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The effects of an 8-week Taekwondo exercise intervention on inhibitory control in university students with depressive symptoms demonstrated the following—evidence from behavior and ERPs

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Abstract

Background In university students with depressive symptoms, inhibitory control dysfunctions strongly contribute to functional impairments, yet they are not adequately addressed in current therapies. This study aims to investigate the intervention effect of an 8-week Taekwondo exercise program on inhibitory control in individuals with depressive symptoms.

Methods A total of 41 university students with depressive symptoms were randomly divided into a Taekwondo group and a control group. The Taekwondo group participated in an 8-week intervention. Behavioral and ERP measures were collected before and after the intervention during a response inhibition task.

Results 1.The 8-week Taekwondo exercise intervention significantly improved depressive symptoms in the exercise group ($P<0.05$), while depressive symptoms in the control group worsened, although the difference was not statistically significant;2.The results from the behavioral task showed a statistically significant difference in accuracy between the Taekwondo group and the control group in the Go condition during the post-test stage ($P<0.05$). In the Nogo condition, there was also a significant difference in accuracy between the two groups ($P<0.05$). Notably, only the Taekwondo group exhibited a significant improvement in Nogo condition accuracy from pre-test to post-test ($P<0.001$);3.The event-related potential (ERP) results revealed a significant time × group interaction effect for N2 amplitude, $F(1, 39)=4.821$, $P=0.034$, $\eta_p^2=0.110$. Additionally, there was a significant condition × electrode interaction effect, $F(3, 117)=18.368$, $P<0.001$, $\eta_p^2=0.320$. For N2 latency, the time × group interaction effect was significant, $F(1, 39)=13.028$, $P<0.001$, $\eta_p^2=0.250$, and a significant time × condition × electrode interaction effect was also observed, $F(3, 117)=3.199$, $P=0.026$, $\eta_p^2=0.076$.

Conclusion Regular moderate-intensity Taekwondo exercise can effectively improve response inhibition in university students with depressive symptoms, along with improvements in depressive symptoms. The changes in

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N2 amplitude and latency at the Fz, Cz, and Pz electrode sites under task conditions may represent the cognitive neural processing mechanism through which Taekwondo enhances response inhibition in students with depressive symptoms.

Keywords Depressive symptoms, Response inhibition, University students, ERPs, Physical exercise, Taekwondo

Introduction

Depression is a critical global public health challenge, with university students being particularly vulnerable. Epidemiological data reveal that depressive symptoms affect approximately 21.48% of Chinese university students, highlighting the urgent need for effective interventions [1]. These symptoms are often exacerbated by academic pressures, interpersonal relationships, and concerns about future career prospects. As a result, students may experience varying degrees of depressive symptoms, which not only impair their daily functioning and academic performance but also detrimentally affect cognitive functions, particularly in the domain of executive function. Response inhibition, an essential aspect of cognitive control [2], is critical in regulating impulsive behaviors and processing interfering stimuli. Deficits in response inhibition are directly linked to difficulties in emotional and behavioral regulation in individuals with depressive symptoms. For instance, these individuals may exhibit diminished capacity to suppress the impact

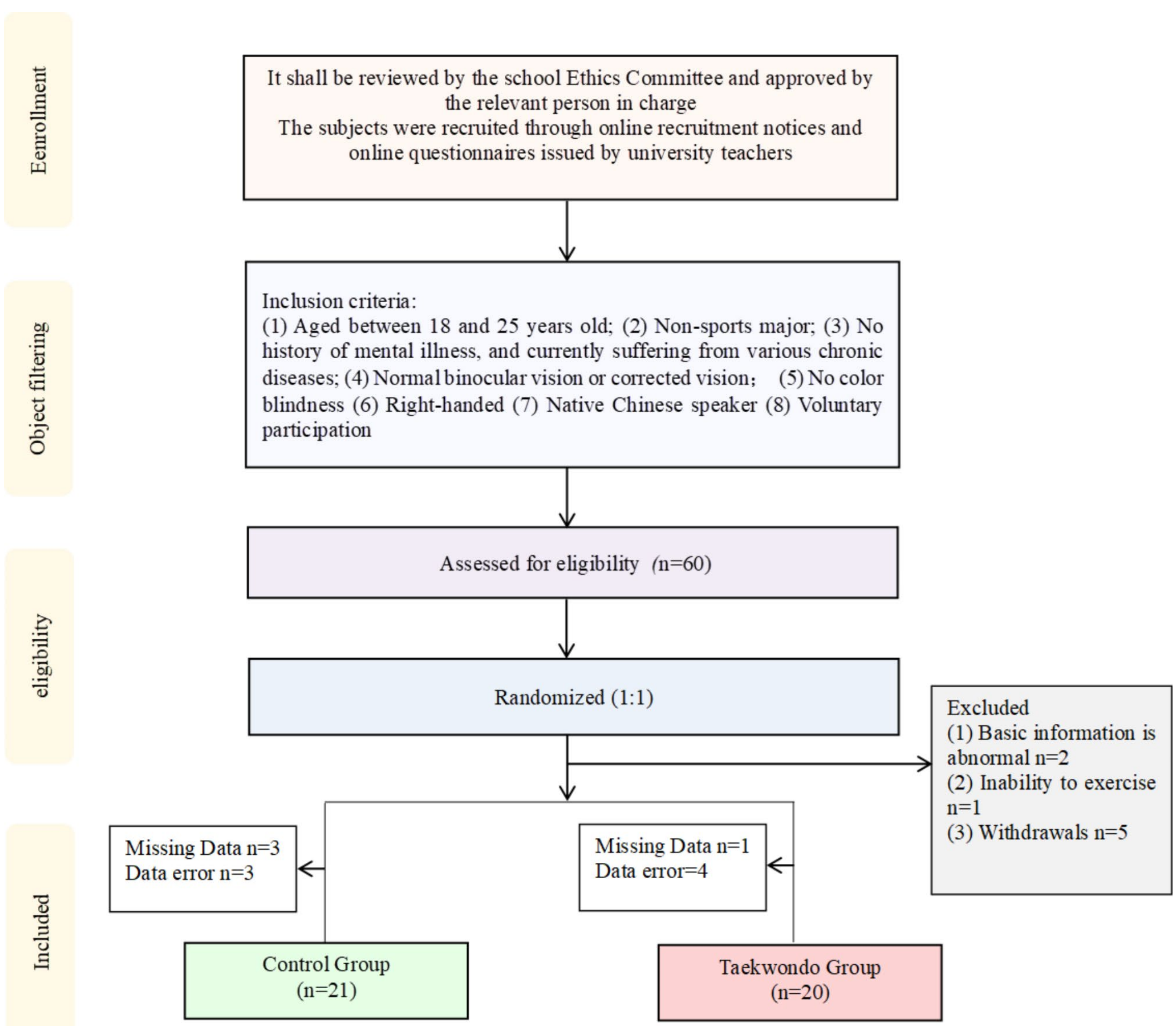

Fig. 1 Flowchart of recruitment

of negative stimuli under stress. The long-term absence of effective treatment can exacerbate physical and mental health issues, significantly reducing quality of life [3], while also placing considerable strain on healthcare resources. Therefore, improving both the negative emotional states and response inhibition abilities of individuals with depressive symptoms has become a critical social concern.

Event-related potentials (ERPs) are a technique for assessing brain electrophysiological responses, offering valuable insights into the neural mechanisms underlying cognitive tasks. The characteristic waveforms of ERPs are extensively employed in research on cognitive control and information processing, particularly in studies exploring response inhibition [4]. The N2 wave, a component of ERPs, is commonly associated with cognitive control processes, including response inhibition. Previous research has demonstrated that the amplitude and latency of ERP components, such as the N2 wave, can provide important information regarding how the brain regulates and executes response inhibition tasks, thereby offering a mechanistic window into cognitive dysfunctions in individuals exhibiting depressive symptoms [5].

Previous studies on university students have highlighted the significant influence of lifestyle, dietary habits, and nutritional education on health behaviors, emphasizing the importance of lifestyle interventions [6]. Another investigation [7]into the physical characteristics of university students confirmed the close relationship between physical health and cognitive function. Exercise therapy [8] is recognized for its positive impact on mental health, offering advantages such as low cost, high safety, good tolerance, and long duration [9]. Regular physical activity can enhance brain function and mental health, especially in improving response inhibition abilities. Research has shown a correlation between blood lactate levels and cortical excitability in Taekwondo athletes and non-athletes after handgrip exercise, providing new insights into the relationship between physical exercise and neural plasticity. This suggests that regular physical exercise can improve negative emotions and cognitive function by regulating neurotransmitter levels and promoting neuroplasticity in the brain [10].Recent studies on various types of exercise have demonstrated their effectiveness in enhancing cognitive inhibition in specific populations. For example, perceptual-motor training significantly improved the cognitive inhibition dynamics in children with developmental coordination disorder, highlighting the interaction between the motor system and cognitive system in the inhibition process [5].Additionally, single-session dynamic seated exercises significantly enhanced Stroop task performance and improved sleep quality in cognitively impaired elderly individuals, emphasizing the acute effects of exercise on cognitive flexibility and self-regulation [11]. These findings collectively suggest that exercise has widespread and adaptable effects on cognitive functions such as inhibition control.

However, research focusing on the effects of specific exercise types, such as Taekwondo, on response inhibition in individuals with depressive symptoms remains limited. Taekwondo, a martial art that combines physical training with cognitive and emotional regulation, offers unique research potential to explore its impact on executive functions, particularly response inhibition. Therefore, this study aims to quantitatively analyze whether an 8-week Taekwondo exercise intervention improves response inhibition in university students with depressive symptoms, based on behavioral and ERP electrophysiological evidence. Additionally, the study seeks to investigate the underlying cognitive neural processing mechanisms through which Taekwondo affects response inhibition. The findings will provide clinical evidence to guide exercise interventions for university students with depressive symptoms and contribute to the scientific foundation for non-pharmacological treatments for depression.

Subjects and methods

Sample Size Estimation In this study, the sample size required for testing was estimated using G*Power version 3.1.9.2. Based on the study's objectives, an F-test was selected with a priori analysis for the effect of interaction. The effect size (Partial η^2) was set at a moderate level (0.06), resulting in an estimated effect size of 0.252. The significance level (α) was set at 0.05, and the desired power (1-β) was set at 0.8. With 2 groups and 2 measurement occasions, the minimum total sample size required for testing was determined to be 34 participants. Considering potential sample attrition, the study aimed to recruit 40 participants, and ultimately, 60 were recruited, with 41 participants included in the final analysis.

Recruitment procedures and grouping

This study outlines ethics in accordance with the Declaration of Helsinki, and was approved by the Ethics Committee of Shanghai Sport University (Ethics Registration Number: 102772023RT075) and the World Health Organization International Clinical Trials Registry Platform Level 1 Registry (China Clinical Trials Registry, Registration Number: ChiCTR2400087257, registration period is July 23). All participants were recruited in the university town of Songjiang District, Shanghai, and the method of convenient sampling was used to recruit exercise intervention among undergraduates through the promotion of university teachers. The subjects eligible for the study were numbered sequentially and randomly assigned to the taekwondo group and the control group in a 1:1 ratio. Inform the subjects of the purpose and content of the study before the test, and sign the informed consent form to indicate their willingness to participate in this study. The recruitment and experimentation period is from October 31 to December 29, 2023.

Inclusion and exclusion criteria

(1) Aged 18–25 years. (2) Non-physical education majors. (3) Beck Depression Inventory Second Edition (BDI-II) score > 13.4.No history of psychiatric disorders or current chronic diseases.5.Normal or corrected vision, without color blindness.6.Right-handedness.7.Native Mandarin speakers.8.Voluntary participation in the experimental study. (Fig. 1)

Experimental tools

Demographic information

A self-designed demographic information questionnaire was administered to the university students to gather baseline data. The questionnaire included the following content: Height、Weight、Age、Gender、Acad emic Year、Major、History of smoking and alcohol consumption、Previous psychiatric history.

Beck depression inventory II (BDI-II)

BDI-II [12]is the most widely used self-assessment tool for screening depression symptoms and assessing the severity of depression. It primarily evaluates depressive symptoms over the past two weeks. This scale consists of 21 items that assess the severity of depressive symptoms based on the original scale provided by Beck et al. It uses a 4-point scoring system from 0 to 3, where scores of 0–13 indicate no depressive symptoms, 14–19 indicate mild depressive symptoms, 20–28 indicate moderate depressive symptoms, and ≥ 29 indicate severe depressive symptoms. The internal consistency coefficient of the BDI-II self-assessment scale in this study is 0.948 [13].

Physical activity rating scale (PARS-3)

This study utilizes a revised Chinese version of the PARS-3 scale developed by Liang De qing et al. The scale focuses on the physical exercise habits of the participants over the past month. It is commonly used to measure the basic physical activity levels of individuals, including exercise intensity, time, and frequency across three dimensions. Intensity and frequency are rated on a scale of 1 to 5, while time is rated on a scale of 0 to 4. The scale uses a scoring system of 1 to 5 for intensity and frequency, and 0 to 4 for time. The criteria for rating physical activity levels are as follows: 0–19 points indicate low physical activity, 20–42 points indicate moderate physical activity, and ≥ 43 points indicate high physical activity. This scale has been found to have good reliability and validity in assessing physical exercise among Chinese university students [14].

Rating of perceived exertion (RPE)

For moderate-intensity exercise, the recommended perceived exertion (RPE) range is approximately 12–15. If an individual reports an RPE value greater than 18, the experimenters must immediately stop the exercise.

Response inhibition task

This experiment utilizes the Go/Nogo task to measure response inhibition. The experimental design is mixed, with group as the independent variable (Taekwondo group and control group) and the Go/Nogo task as the dependent variable (Go reaction time, Go accuracy, and Nogo accuracy). The Go/Nogo task is conducted on a Windows laptop equipped with MATLAB 2022b software. The screen measures 12.4 inches with a resolution of 2256 × 1504, operating on Windows OS, and set to a refresh rate of 60 Hz. Participants are instructed to maintain a distance of approximately 50 cm from the screen to avoid excessive blinking, remain relaxed in their sitting posture, and focus on quickly responding to target stimuli. The experiment is programmed and executed using MATLAB 2022b software. Stimuli are presented randomly, and MATLAB 2022b records all participants' reaction times, accuracy, missed responses, and errors. The letter "M" represents Go stimuli, and the letter "W" represents Nogo stimuli. Participants are instructed to respond with different key presses: when a Go stimulus appears in the center of the screen, they should quickly press the "J" key with their index finger; no action is required for Nogo stimuli. The target stimulus disappears immediately after the key press; if no key is pressed, the stimulus disappears automatically after 1000 ms. Prior to the formal experiment, there is one practice session where participants first perform a key press practice to familiarize themselves with the keyboard layout. After practicing and fully understanding the experimental process, participants can proceed to the formal experiment. During the experiment, stimuli will randomly appear in the center of the screen, each displayed for 800 ms, with random intervals of 200–800 ms between stimuli. There will be a total of 120 trials, with 90 Go presentations and 30 Nogo presentations, with probabilities of 75% and 25%, respectively [15]. At the end of each trial, the computer records the participant's reaction time and accuracy (Fig. 2).

Experimental equipment

EEG tester

The EEG and evoked potential device used is manufactured by Shanghai Nuocheng Electric Ltd. (NCERP-190012). This equipment has a maximum sampling rate of 8 kHz per channel and a resolution of 32 bits, which has been proven to be advantageous for research purposes [16–18].

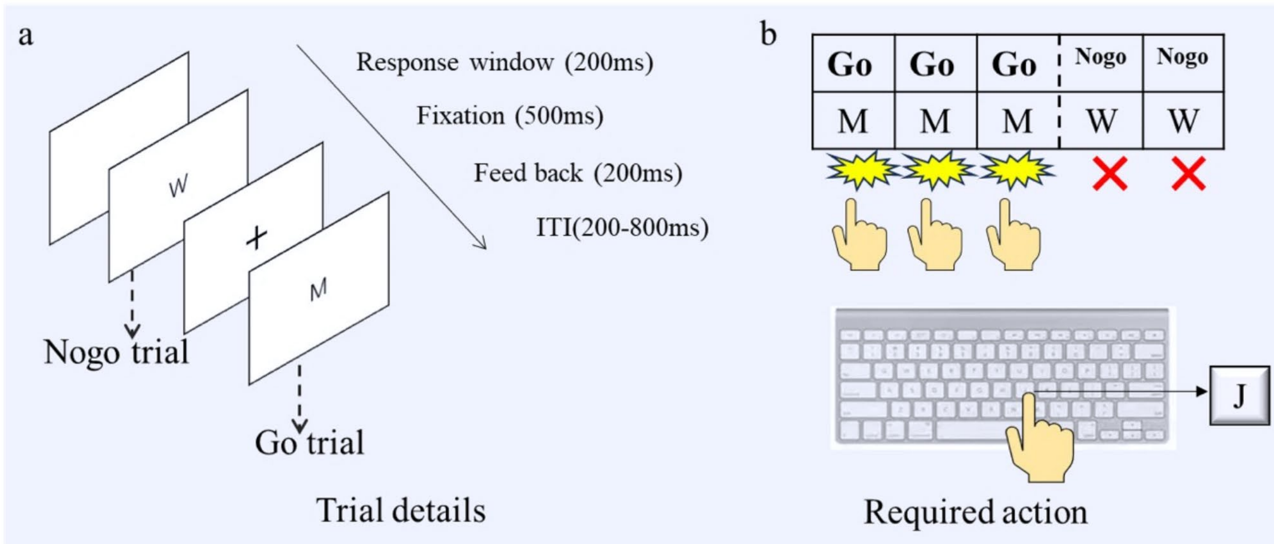

Fig. 2 Flowchart of Go/Nogo task

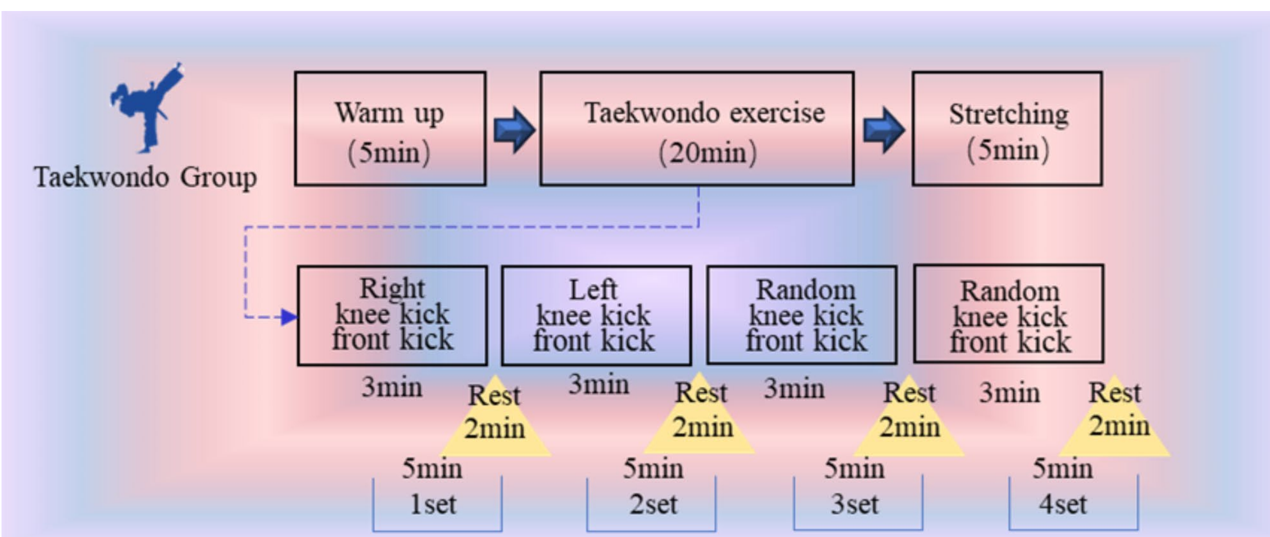

Fig. 3 Exercise program

One HP desktop computer (model P22vG5FHD) with a 15-inch screen and a resolution of 1024 × 768, operating on Windows OS, is used to monitor brain waves.

Laptops

Two Windows laptops with 12.4-inch screens and a resolution of 2256 × 1504: one is used for behavioral task stimuli, and the other is used for data storage and processing.

Heart rate monitor

Polar H10 heart rate monitor from Polar Electro Inc., Finland.

Intervention program

Taekwondo group

Participants will engage in reaction target practice, including knee kick and front kicks in a mixed Taekwondo intervention. A total of 4 sets will be conducted, each lasting 5 min, which includes 3 min of exercise and 2 min of marching in place. The total duration of the intervention is 30 min, including 5 min of warm-up, 5 min of relaxation, and 20 min of moderate-intensity (64-76% HRmax) interval exercise. Participants are required to complete the intervention within the allocated time. (Fig. 3)

Control group
Participants will sit quietly in a quiet room for 30 min, during which they may choose to read materials related to mental health education for university students.

Quality control
Time arrangement
The exercise time for participants is primarily concentrated during the day, specifically from 1:00 PM to 5:00 PM. The control group will not engage in regular exercise during the intervention period.

Testing location
The Taekwondo group's intervention will begin one week after baseline testing. All physical exercise interventions will take place in a safe exercise room equipped with Taekwondo mats. Participants will wear heart rate monitors throughout to monitor target intensity.

Personal arrangement
Based on previous studies on depressed populations, and considering the psychological acceptance and rejection effects of depressed university students along with their academic schedules, this study's long-term physical exercise intervention cycle is set for 8 weeks, with a frequency of 3 times per week, for 30 min each session. Two Taekwondo professionals participating in this study will be fixed to assist in organizing the sessions. Participants from both the Taekwondo and control groups will come from the same university campus in Songjiang, ensuring a consistent living environment, with attendance and exercise frequency being monitored.

Lifestyle control
During the experiment, this study controlled the participants' basic lifestyle habits (e.g., smoking, drinking, interpersonal relationships, sleep, etc.) based on questionnaire results to ensure baseline consistency. All participants were instructed to maintain their normal lifestyle habits throughout the duration of the study.

Data analyses
Behavioral data
Behavioral data on reaction times and accuracy will be collected using MATLAB 2022b software. Reaction time data that falls outside three standard deviations from the mean will be excluded, and the cleaned data will be imported into Excel. Data analysis will be conducted using IBM SPSS 29.0 statistical software, with count data expressed in frequencies or percentages.

Event-related potential (ERP) data
This study focuses on analyzing the ERP components evoked by target stimuli. Based on the stimuli induced by the behavioral tasks, EEG ERP signals will be obtained. Data collection will be conducted using an EEG cap, and the collected EEG signals will be exported in EDF format using specialized software for further processing. The data processing steps are as follows:

1. To import single data, load the raw data in EDF format.
2. Determine the number of channels in the data for electrode potentials.
3. Set the sampling rate to 256 Hz.
4. Convert the reference electrode to bilateral mastoid (A1, A2) reference for re-referencing.
5. Use a 0.1 Hz high-pass filter to remove non-physiological slow drifts from the EEG recordings. Apply a band-pass filter of 0.1–30 Hz to eliminate voltage drifts caused by sweating and high-frequency noise above 30 Hz.
6. Create an event list.
7. Import bin statements.
8. In ERP studies, segment the EEG signals according to different experimental conditions. For this study, segment the data according to markers to obtain key EEG ERP signal segments, using the appearance of the point stimulus as time zero, and extract data from − 200 to 800ms. This requires baseline correction.
9. During data inspection, delete segments with significant drift or those that cannot be corrected using ICA. Exclude data with amplitudes exceeding + 100μV after segmentation.
10. Use ICA to remove EEG artifacts and reconstruct EEG signals using the remaining components.
11. Use ADJUST to remove low-frequency noise caused by baseline drift.
12. Average the data to improve the signal-to-noise ratio and collect the EEG ERP signals evoked during the behavioral tasks of individual participants. Export the data.
13. To import batch data, load data from multiple participants
14. Average the ERP data for participants in both the Taekwondo group and control group within their respective groups to acquire ERP signals for both groups.
15. Save the average data for multiple groups. Based on previous studies and the primary brain regions involved in inhibition functions, this research selects the Fz, Cz, Pz, and Oz electrode sites for analysis. The ERP averaged data will specifically focus on the N2 component's amplitude and latency in the 200-400ms time window during the Go/Nogo task related to response inhibition; data exceeding three

standard deviations above the mean will be excluded from subsequent analyses.

Experimental procedure

(1) Before the start of the behavioral task testing, participants will wear a 32-channel EEG cap, and conductive paste will be applied to reduce the impedance of the scalp and electrodes to below 5Ω. While reducing the resistance, the entire experimental procedure will be explained to the participants. After understanding the entire experiment, MATLAB 2022b software will be opened, and participants will be guided to carefully read and familiarize themselves with the testing tasks. Only then will the formal testing begin.

(2) The behavioral task will be conducted in front of a laboratory computer using a Go/Nogo task. Participants will undergo the behavioral testing while their data and event-related potentials are recorded. Each experimental session will last approximately 10 min. During the experiment, participants will be provided with physical and psychological adjustments to ensure they remain alert and relaxed. After proper adjustments, the experimental signal collection will be restarted.

(3) The Taekwondo group will perform their exercises in a designated intervention room. Before the actual exercise, participants will wear appropriate sports clothing, and efforts will be made to minimize disturbances from others during the testing process. Participants will wear heart rate monitors on their chests (just below the breasts) and engage in approximately 5 min of warm-up activities.

(4) During the exercise, to ensure the intensity of the intervention is maintained, real-time heart rate telemetry systems will be used to monitor exercise intensity, starting timing when the target heart rate zone is reached. Every 5 min, participants will be asked to rate their exertion using the Rate of Perceived Exertion (RPE) scale. If participants feel any discomfort during the exercise, the process will be halted immediately. After 20 min of exercise intervention, a 5 min relaxation period will follow. During the exercise, physical and psychological adjustments will be made to ensure that participants remain alert and relaxed. The control group will be required to sit quietly in a calm room for 30 min, during which they may choose to read materials related to mental health education for university students.

(5) Once the exercise duration reaches 30 min, participants will stop exercising. After completing the exercise, their scalps will be dried, and the EEG cap will be reapplied to maintain the experimental conditions. To achieve optimal experimental control, the preparation time for the experiment must be precisely controlled within 5 min. After the experimental preparation is completed, the second phase of the signal stop task will commence, while their data and event-related potentials are recorded. After the experiment, participants will wash their hair to remove any residual EEG paste, and they will be thanked for their participation. The experiment lasts for 8 weeks, with each participant engaging in 30 min of moderate-intensity Taekwondo exercise three times per week. (Fig. 4)

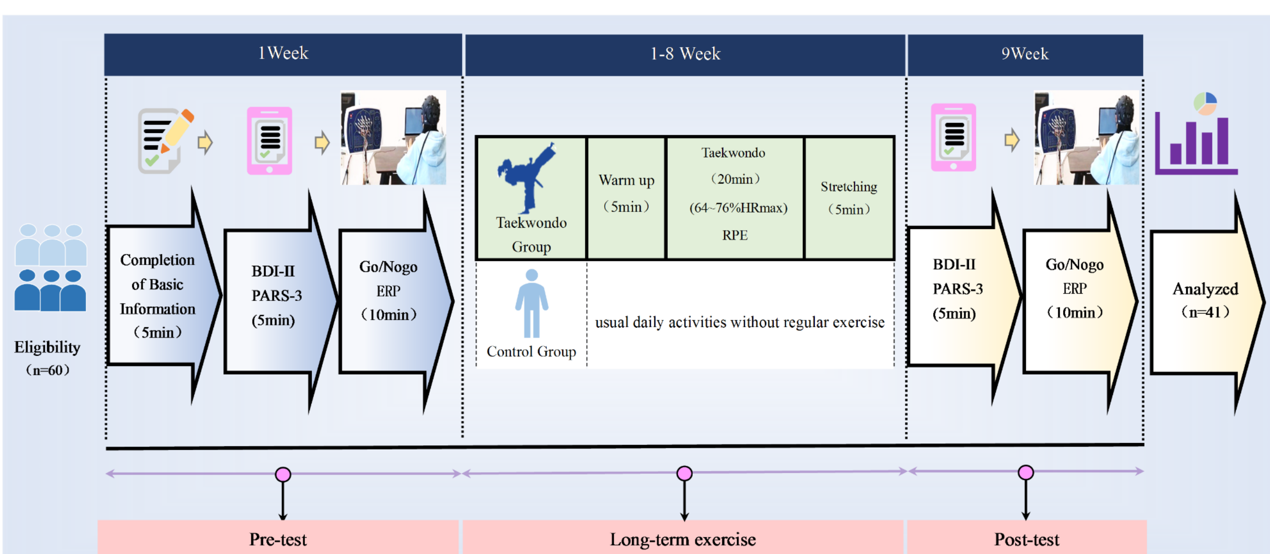

Fig. 4 Flowchart of study experimental Procedure

Table 1 Baseline sample characteristics of University students with depressive symptoms

Variables	Taekwondo Group($n = 20$)	Control Group($n = 21$)	Difference test
Age(years)	19.60 ± 1.429	19.86 ± 1.315	$P = 0.553$
Gender (Male/%)	35.00	38.09	$P = 0.616$
Drinking (Yes/%)	10.00	14.28	$P = 0.683$
Smoke (Yes/%)	0	4.76	$P = 0.329$
Single child (Yes/%)	65.00	57.14	$P = 0.616$
Single Parent (Yes/%)	10.00	9.52	$P = 0.960$
Height (cm)	1.667 ± 0.088	1.670 ± 0.107	$P = 0.922$
Weight (kg)	58.415 ± 11.366	60.190 ± 12.201	$P = 0.632$
BMI(kg/m^2)	20.885 ± 2.774	21.437 ± 2.507	$P = 0.509$
Interpersonal relationships			$P = 0.942$
Poor (%)	60.000	57.142	
Average (%)	25.000	57.142	
Good (%)	20.000	14.285	
Sleep quality			$P = 0.704$
Poor (%)	10.000	19.047	
Average (%)	45.000	38.095	
Good (%)	45.000	42.857	
Social activities			$P = 0.368$
None (%)	25.000	38.095	
1–3 times a week(%)	75.000	61.904	
4–6 times a week (%)	0	0	
Every Day (%)	0	0	
PARS-3 Score	24.35 ± 17.892	17.14 ± 15.242	$P = 0.174$
BDI-II Score	18.40 ± 5.816	17.62 ± 3.106	$P = 0.598$

Data processing

All data processing and chart creation in this study were conducted using MATLAB and SPSS 29.0 for analysis, If participants dropped out during the experiment due to health or academic issues, their data were excluded from the analysis. Continuous variables were analyzed using independent samples t-tests, while categorical variables were analyzed using chi-square tests. Repeated measures ANOVA was used to compare differences between groups, conditions, and potential changes. All statistical inferences were based on a two-tailed test with a significance level of α set at 0.05. A *p*-value greater than 0.05 indicates that the difference is not statistically significant, while *p*-values less than 0.05, 0.01, and 0.001 denoting statistically significant differences. If data loss occurred during the experiment, multiple imputation or listwise deletion was employed for relevant processing.

Results

Basic information of university students with depressive symptoms

Comparison of Basic Information of University Students with Depressive Symptoms. Before the experiment, a difference test was conducted on the age, height, weight, BMI, PARS-3, and BDI-II scores of the two groups of participants. The results indicated that there were no statistically significant differences in any of the indicators between the two groups ($P > 0.05$). All demographic factors were controlled before grouping, and all subjects were required to maintain normal lifestyle habits during their participation in the long-term experiment to avoid interference from other factors in the experimental results. (Table 1)

Changes in BDI-II scores of the taekwondo group and control group before

The 8-week Taekwondo exercise intervention significantly improved depressive symptoms in the exercise group (with a significant decrease in BDI-II scores), while depressive symptoms in the control group worsened, although the difference was not statistically significant. Furthermore, after 8 weeks of exercise, the difference in BDI-II scores between the two groups was statistically significant, indicating that regular moderate-intensity Taekwondo exercise intervention has a positive effect on alleviating depressive symptoms (Table 2; Fig. 5). These results suggest that engaging in regular Taekwondo exercise, while maintaining existing lifestyle habits, could be an effective non-pharmacological approach to improving depressive symptoms.

Behavioral task results

In the behavioral results of the response inhibition task (Go/Nogo), repeated measures ANOVA showed(Table 3) that there were no significant differences between groups under both Go and Nogo conditions in the pre-test phase ($P > 0.05$). In the post-test phase, the accuracy rates under the Go condition between the Taekwondo group and the control group showed statistically significant differences ($P < 0.05$), as did the accuracy rates under the Nogo condition ($P < 0.05$). For the control group, there were no significant differences in accuracy rates between the pre-test and post-test under both conditions ($P > 0.05$). However, the Taekwondo group showed significant differences in accuracy rates under the Nogo condition between the pre-test and post-test ($P < 0.001$); the post-test accuracy rate under the Nogo condition for the Taekwondo group

Table 2 Comparison of BDI-II scores between the Exercise Group and Control Group before and after 8 weeks of intervention

	Pre-test	Post-test	Difference test	Difference test
Exercise group	18.40 ± 5.816	11.85 ± 5.932	t = 5.372, $P < 0.001$	t = 4.36, $P < 0.001$
Control group	17.62 ± 3.106	18.43 ± 3.472	t=-1.718, $P = 0.101$	

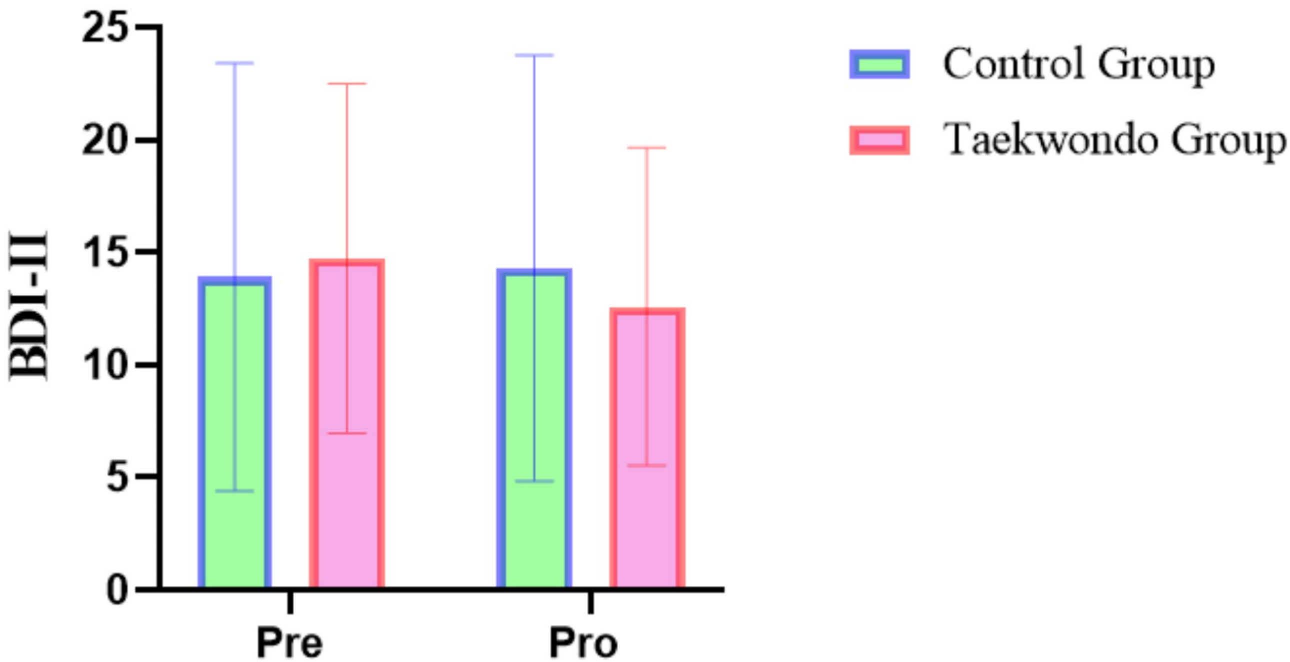

Fig. 5 Changes in BDI-II Scores of the Taekwondo Group and Control Group Before and After 8 Weeks

Table 3 Comparison of the Effect of 8 weeks of Taekwondo Training on Response Inhibition in University students with depressive symptoms

Group		Go RT (ms)	Go ACC (%)	Nogo ACC (%)
Control Group	Pre-test	0.325 ± 0.034	93.708 ± 7.896	64.484 ± 18.502
(*n* = 21)	Post-test	0.320 ± 0.057	95.158 ± 6.181	66.475 ± 22.715
Taekwondo Group	Pre-test	0.330 ± 0.040	97.142 ± 6.129	55.033 ± 25.677
(*n* = 20)	Post-test	0.324 ± 0.045	93.208 ± 22.082	74.991 ± 15.646

was significantly higher than that of the control group ($P < 0.001$).Regarding reaction times in the response inhibition task (Go/Nogo), repeated measures ANOVA results indicated that there were no statistically significant differences in reaction times before and after the tests across different groups ($P > 0.05$). Furthermore, the differences in reaction times between the two groups at different time points were also not statistically significant ($P > 0.05$).

These results suggest that Taekwondo training may selectively enhance response inhibition in individuals with depressive symptoms by improving the accuracy of decision-making under challenging conditions. The lack of significant changes in reaction times indicates that the cognitive benefits of exercise may primarily target higher-order executive functions rather than basic sensorimotor processes. This highlights the potential of cognitively engaging physical activities, such as Taekwondo, as effective interventions for improving specific aspects of cognitive performance in this population.

ERPs results

N2 amplitude

In the response inhibition task (Go/Nogo), the results of the repeated measures ANOVA for N2 amplitude showed significant main effects for time (Table 4; Fig. 6), $F(1,39) = 4.217$, $P < 0.047$, $\eta p^2 = 0.098$; for condition, $F(1,39) = 67.162$, $P < 0.001$, $\eta p^2 = 0.633$; and for electrode site, $F(3,117) = 51.048$ $F(3,117) = 51.048$, $P < 0.001$, $\eta p^2 = 0.567$. The interaction effect between time and group was significant, $F(1,39) = 4.821$, $P = 0.034$, $\eta p^2 = 0.110$; the interaction effect between condition and electrode site was also significant, $F(3,117) = 18.368$, $P < 0.001$, $\eta p^2 = 0.320$. In the interaction effect between time and group, there were no statistically significant differences between the Taekwondo group and the control group in the pre-test ($P > 0.05$). However, differences were found in the post-test, which were statistically significant ($P < 0.05$). In the interaction effect of group and time, the control group showed no statistically significant differences between pre-test and post-test ($P > 0.05$), while the Taekwondo group exhibited significant differences ($P < 0.05$). The N2 amplitude differences at electrode sites Fz, Cz, Pz, and Oz between the Taekwondo and control

Table 4 N2 ERP amplitudes (μV) across condition and time

N2	Control group(*n*=21) amplitude(μV)		Taekwondo group(*n*=20) amplitude(μV)	
	Pre-test	**Post-test**	**Pre-test**	**Post-test**
Go trial				
Fz	-6.328±2.468	-7.394±2.280	-7.482±2.892	-9.074±3.297
Cz	-6.049±2.912	-6.487±2.512	-6.729±2.753	-8.220±2.836
Pz	-6.062±2.049	-6.661±2.339	-5.687±1.921	-6.383±1.749
Oz	-5.666±2.423	-4.994±2.301	-4.790±2.723	-5.181±2.066
Nogo trial				
Fz	-12.443±5.671	-11.613±6.478	-13.824±7.687	-15.388±5.289
Cz	-11.880±6.805	-10.372±4.636	-12.704±6.358	-14.248±6.049
Pz	-10.067±4.821	-8.785±4.748	-9.361±5.323	-10.789±3.901
Oz	-8.281±3.740	-6.746±3.549	-7.040±4.109	-9.354±5.719

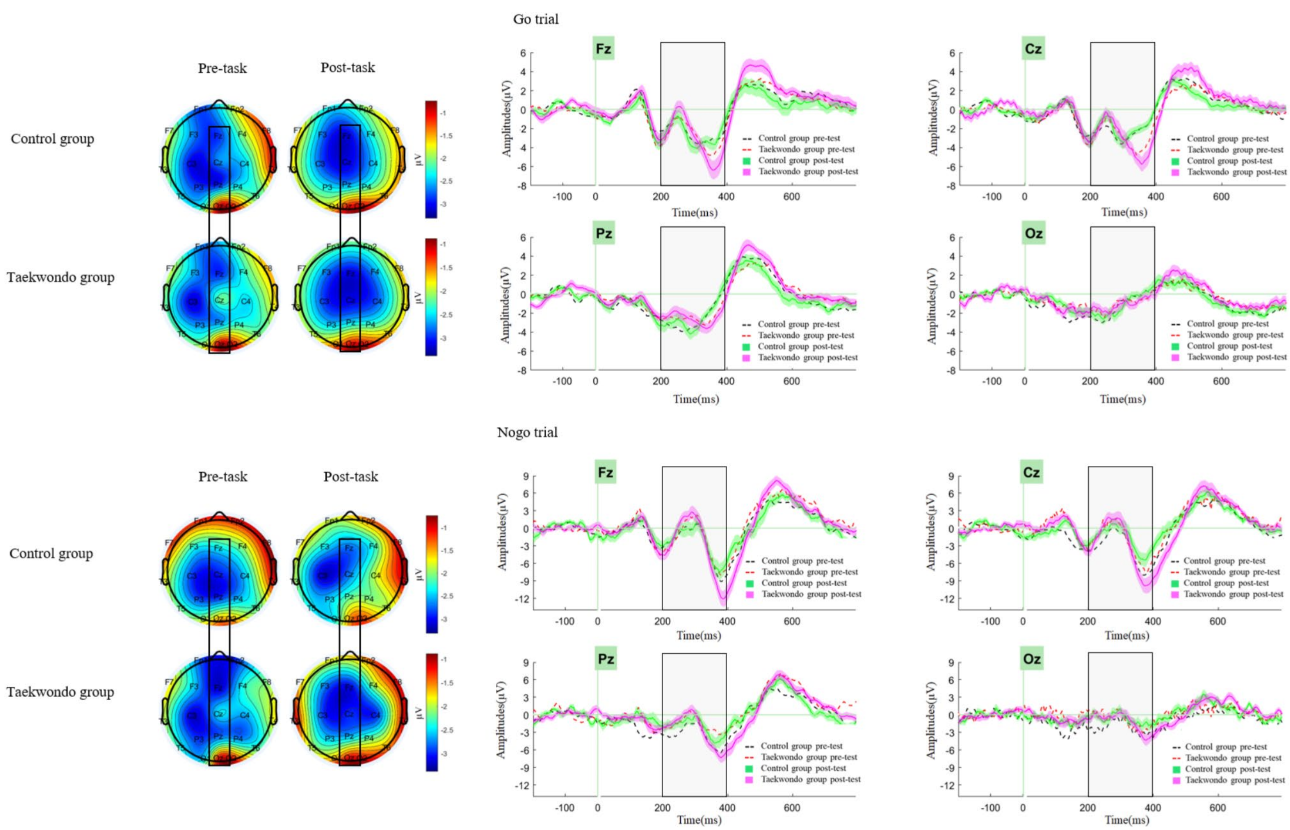

Fig. 6 Difference scalp maps and waveforms averaged across a region-of that the electrodes (Fz, Cz, Pz, Oz) by treatment

groups were not statistically significant ($P>0.05$).In the interaction effect of group and electrode site, there were no statistically significant differences in N2 amplitude between Fz and Cz in the control group ($P>0.05$), but significant differences were observed between Pz and Oz ($P<0.05$); significant differences were also found between Cz and Pz ($P<0.05$), between Cz and Oz ($P<0.05$), and between Pz and Oz ($P<0.05$). In the Taekwondo group, there were no statistically significant differences in N2 amplitude between Fz and Cz ($P>0.05$), while significant differences were found for Pz ($P<0.05$) and Oz ($P<0.05$). Additionally, there were significant differences between Cz and Pz ($P<0.05$), between Cz and Oz ($P<0.05$), and between Pz and Oz ($P<0.05$).In the interaction effect of condition and electrode site, significant differences in N2 amplitude were observed between Fz and Pz, Cz, Oz under the Go condition ($P<0.05$); significant differences were also found between Cz and Pz, Oz ($P<0.05$), and between Pz and Oz ($P<0.05$). Under the Nogo condition, no statistically significant difference was found between Fz and Cz ($P>0.05$), but significant differences were present between Fz and Pz, Oz ($P<0.05$); and

Table 5 N2 ERP latency (ms) across condition and time

N2	Control group($n=21$) latency(ms)		Taekwondo group($n=20$) latency(ms)	
	Pre-test	**Post-test**	**Pre-test**	**Post-test**
Go trial				
Fz	283.668 ± 68.726	299.479 ± 94.756	318.164 ± 91.095	304.209 ± 83.496
Cz	266.927 ± 66.810	289.062 ± 104.982	296.289 ± 91.436	289.125 ± 81.284
Pz	239.025 ± 53.710	276.785 ± 114.548	319.140 ± 65.488	275.020 ± 63.757
Oz	243.303 ± 120.329	246.093 ± 107.900	274.804 ± 144.468	216.601 ± 82.664
Nogo trial				
Fz	340.215 ± 86.078	366.629 ± 67.243	373.437 ± 82.489	325.390 ± 100.258
Cz	320.126 ± 92.838	329.055 ± 86.934	369.335 ± 64.541	294.921 ± 95.123
Pz	264.508 ± 122.035	354.166 ± 97.173	354.492 ± 80.911	317.773 ± 92.606
Oz	218.563 ± 98.986	291.852 ± 109.786	333.984 ± 126.751	300.585 ± 117.717

significant differences were also found between Cz and Pz, Oz ($P<0.05$), and between Pz and Oz ($P<0.05$).In the interaction effect of electrode site and condition, significant differences in N2 amplitude were found among Fz, Cz, Pz, and Oz between the Nogo and Go conditions ($P<0.05$). (Fig. 6; Table 4)

These findings suggest that Taekwondo training led to significant improvements in neural processing related to response inhibition, as indicated by the enhanced N2 amplitude observed in the post-test phase for the exercise group. The N2 component, which is associated with conflict monitoring and cognitive control, showed notable sensitivity to Taekwondo training, particularly under the Nogo condition where inhibitory demands are higher. This result implies that such exercise may enhance the neural mechanisms underlying conflict resolution and inhibitory control, likely through increased engagement of prefrontal cortical areas. Underscore the potential of structured physical activities like Taekwondo to target specific neural processes and improve executive function in individuals with depressive symptoms.

N2 latency

The results of the repeated measures ANOVA for N2 latency indicated significant main effects for condition (Table 5; Fig. 6), $F(1,39)=32.957$, $P<0.001$, $\eta p^2=0.458$; and for electrode site, $F(3,117)=15.914$, $P<0.001$, $\eta p^2=0.290$. The interaction effect between time and group was significant, $F(1,39)=13.028$, $P<0.001$, $\eta p^2=0.250$; and the interaction effect between time, condition, and electrode site was also significant, $F(3,117)=3.199$, $P=0.026$, $\eta p^2=0.076$.In the interaction effect between time and group, the Taekwondo group showed significant differences in N2 latency between the pre-test and post-test phases ($P<0.05$). The control group did not show any statistically significant differences in N2 latency ($P>0.05$). In the interaction effect of time, condition, and electrode site, significant differences were found in N2 latency between Nogo and Go conditions at Fz and Cz in the pre-test phase ($P<0.05$), while no significant differences were observed at Pz and Oz ($P>0.05$). In the post-test phase, significant differences were found in N2 latency between Nogo and Go conditions at Fz, Pz, and Oz ($P<0.05$), whereas no significant differences were found at Cz ($P>0.05$).Under different conditions, there were no statistically significant differences in N2 latency between pre-test and post-test for all electrode sites under the Go condition ($P>0.05$), and similarly, no significant differences were found under the Nogo condition ($P>0.05$). In the interaction effect of time, condition, and electrode site, no significant differences were observed in N2 latency among all electrode sites under the Go condition during the pre-test phase ($P>0.05$). For the Nogo condition, no significant differences were found between Fz and Cz ($P>0.05$), while significant differences were found between Fz and Pz, Oz ($P<0.05$), and between Cz and Pz, Oz ($P<0.05$). Significant differences were also observed between Pz and Oz ($P<0.05$).In the post-test phase under the Go condition, no significant differences were found in N2 latency between Fz and Cz, Pz ($P>0.05$), but significant differences were observed between Fz, Cz, Pz and Oz ($P<0.05$). (Fig. 6; Table 5)

These findings indicate that Taekwondo training led to significant changes in N2 latency, a neural marker associated with conflict detection and cognitive control, particularly under conditions requiring response inhibition (Nogo). The shorter N2 latency observed in the Taekwondo group post-intervention suggests enhanced efficiency in neural processing during tasks involving inhibitory control. The results also highlight regional differences across electrode sites, with significant N2 latency effects emerging more prominently in frontal and parietal regions, which are critically involved in executive function and attention regulation. These findings suggest that Taekwondo training may improve the speed and coordination of neural activity underlying response inhibition, reflecting the enhanced integration of cortical areas associated with cognitive control. Furthermore, the absence of significant latency changes in the control group underscores the unique impact of structured physical activity in modulating these cognitive and neural processes.

Discussion

This study ultimately included 41 university students with depressive symptoms in the analysis of changes before and after an 8-week Taekwondo intervention. The results indicated that the Taekwondo group showed an increase BDI-II scores after the intervention. This suggests that Taekwondo training may have a positive effect on improving depressive symptoms and inhibitory function in university students. In contrast, the control group showed an increase in BDI-II scores after 8 weeks, which may indicate that their depressive symptoms did not improve during the experimental period [19]. From a neurobiological perspective, physical activities such as Taekwondo may improve inhibitory function by enhancing the function of the prefrontal cortex. The prefrontal cortex is a critical area for executive functions and is closely related to emotional regulation and cognitive control. Moreover, exercise can promote neurogenesis in the hippocampus, a brain region associated with emotional regulation and memory formation, which is often impaired in depression [20]. Biochemically, aerobic exercises like Taekwondo can increase levels of endorphins and serotonin in the serum, which are neurotransmitters related to emotional regulation and can alleviate depressive symptoms [21]. Exercise can also reduce cortisol levels, a hormone associated with stress responses, which is often elevated in patients with depression. In summary [22], Taekwondo and other forms of exercise may positively impact depressive symptoms and inhibitory function by improving brain function and regulating physiological and biochemical responses.

This study found that 8 weeks of Taekwondo training significantly improved the response inhibition ability of college students with depressive symptoms, particularly in terms of accuracy in the Nogo condition. Firstly, in terms of reaction time, although the main effect of group was not significant, the main effect of time was significant, indicating that the reaction time of the Taekwondo group was significantly shorter in the post-test. This suggests that college students who participated in Taekwondo training responded more quickly in the response inhibition task. This change may be closely related to the enhancement of executive functions in the brain. Executive functions, including task switching, working memory, and response inhibition, are primarily regulated by the prefrontal cortex (PFC) [23]. Research has demonstrated that regular physical activity can enhance both the function and structure of the prefrontal cortex [24], potentially facilitating faster cognitive processing in response inhibition tasks, thereby leading to quicker reaction times.Regarding accuracy in the response inhibition (Go/Nogo) task, the significant main effect of time also showed improvement in the response inhibition ability of the Taekwondo group after 8 weeks of training. Specifically, the Taekwondo group exhibited a significant increase in accuracy in the Nogo condition during the post-test. This could be attributed to enhanced functional connectivity in brain regions such as the prefrontal cortex and the anterior cingulate cortex (ACC) [25], which play central roles in emotional regulation, conflict monitoring, and cognitive control [26]. Taekwondo training may have facilitated the enhancement of these brain regions, thereby improving response inhibition ability, especially in tasks requiring stronger cognitive inhibition, such as the Nogo task. Additionally, the study found higher accuracy in the Go condition, with no significant main effect of group in this condition. This phenomenon may be due to the lower conflict monitoring demands in the Go condition. In the Go task, the brain primarily executes simple responses with lower cognitive demands, leading to less activation in the relevant brain regions compared to the Nogo condition. This may explain why there were no significant differences between the groups in the Go condition.In summary, 8 weeks of Taekwondo training improved the cognitive control network in the brain, particularly enhancing the functions of the prefrontal cortex and anterior cingulate cortex, which in turn increased the response inhibition ability of college students with depressive symptoms, especially in the Nogo task.

The ERP results indicated that in the interaction effect of time and group, the Taekwondo group exhibited significant changes in N2 amplitude after training, while the blank control group showed no significant changes. This suggests that Taekwondo training may enhance participants' response inhibition capabilities, as reflected in the post-test. The N2 amplitude is widely regarded as related to cognitive control processes, particularly during conflict resolution or response inhibition. Therefore, our findings may indicate that Taekwondo training enhances the cognitive control mechanisms of the brain, thereby improving executive function. In analyzing the interaction effect of electrode site and group, we found significant N2 amplitude changes at Pz and Oz in both the blank control and Taekwondo groups. The changes at Pz are particularly noteworthy as they relate to spatial attention and the regulation of working memory, while changes at Oz may reflect improvements in visual processing abilities. Taekwondo training emphasizes the use of visual-spatial skills, which may explain the observed N2 amplitude changes at these specific electrode sites. Under the interaction effect of electrode site and condition, we found significant changes in N2 amplitude at Fz, Cz, Pz, and Oz, further supporting the notion that Taekwondo training can improve cognitive control and response inhibition. Notably, the significant increase in N2 amplitude under the Nogo condition may reflect higher levels of inhibitory control, associated with enhanced prefrontal cortex activity. The impact of Taekwondo training on N2 amplitude changes in the response inhibition (Go/Nogo task) reveals potential neuroplasticity and improvements in cognitive control mechanisms. The enhancement of the N2 component under the Nogo condition indicates an improvement in cognitive control capabilities associated with increased pre-frontal cortex (PFC) functionality [23]. The PFC is a key area closely linked to higher cognitive functions such as decision-making, attention, and executive control, facilitating the processing of task-relevant in-formation by inhibiting the processing of irrelevant or distracting stimuli [27]. At the biological level, Taekwondo training may affect PFC function by promoting synaptic plasticity and increasing the expression of neurotrophic factors. Synaptic plasticity, particularly long-term potentiation (LTP) and long-term depression (LTD), are crucial mechanisms for learning and memory, serving as the foundation for improvements in cognitive function [28]. Exercise training has been shown to increase levels of neurotrophic factors like brain-derived neurotrophic factor (BDNF), which are essential for maintaining and enhancing synaptic connections [10, 29]. Furthermore, Taekwondo training may impact neural networks related to PFC function through enhanced inhibitory control. This includes interactions with the dorsolateral prefrontal cortex (DLPFC) and anterior cingulate cortex (ACC) [25], both of which play central roles in response inhibition, error detection, and conflict monitoring [30]. Particularly, increased ACC activity is associated with more effective cognitive control and inhibition, which may explain the observed increase in N2 amplitude under the Nogo condition. Additionally, Taekwondo training may enhance visual-spatial information processing abilities, as reflected in the N2 amplitude changes observed at Pz and Oz, potentially indicating improvements in the functions of the parietal and occipital lobes. These areas are critical for processing visual information and spatial attention, which are essential for executing complex motor tasks and responding to environmental changes [31].

The results of this study also reveal the complex dynamics of how different task conditions and Taekwondo training influence N2 latency in the response inhibition (Go/Nogo) task, particularly the changes across different electrode sites and conditions. In the pre-test phase, Fz and Cz showed significantly prolonged N2 latencies under the Nogo condition compared to the Go condition, which may indicate the activation of the prefrontal cortex during inhibitory task execution [32]. The prefrontal cortex plays a key role in regulating attention, decision-making, and executive control, with increased activation generally associated with greater task difficulty or cognitive demand [33]. Notably, the enhanced activity of Fz and Cz may reflect a more focused attention and higher-level information processing, crucial for inhibiting non-target responses. In the post-test phase, although the N2 latency differences at Cz between the Nogo and Go conditions were no longer significant, significant prolongations in N2 latency were observed at Pz and Oz under the Nogo condition. This change may indicate adjustments in the cognitive control strategies of the participants, along with enhanced functions of the parietal and occipital lobes in processing visual-spatial information and executing control tasks. The parietal cortex is involved in spatial attention and perceptual integration, while the occipital lobe is primarily concerned with visual processing [28]. These results suggest that enhancing the processing and integration of visual-spatial in-formation may have improved participants' executive control capabilities in complex tasks. In terms of cognitive neuroprocessing mechanisms, our results indicated that only the Taekwondo group exhibited differences in N2 latency before and after testing. We propose that long-term Taekwondo training may have promoted more effective coordination between key networks in the brain involved in executive control and attention regulation. The enhanced connectivity between the prefrontal and parietal cortices is particularly important, as these areas collaborate in response inhibition, error monitoring, decision-making, and working memory [32].Changes in N2 latency may reflect the outcomes of this network adjustment, particularly under the Nogo condition, which requires inhibiting non-target responses. Such adjustments may enhance cognitive control by optimizing resource allocation and improving processing efficiency [34]. Based on previous research, we suggest that Taekwondo training may influence cognitive control by modulating the activity of specific neurotransmitter systems. For instance, the dopaminergic system in the prefrontal cortex plays a central role in regulating attention, motivation, and reward-dependent learning [35]. Enhanced release of dopamine may improve signal processing in the prefrontal regions, thereby increasing the efficiency of processing tasks requiring higher inhibitory control. Furthermore, long-term Taekwondo training may promote the structural and functional plasticity of the potentials associated with cognitive control, including the capacity for synaptic plasticity and neuronal regeneration [36]. Studies have confirmed that exercise training increases levels of BDNF, a key neurotrophic factor vital for promoting synaptic plasticity, neuronal survival, and neurogenesis [10, 29]. By enhancing brain plasticity, Taekwondo training may improve the efficiency and adaptability of cognitive control networks, resulting in better performance in complex cognitive tasks.

Combining the synchronized results from behavioral performance and ERPs, the effects of an 8-week moderate-intensity Taekwondo intervention on response inhibition in university students with depressive symptoms may involve the following cognitive neural processing mechanisms:1.Regular moderate-intensity Taekwondo exercise can enhance signal transmission in the prefrontal cortex, which plays a pivotal role in attention allocation and decision-making processes.2.Long-term physical exercise may improve the efficiency of cognitive resource mobilization by strengthening the collaboration between the frontal-central (Fz) and central-parietal (Cz, Pz) regions, thereby optimizing executive function.3.In terms of visual-spatial information processing, significant changes in the occipital region (Oz) may reflect the modulatory effects of exercise training on the parietal-occipital pathway, which plays a critical role in information integration during complex task situations.These mechanisms not only demonstrate the potential value of long-term exercise interventions in improving cognitive function in university students with depressive symptoms but also offer a new perspective for further exploration of the effects of exercise from the standpoint of cognitive neural processing mechanisms.

Conclusion

This study, based on questionnaire scores, behavioral performance, and event-related potentials (ERPs) evidence, confirmed that an 8-week Taekwondo exercise intervention had an improvement on the inhibitory control function of university students with depressive symptoms. The changes in Fz, Cz, and Pz electrode activation levels under task conditions may represent the cognitive neural processing mechanisms by which Taekwondo exercises improve inhibitory control in students with depressive symptoms.

Limitations and future directions

1. This study was conducted using a convenience sampling method, which, while convenient, still carries a certain degree of bias. Future research will adopt more accurate and representative methods, such as stratified random sampling or cluster sampling, to enhance the precision of the research findings.
2. The participants in this study were limited to college students from a specific region in China, which may not comprehensively reflect the situations of populations from different regions, cultural backgrounds, or age groups. Additionally, the sample size was estimated using G-power software, which may limit the broader applicability of the statistical analyses. Future studies should expand the sample size to improve the generalizability of the findings.
3. Due to limitations in technical conditions, this study only measured event-related potentials (ERPs) at four electrode sites (Fz, Cz, Pz, and Oz) and did not perform data-driven analyses across the full electrode array. Future research could employ more electrode sites and incorporate multimodal techniques, such as fMRI, near-infrared spectroscopy, or nuclear magnetic resonance, to conduct more comprehensive studies.
4. Although this study employed an 8-week cognitive engagement exercise intervention, it did not explore the specific time effects of the intervention on the inhibitory function of college students with depressive symptoms at different time points (e.g., the 2nd, 4th, 6th, or 8th week). Consequently, the sustainability of the intervention effects remains unclear. Future studies will further investigate the impact of exercise interventions over various time periods on the inhibitory function of depressed college students.
5. This study primarily analyzed behavioral changes in response inhibition, changes in brain activation at different electrode sites, and variations in depressive symptoms and physical activity levels after a long-term exercise intervention. However, other demographic characteristics, such as sleep quality and interpersonal relationships, were not followed up. Future research could explore the sustained effects of long-term exercise on these factors by conducting surveys on non-medical variables at multiple time points using both online and offline methods.

Author contributions

Mrs. S.Y.: data collect and manuscript editing；Mr. Z. G.: data collect；Mrs. S.L.: data collect；Mrs. S.J.: data collect；Mr. C. L.: data collect；Mrs. X.W.: data collect；Mr. X. W.: data analysis；Mrs.H.W.: review and editing.

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Data availability

This study was reviewed and approved by the relevant authorities of the Chinese Clinical Trial Registry (Registration Number: ChiCTR2400087257, the registration period is July 23, 2024). All data are subject to confidentiality agreements signed by the researchers.

Declarations

Ethical approval and consent to participate

This study was conducted in accordance with the ethical principles outlined in the Declaration of Helsinki and was approved by the Shanghai Sport University (Ethics Registration Number: 102772023RT075). All participants provided written informed consent prior to their inclusion in the study. They were informed of the study's purpose, procedures, potential risks, and benefits, as well as their right to withdraw at any time without penalty. For participants diagnosed with depressive symptoms, additional care was taken to ensure they fully understood the study procedures, and resources for mental health support were made available as needed. The confidentiality and anonymity of all participants were strictly maintained throughout the research process.

Consent for publication
All authors consented to the publication of the manuscript.

Competing interests
The authors declare no competing interests.

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