RESEARCH ARTICLE

Effect of physical exercise on improving mental health of patients with depression based on deep learning

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Extensive research has shown that regular exercise can alleviate depression symptoms. This study investigated the impact of physical exercise on improving the mental health of patients with depression. A total of 100 participants diagnosed with moderate to severe depression were divided into an experimental group (50 participants) and a control group (50 participants). The experimental group engaged in a 12-week exercise program, while the control group maintained their usual activities. A deep learning model was employed using TensorFlow to analyze data including heart rate, sleep quality, and mood state scores. Metrics used to evaluate the effectiveness of the exercise program included changes in heart rate variability, sleep duration and efficiency, and emotional state scores. The results showed that the experimental group demonstrated significant improvements in both mood and sleep quality compared to the control group, highlighting the potential of physical exercise as an effective non-pharmacological intervention for depression.

Keywords: deep learning; physical exercise; depressive disorder; mental health.

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Introduction

Depression has become a mental health problem affecting people's quality of life worldwide. According to the World Health Organization (WHO), depression has become a leading cause of the global burden of disease. With the increasing social pressure and the quickening pace of life, more and more people are suffering from depression. Although traditional medication and psychotherapy provide relief to some extent for people with depression, these approaches are often accompanied by long treatment cycles and side effects that cannot be ignored. Finding an effective treatment for depression with less side effects has become an important research direction in the field of mental health. In recent years, depression and its links to multiple physical and cognitive conditions have become the focus of research. van Zutphen *et al*. investigated the significance of cardiovascular risk indicators in depressed patients and explored the complex association between mental health and cardiovascular health [1]. Veal *et al*. found a correlation between subjective cognitive and memory problems and objective cognitive performance, fatigue, and depression in breast cancer survivors and emphasized the impact of mental state on cognitive health [2]. Further, Gallagher *et al*. discussed the avoidance tendency of depressed individuals to positive emotions, providing a new

perspective for understanding the deep psychological mechanism of depressive emotions [3]. Lau *et al*. used the ecological transient assessment method to study the moderating effects of motivation on fatigue, cognitive complaints, pain, and depression among stroke survivors, revealing the important influence of mental state on the rehabilitation process [4]. Rollandi and colleagues evaluated the effect of video psychotherapy on abused elderly patients with depression during COVID-19 and confirmed the effectiveness of remote psychological intervention in special circumstances [5]. Solomonov *et al*. systematically reviewed and meta-analyzed differences in social reward processing across the life cycle between depressed and healthy individuals, highlighting the potential difficulties in social interaction in depressed individuals [6]. Moreover, Qian *et al*. studied the brain functional connectivity of depressed patients by using the polynomial kernel Granger causality analysis method, providing new data for understanding the neural mechanism of depression [7]. Morales *et al*. explored the developmental trajectory of aggression, hyperactivity/inattention, and anxiety and depression in the Chilean context, and studied the common pattern of occurrence of these psychological problems [8]. All these studies highlighted the complex interplay between depression and physical health, cognitive function, and social interactions.

Physical exercise has been widely considered by researchers in recent years because of its significant positive impact on improving individual mental health level. Many studies have shown that regular physical exercise can effectively improve the emotional state of depressed patients and reduce depressive symptoms. On the other hand, the rapid development of deep learning techniques has opened new possibilities for analyzing and understanding the complex relationship between physical exercise and mental health. By using deep learning models to analyze large amounts of health data, researchers can accurately predict the effect of physical exercise on the mental health of people with depression, thereby providing a scientific basis for developing personalized exercise programs. With the increasing prominence of mental health problems, finding effective treatment methods for depression has become an urgent need.

This study aimed to explore the effect of physical exercise based on deep learning to improve the mental health of patients with depression by providing a new perspective and a non-drug treatment method for depression. Through the application of advanced deep learning technology, this study could provide a new scientific basis for the role of physical exercise in the treatment of depression and helped to promote the application of physical exercise in mental health intervention. By analyzing big data, the study would provide the possibility for depression patients to explore the best physical exercise patterns and develop personalized exercise plans, which could effectively promote patients' mental health recovery. By exploring in depth the multifaceted effects of depression, this work would provide an important foundation for developing more effective treatment strategies for the prevention and treatment of depression [9, 10].

Materials and methods

Participant recruitment

A total of 100 patients with 50 males and 50 females, aged from 18 - 60 years old with 30% aged 18-30, 35% aged 31-40, 25% aged 41-50, 10% aged 51-60, and education levels as 20% at high school or below, 20% with college, 40% holding an undergraduate degree, and 20% posing a graduate degree or above. The period of diagnosed depression was 0.8 to 4.2 years and was diagnosed by psychiatrists in either Beijing Anding Hospital (Beijing, China) or Shanghai Mental Health Center (Shanghai, China) from January 2023 to March 2023 with 10% less than 1 year, 25% for 1-2 years, 30% for 2-3 years, and 35% for more than 3 years. The diagnosis was made based on the Diagnostic and Statistical

Manual of Mental Disorders (Fifth Edition) (DSM-5) and validated by the Hamilton Depression Rating Scale (HDRS) (American Psychiatric Association, Washington, D.C., USA) to ensure that all participants were in moderate to severe depression. 40% of participants had received medication, while 30% had undergone psychological counseling and 30% had no treatment experience. All participants were given and signed an informed consent form. The procedures of this study were approved by the Ethics Committee of Peking University Health Science Center (Beijing, China) (Approval No. 2023-BMU-IRB-001). Participants were required to pass a basic physical fitness examination prior to physical exercise to exclude individuals with serious cardiovascular disease, musculoskeletal problems, or other health problems that might affect participation in exercise. Patients who were receiving medications for depression were allowed to participate, but the type and dosage of medication should be consistent over the study period to reduce the interference of medication changes to the study results.

Study groups

The basic information of the patients including age, gender, occupation, educational background, duration of depression diagnosis, previous treatment experience was collected through a standardized questionnaire. Individuals with serious mental illness such as bipolar disorder and schizophrenia, serious physical illness such as heart disease and cancer, or in receiving other mental health interventions such as cognitive behavioral therapy were excluded from this study [13]. The participants were randomly divided into experimental and control groups. The experimental group included 50 patients who attended a prescribed 12-week comprehensive physical exercise program including moderate intensity aerobic exercise of fast walking, jogging, cycling, or swimming in a duration of 30 – 45 minutes for each session and three times a week, strength training of dumbbells, elastic bands, or body weights designed once a week for 30 to 60 minutes for all major muscle groups, flexibility exercises such as yoga or stretching once a week for 20 to 30 minutes at a low to moderate intensity [14]. The control group also included 50 patients who maintained their daily habits without additional exercise.

Physical exercise data collection

For the experimental group, physical exercise data was collected immediately after each exercise through wearable devices such as smart bands or fitness trackers to record the duration, intensity, and frequency of each exercise. In addition, participants recorded the type of exercise and subjective feelings in a specially designed app after each workout. The data was collected to provide quantitative information about the participants' exercise habits, as well as direct feedback on the impact of exercise on an individual's mental state [15]. The physical exercise data included average heart rate, maximum heart rate, heart rate variability, total exercise time, time per exercise session, weekly exercise duration, average exercise intensity, maximum exercise intensity, steps and distance walked, range of motion and flexibility test, weight lifted and repetitions, average and maximum respiratory rates, total calories burned per exercise session and per week.

Mental health assessment data collection

The mental health assessment data of experimental group was collected using HDRS at the time of before (week 0), during (week 6), and end (week 12) of the physical activity program. These assessments were designed to measure the severity of the participants' depressive symptoms and their overall mental health status including mood, cognitive function, sleep duration, sleep efficiency, sleep latency, wake after sleep onset, mood scores before and after exercise, and ability to perform routine daily activities. For the control group, the participants were also required to complete the mental health assessments at the same time points of experimental group for valid comparison. To ensure the accuracy and reliability of the data, all participants received detailed instructions before data collection, learned how to use wearable

devices and to fill out mental health assessment scale form. The staff of the research team regularly checked the integrity of the data and confirmed the participants' exercise and mental health status through follow-up interviews to supplement and validate the quantitative data.

Comparative analysis

Participants in the experimental group underwent individual assessments prior to the exercise program to determine the type and intensity of exercise that was appropriated for each participant and to ensure the safety and effectiveness of the exercise program. The exercise program was conducted under the guidance of a professional instructor to ensure that participants performed each exercise correctly and maximized the results of the exercise. Meanwhile, the control group were asked not to change their daily activity levels and lifestyle during the study period including avoiding starting any new physical activity or significantly changing their dietary habits. In addition, participants in the control group also received regular health monitoring and counseling during the study period.

Model construction

The Pearson correlation coefficient formula was used to measure the degree of linear correlation between the score changes in mental health and sleep quality before and after physical exercise and was calculated as follows.

$$\rho_{XY} = \frac{\sum_{i=1}^{n}(X_i - \bar{X})(Y_i - \bar{Y})}{\sqrt{\sum_{i=1}^{n}(X_i - \bar{X})^2}\sqrt{\sum_{i=1}^{n}(Y_i - \bar{Y})^2}} \quad (1)$$

where X_i and Y_i were the score changes of emotional state and sleep quality of the first data point, respectively, $\bar{X}$ and $\bar{Y}$ were the average values of these changes. n was the number of data points. Three participants from the experimental group were selected to explore the score changes in emotional state and sleep quality.

Deep learning model application

In one training step, weights and biases were randomly initialized and a batch of data including heart rate change and sleep quality score change were fed forward through the model. The network parameters were then adjusted based on the error between the actual change in sentiment score and the predicted value of the model. This process was repeated on the entire dataset until the model performance reached a satisfactory level. Using a deep learning model to process the data, this network consisted of an input layer, a hidden layer, and an output layer. The input layer received two inputs including heart rate change (HR_{Δ}) and sleep quality score change (SQ_{Δ}). The hidden layer contained two neurons, H1 and H2. The output layer produced an output of emotion score change (ΔE). The activation function f was the ReLU function as below.

$$f(x) = max(0, x) \quad (2)$$

Statistical analysis

SPSS (IBM, Armonk, New York, USA) was employed for data statistical analysis. Independent sample t test and Pearson correlation analysis were used in this study. *P* value less than 0.05 was defined as significant differences between the tested groups.

Results and discussion

Data processing

The data processing in this study mainly included data teleprocessing, feature extraction, and dataset preparation for analysis.

(1) Data teleprocessing

The purpose of data teleprocessing was to ensure data quality and improve the accuracy and reliability of subsequent analysis. The missing values were checked. For minor omissions, interpolation methods such as linear interpolation or interpolation based on neighboring points were used to fill them. For a

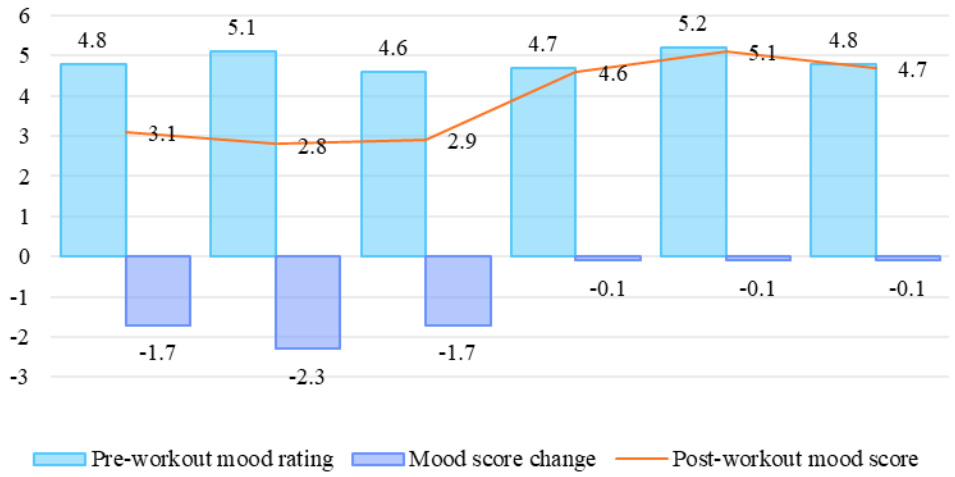

Figure 1. Changes of emotional state scores before and after exercise.

large number of missing cases, the relevant samples or features were eliminated [16]. Outlier processing included identifying outliers using boxplot analysis or standard deviation method. Data points identified as anomalies would be corrected or eliminated depending on the circumstances. Data normalization or standardization was to eliminate the impact of data of different magnitudes. The data was normalized using MinMaxScaler method to scale the data to the interval [0, 1]) or standardized using Z-score standardization method.

(2) Feature extraction

Feature extraction was to extract information useful for research purposes from the original data to simplify the subsequent analysis process, which included time dimension that participants' activity frequency, duration, *etc*. during the study period were analyzed to assess the regularity and intensity of physical exercise, frequency domain dimension that the difference of physiological responses of participants before and after exercise was analyzed through physiological indicators such as heart rate change, and change in emotional state that the amount of change in emotional score was calculated as an important indicator to evaluate the effect of mental health improvement.

(3) Data set preparation

The data from the experimental and control groups were processed separately for comparative analysis. The extracted features were constructed as feature vectors, and each feature vector corresponded to one participant. Data from the experimental and control groups were labeled as "0" for the control group and "1" for the experimental group, or different labels were assigned according to the degree of improvement in mental health.

Comparison analysis

The data of the experimental group and the control group were compared and analyzed to evaluate the impact of physical exercise on the improvement of mental health of patients with depression. The results demonstrated that participants in the experimental group showed significant improvements in mental health scores including emotional state and sleep quality after completing the physical exercise program compared with that in control group. There was a positive correlation between changes in center rate and improvements in emotional state scores in the experimental group, suggesting a correlation between the intensity of physical exercise and improvements in mental health. Participants in the experimental group had a significant improvement in sleep quality compared to that in the control group, which might have been an important factor in the

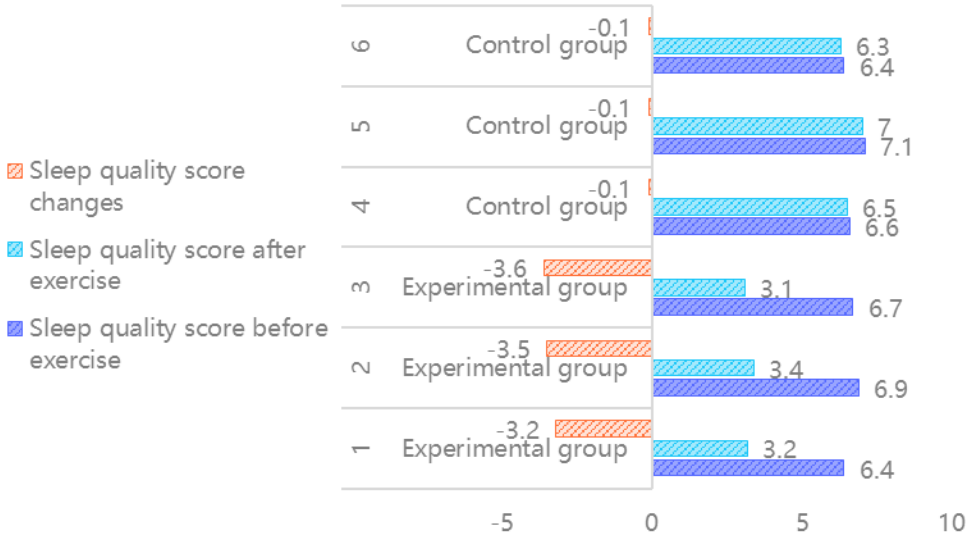

Figure 2. Changes in sleep quality scores before and after exercise.

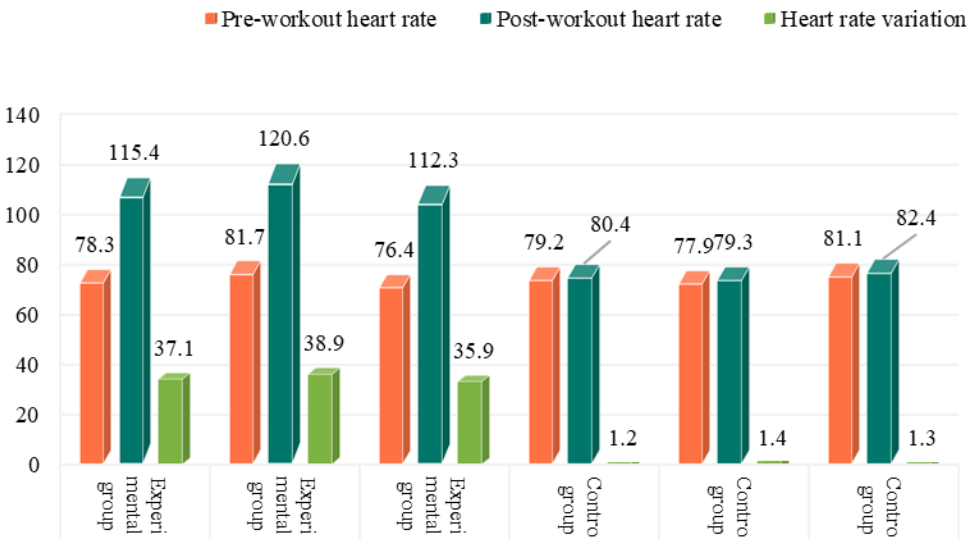

Figure 3. Comparison of heart rate changes before and after exercise.

improved mood. The comparison of psychological health scores between the experimental group and the control group revealed significant differences in the improvement of emotional state and sleep quality. The calculation of changes in emotional state scores and sleep quality scores for three participants indicated a positive correlation between these two variables. Specifically, the changes in mood state scores were 1.7, 2.3, and 1.7 for each participant, respectively (Figure 1), while their corresponding changes in sleep quality scores were 3.2, 3.5, and 3.6, respectively (Figure 2). The experimental group that engaged in regular physical exercise showed an average improvement in mood state score of 2.0 and an average improvement in sleep quality score of 3.3. In contrast, the control group that did not participate in any specific physical exercise program only exhibited an average improvement in mood state score of 0.1 and an average improvement in sleep quality score of 0.1. This

substantial disparity indicated that regular physical exercise significantly enhanced the mental health of patients with depression, particularly in terms of emotional state and sleep quality. This positive correlation suggested that improvements in sleep quality were associated with improvements in emotional state among the participants. Further, the participants in experimental group demonstrated the higher average heart rate after the exercise with the significant difference between pre- and post-workout heart rates compared to that in control group (Figure 3). Combined with the results of emotional state score changes and sleep quality score changes, there was a positive correlation between the amount of heart rate change and the improvements of emotional state and sleep quality scores.

Suggestions

The results of this study suggested that mental health professionals and therapists should consider physical activity as part of depression treatment. A customized exercise program can be tailored to the patient's specific circumstances and abilities to ensure it is both safe and effective. Healthcare providers should increase patient education about the benefits of physical activity, emphasizing its role in improving mental health. By providing clear exercise guidelines and encouraging patient participation, patient adherence to an exercise program could be improved. In addition, an interdisciplinary collaboration between mental health professionals, sports scientists, and healthcare providers was recommended to develop and evaluate physical exercise programs for people with depression, which could optimize the design of exercise programs, ensuring that it was both scientific and humane [17]. Future research should further explore the specific effects of different types, intensities, and frequencies of physical exercise on the mental health of patients with depression. Studies should evaluate the effects of physical exercise on patients with different levels of depression severity, as well as the sustainability and benefits of long-term exercise programs. Patient participation in physical activity could be encouraged by using technologies such as mobile health apps, wearables, and online health communities.

The findings of this study underscored the importance and effectiveness of physical activity as a non-pharmacological intervention in mental health management. Regular engagement in physical exercise not only helped improve mood and emotional well-being but also positively impacted sleep quality, which was crucial for overall mental health. These results suggested that incorporating physical exercise into treatment plans for depression could be highly beneficial. However, it was important to note that this calculation was based on simulated data and a simplified process. In practical applications, calculating correlation coefficients would involve a larger number of data points and more complex data processing steps. Such steps might include more comprehensive data collection, normalization, and statistical analysis to ensure the accuracy and reliability of the results. Based on these initial simulated data, this study provided a preliminary understanding of the relationship between sleep quality and emotional state in individuals undergoing physical exercise. Future research should delve deeper into the effects of different types and intensities of physical exercise on the mental health of individuals with depression. It is also vital to investigate the underlying biological and psychological mechanisms that mediate these beneficial effects. Understanding these mechanisms can provide insights into optimizing exercise programs for mental health improvements and tailoring interventions to individual needs. The study's results advocate for a holistic approach to mental health treatment, integrating regular physical activity to complement traditional therapeutic methods. By continuing to explore and validate the role of exercise in mental health management, we can develop more effective, comprehensive strategies for improving the well-being of those suffering from depression.

Conclusion

This study explored the effect of physical exercise based on deep learning on mental health improvement in patients with depression using a 12-week physical activity program. The study found that participants in the experimental group who regularly participated in physical activity showed significant improvements in both their emotional state and sleep quality compared with that in the control group who maintained their daily habits. In addition, there was a positive correlation between the amount of heart rate change and the improvement of emotional state score, indicating that there was a correlation between the intensity of physical exercise and the improvement of mental health. The application of the deep learning model provided a powerful data analysis tool for this study, allowing the research team to effectively process and analyze a large amount of complex data to gain a deep understanding of how physical exercise affected the mental health of patients with depression. Through pre-processing data, feature extraction, and model training, the study revealed the potential mechanism of physical exercise to improve the mental state of patients with depression, underscoring the importance of physical exercise as an effective non-pharmacological intervention in mental health management.

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