14].

Figee's team in their study found that targeting white matter bundle combinations was more necessary for antidepressant treatment of DBS compared to specific gray matter regions based on neural bundle contrast imaging [15]. This study focused on the subcallosal cingulate cortex (SCC), lateral ligament (LHb), ventral internal capsule/ventral striatum (VC/VS), medial forebrain bundle (MFB) & hypothalamus stalk (ITP) for five types of targets.

The data obtained from DBS treatment of these targets showed that the average remission rate reached more than 50% for LHb and MFB target locations (for ITP location, there was only one sample with a 100% remission rate), and was quite effective in other targets, with a remission rate of more than 30%. Related studies have demonstrated that multi-target combined stimulation leverages the effectiveness of different targets on various depressive symptoms. This approach provides a comprehensive and stable therapeutic effect, offering a clinical foundation for future target selection in DBS treatments [16].

2.2.2 Healing in MDD patients with DBS

Isidoor et al. investigated the long-term efficacy and quality of life 6-9 years after DBS treatment [17]. As shown in Table 1, the researchers tracked patients from the beginning of the treatment through subsequent years. They categorized improvement status into four tiers, ranging from weak to strong. Additionally, they evaluated patients' depression using the HAMD scale, as mentioned earlier. The results reveal a year-by-year decrease in average depressive tendencies among patients post-treatment. Concurrently, the number of patients showing strong improvement increased annually. These findings provide clinical evidence for the long-term effectiveness of DBS treatment, while also revealing its nature and duration. However, it's important to note that the study also sheds light on the potential long-term side effects of DBS treatment.

3. Discussion

Based on the aforementioned research advances in EEG-based assessment and treatment of MDD, this paper proposes the following ideas:

3.1 The concept of diagnosis and treatment all-in-one machine

In medical imaging, many fusion devices have successively appeared in the public eye and been put into clinical use. See Table 1 is a collation of some existing fusion devices, including the fusion of mechanical equipment with different functions, which greatly improves the efficiency of imaging examination and diagnostic accuracy, on the other hand, it is the effective fusion of diagnostic and therapeutic functions together (e.g. MRI-guided therapy system, radiation therapy machine), the patient in the diagnosis, at the same time, can be visualized and other related technologies to help physicians to more accurately localize the location of the lesion, and thus remove the lesion.

Table 1. Sorting out the current fusion equipment

Device Name	Purpose	Function	Mechanical Components	Development Time
PET-CT	Diagnosis and assessment of tumors, heart diseases, and brain disorders	Combines PET and CT technology to provide metabolic and anatomical information	PET detectors, CT scanner, computer processing system	2000s
MRI-Guided Therapy System	Tumor treatment and precise surgery	Real-time navigation using MRI images and treatment devices	MRI equipment, treatment devices (e.g., RF ablation), computer control system	2000s
Ultrasound-Guided Therapy System	Interventional procedures, such as biopsies and injections	Real-time guidance of needles or other treatment tools using ultrasound	Ultrasound probe, display, control console	1980s

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Device Name	Purpose	Function	Mechanical Components	Development Time
Multifunctional Monitor	Real-time monitoring of multiple vital signs	Monitoring ECG, blood pressure, blood oxygen saturation, etc.	Monitoring probes, display, alarm system, data recording unit	1990s
Radiation Therapy Machine	Radiation treatment for cancer patients	Precisely irradiates tumor areas, minimizing damage to surrounding healthy tissue	Radiation source, irradiation device, computer control system	Mid-20th century
Integrated Imaging Workstation	Processing, analyzing, and storing imaging data	Integrates various imaging data to provide diagnostic support	High-performance computer, display, storage devices	1990s

Based on the experience of the above related technologies, the conceptual hypothesis of diagnosis and treatment all-in-one machine based on EEG technology can be proposed, which can be parameterized according to the previous conclusions for different parts, gender, age and other factors, in order to effectively identify the diseased parts of patients with MDD and carry out targeted treatment.

3.2 Integrated treatment

Currently, Deep Brain Stimulation (DBS) is considered a treatment option for Treatment-Resistant Depression (TRD). However, using DBS as a single treatment modality still has limitations. The possibility of better therapeutic effect exists by allowing MDD patients to actively cooperate with medication or biotargeted therapy, giving the clinic a new research path. In addition to DBS and medication, various complementary therapies can be incorporated to alleviate depression symptoms. These may include meditation therapy, acupuncture, and tuina (traditional Chinese massage).

4. Conclusion

Current research highlights the effectiveness of EEG technology in identifying unique frequency bands associated with Major Depressive Disorder (MDD). This capability has the potential to significantly enhance clinical assessment processes, offering a more objective means of diagnosis. By providing quantifiable data, EEG can reduce the incidence of misdiagnosis and improve the overall accuracy of MDD diagnoses. Looking ahead, the integration of EEG technology with advancements in machine learning and artificial intelligence could further refine its diagnostic capabilities. By analyzing complex patterns in brain activity, these technologies may enable clinicians to develop predictive models that can tailor treatment plans based on individual EEG profiles. Such personalized approaches could lead to more effective interventions, minimizing the trial-and-error nature of current treatment strategies. Additionally, ongoing studies into biomarkers in MDD patients reveal distinct differences in brain activity during specific periods and in particular regions. This knowledge provides a solid technical foundation for targeted clinical treatments. For instance, if certain biomarkers are consistently linked to treatment responses, clinicians could utilize this information to customize therapies to target these specific brain areas, enhancing treatment efficacy.

The application of Deep Brain Stimulation (DBS) technology, in conjunction with EEG monitoring, presents another promising avenue for future research. As this paper gain a deeper understanding of the varied feedback mechanisms associated with stimulating different brain regions, this paper may be able to optimize DBS protocols for individual patients. This could lead to breakthroughs in managing refractory depression, offering hope to those who have not responded to traditional therapies. Despite these advancements, EEG-based diagnosis and treatment face several challenges that must be addressed. A lack of comprehensive clinical studies limits our understanding of the technology's full potential. To overcome this, collaborative research initiatives involving neuroscientists, clinicians, and engineers are essential. These partnerships can facilitate the design of robust clinical trials that validate the effectiveness and safety of EEG applications in MDD treatment. Furthermore, issues surrounding equipment portability and data collection accuracy must be tackled. The development of wearable EEG devices could revolutionize how this paper monitors brain activity, allowing for continuous assessment in naturalistic settings. This would not only enhance data accuracy but also improve patient compliance and engagement in their treatment processes. Safety assessments will remain a critical focus as EEG technology becomes more integrated into clinical practice. Rigorous evaluations will ensure that the benefits of EEG applications outweigh any potential risks, fostering trust among clinicians and patients alike.

In conclusion, the future of EEG technology in the treatment of MDD is bright. With ongoing research and technological advancements, EEG has the potential to transform how this paper diagnose and treat this complex disorder. As this paper continues to explore its capabilities, this paper may unlock new pathways to effectively manage and potentially cure patients with MDD, ultimately enhancing their quality of life and well-being.

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