



Research on the effect of electronic brain game training on executive function in the elderly from the perspective of neuroplasticity

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SUMMARY: *In order to explore the effect of electronic brain game training on the executive function of the elderly and its neuroplasticity mechanism, this paper constructed a research framework of "training stimulation-neural adaption-executive function improvement". Eighty elderly people aged 60-80 years old were selected and divided into electronic brain game training group and routine activity control group. The intervention experiment lasted for 8 weeks, 30 to 40 minutes each time, 3 times a week. The training content covered working memory, inhibitory control, cognitive flexibility and attention control modules, and was evaluated in combination with indicators such as reaction time, accuracy rate, error rate, completion rate, prefrontal HbO activation and functional connectivity strength. The results showed that the comprehensive score of executive function in the experimental group increased from 68.4 to 82.9, the reaction time decreased from 845 ms to 706 ms, the correct rate increased from 78.6% to 89.4%, and the error rate decreased from 18.7% to 10.2%. At the same time, the amplitude of prefrontal HbO activation increased from 0.31 to 0.48, and the correlation coefficient between the neuroplasticity response index and the improvement rate of executive function reached 0.88. Studies have shown that electronic brain game training can promote the improvement of executive function in the elderly through continuous cognitive stimulation, difficulty adaptation and immediate feedback.*

KEYWORDS: *neuroplasticity; Electronic brain game; The elderly; Executive function*

1 Introduction

As the degree of population aging continues to deepen, the decline of cognitive function in the elderly has become a key issue affecting healthy aging and life independence. Among them, executive function, as an important component of advanced cognitive control ability, is directly related to the performance of the elderly in planning, attention allocation, interference suppression, task switching and daily decision-making. The decline of executive function is not a single behavioral problem, but is closely related to neurophysiological changes such as the decline of prefrontal regulation ability, the weakening of brain network connection efficiency, and the reduction of neural information processing speed. Therefore, exploring the intervention mechanism of executive function in the elderly from the perspective of neuroplasticity can provide a more explanatory research path for digital cognitive training and smart pension services.

In recent years, electronic brain games, computerized cognitive training and online cognitive intervention have gradually become important ways of cognitive health

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management for the elderly. Benge and Scullin (2025) studied the relationship between technology use and cognitive aging, and pointed out that digital technology participation may be associated with cognitive maintenance in old age [1]. Brodaty et al. (2025) found through an online multi-domain lifestyle intervention study that digital intervention can be used for long-term cognitive protection in the elderly at risk of cognitive decline [2]. Turnbull et al. (2024) proposed that digital non-drug intervention should pay attention to the differentiated needs and accessibility of the elderly group, which provided a theoretical basis for the aging design of electronic brain game training [3]. Guimaraes et al. (2025) studied the effective participation in computerized cognitive training for the elderly, emphasizing that training engagement, task persistence and feedback mechanism have an important impact on the training effect [4].

Different from general digital activities, electronic brain game training usually forms a continuous activation of working memory, inhibitory control, cognitive flexibility and attention regulation through immediate feedback, rule switching, difficulty progression and multitask stimulation. Lee et al. (2024) studied the effects of computerized cognitive training on cognitive performance and biomarkers of brain structural aging in the elderly, indicating that such training not only involves behavioral performance improvement, but also may be associated with adaptive changes at the neural level [5]. Hausman et al. (2023) conducted a randomized clinical trial of transcranial direct current stimulation combined with cognitive training, which further suggested that the combination of cognitive training and neural regulation has the potential to improve cognitive function in the elderly [6]. Aksu et al. (2025) conducted a secondary analysis around the ACT Test, focusing on the influence of cognitive training on the executive function of healthy elderly people, which provided reference for the application of executive function indicators such as Stroop test and Trail Making Test [7]. Anthony et al. (2024) studied the relationship between positive emotion, neurodegenerative changes and cognitive training plasticity, indicating that differences in individual psychological states and neural basis may affect the benefits of training [8].

Existing studies have accumulated many achievements from the perspectives of digital cognitive intervention, computerized training, serious games and neural regulation, but there are still three shortcomings. First, some studies focus on the training results, and lack a systematic explanation of the mechanism chain of "training stimulus-neuroplastic response - executive function improvement". Second, the dynamic data such as reaction time, correct rate, difficulty change, and completion rate in the training process of electronic brain games have not been fully transformed into mechanism analysis variables. Third, the effects of different training tasks on each dimension of executive function still need to be further verified. Based on this, this paper intends to construct the analysis framework of the mechanism of electronic brain game training on the executive function of the elderly from the perspective of neuroplasticity. Combined with the training process data, executive function evaluation indicators and neuroplasticity indicators, the effect path of electronic brain game training on the improvement of executive function of the elderly is explored. The content pairs of some representative studies are shown in Table 1.

Table 1: Comparison of representative studies related to electronic brain game training and cognitive intervention for the elderly

No.	Scholar(s) and Year	Research Topic	Research Focus	Implications for This Study
[1]	Benge and Scullin (2025)	Technology use and cognitive aging	Analyzes the relationship between digital technology engagement and cognitive aging	Supports the research background of digital technology intervention in cognitive health among older adults
[2]	Brody et al. (2025)	Online multidomain lifestyle intervention	Verifies the protective effect of online intervention for older adults at risk of cognitive decline	Indicates the value of digital intervention in cognitive health management for older adults
[4]	Guimaraes et al. (2025)	Engagement in computerized cognitive training	Emphasizes training engagement, compliance, and feedback mechanisms	Provides a basis for the process design of electronic brain game training
[5]	Lee et al. (2024)	Computerized cognitive training and biomarkers of brain aging	Focuses on cognitive performance and biomarkers of structural brain aging	Supports the analysis of neuroplasticity mechanisms
[7]	Aksu et al. (2025)	Cognitive training and executive function	Analyzes changes in executive function among healthy older adults	Provides a reference for the selection of executive function assessment indicators
[14]	Choi et al. (2025)	Mobile video game-based cognitive training	Focuses on the effect of game-based training on prefrontal function	Supports the association analysis between electronic brain games and prefrontal mechanisms

2 Theoretical basis of the effect of electronic brain game training on executive function in the elderly

2.1 Neurocognitive features of executive decline in older adults

The decline of executive function in the elderly is mainly manifested as decreased working memory capacity, weakened inhibitory control, delayed task switching and insufficient cognitive flexibility. Its essence is related to the decreased efficiency of prefrontal regulation, the decreased ability of brain network integration and the weakened function of neurotransmitters. Corbett et al. (2024) studied the cognitive effects of short-term computerized cognitive training on elderly people with different genetic risks of Alzheimer's disease, and found that tasks related to executive function are highly sensitive to cognitive changes in the elderly, indicating that task switching and processing speed can be used as important indicators to identify cognitive decline [9]. Carvalho et al. (2025) studied digital cognitive training in the elderly with mild cognitive impairment and pointed out that the effect of cognitive training was not only reflected in the change of test scores, but also correlated

with the maintenance of daily functions [13]. Oudega et al. (2025) studied online cognitive training for people with emotional disorders in late life and found that there was a linkage between subjective cognitive experience and executive function performance, suggesting that emotional states may aggravate or mask the decline of executive control ability in old age [19]. Attarha et al. (2025) further studied computerized cognitive training from the perspective of cholinergic system, indicating that the decline of executive function in the elderly is not only the slow down of behavior, but also involves changes in deep mechanisms such as neurotransmitters, brain region activation and functional connectivity [10]. Therefore, the deterioration of executive function in the elderly should be understood as a continuous process of "decreased behavioral performance, weakened neural regulation, and limited daily function".

2.2 The Functional Logic of Electronic Brain Game Training from the Perspective of Neuroplasticity

From the perspective of neuroplasticity, the core of electronic brain game training is not only to let the elderly complete recreational tasks, but also to continuously mobilize the executive control processes such as attention allocation, information update, rule transformation and response inhibition through repetitive stimulation, immediate feedback, progressive difficulty and multi-sensory interaction. The action logic of electronic brain game training from the perspective of neuroplasticity is shown in Figure 1. Woodruff et al. (2024) studied the differences between bottom-up and top-down digital cognitive training, indicating that different training paths can act on perceptual processing and high-level cognitive control respectively [11]. Funghi et al. (2024) studied online social and cognitive training programs and proposed that digital training can promote social cognition and cognitive participation through interactive tasks [12]. Sato et al. (2023) studied dance video game training and found that somatosensory interactive games can help enhance the cognitive participation and prefrontal related activities of the elderly [15]. Simon et al. (2023) studied the feasibility of the web-based cognitive training platform, indicating that the task context-based design can improve the acceptance and training persistence of the elderly [16]. Abd-Alrazaq et al. (2023) studied the improvement effect of serious games on the attention function of cognitively impaired elderly people, and pointed out that gamified tasks can improve the level of attention maintenance through target feedback and reward mechanism [17]. Another review study also showed that serious games have application potential in elderly cognitive learning and training transfer [18]. Stephan et al. (2024) studied the perception of cognitive, physical, and somatosensory game training in older adults, emphasizing that user experience affects training compliance [20]. It can be seen that the electronic brain game training can form a chain of "task stimulus input-continuous engagement-neural adaption-executive function improvement".

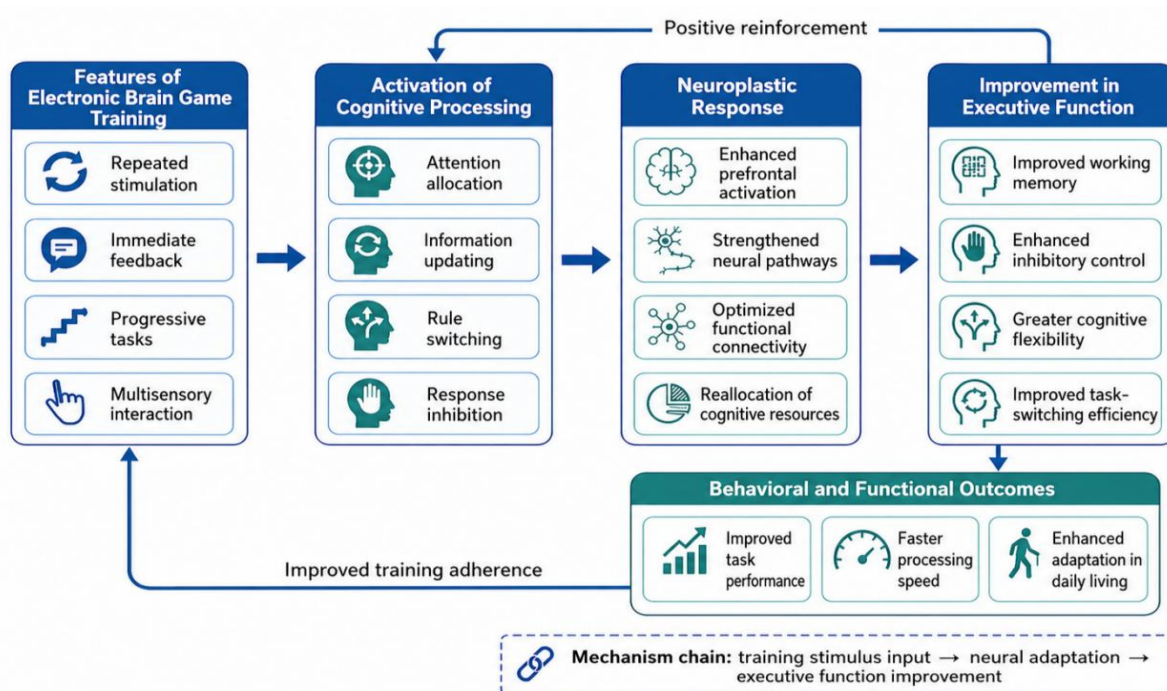


Figure 1: The action logic of electronic brain game training from the perspective of neuroplasticity

3 Electronic brain game training intervention design and executive function evaluation method

3.1 Selection of subjects and experimental group design

The main sample source was the elderly in the community, and four access conditions were set up: age, cognitive status, physical function and ability to operate electronic equipment. The age of the subjects could be controlled between 60 and 80 years old, with basic self-care ability, Mini-Mental State Inventory or Montreal Cognitive assessment results did not reach the level of severe cognitive impairment, and were able to understand the experimental instructions and complete the tablet computer, touch screen or mobile terminal electronic brain game operation. The excluded subjects included those with a definite diagnosis of severe neurological diseases, mental disorders, severely impaired audio-visual function, those who had recently received systemic cognitive training or pharmacological cognitive intervention, and those who could not complete the training cycle continuously. The basic information collection of the sample should cover the variables such as age, gender, years of education, chronic diseases, sleep status, basic cognitive score, previous game experience and frequency of electronic device use, so as to provide a data basis for subsequent covariate control and balance test between groups.

Experimental grouping used a combination of random assignment and baseline matching, and subjects were divided into the electronic brain game training group and the routine activity control group. In order to reduce the interference of age, education level and basic cognition on the results, the individual baseline matching distance function can be constructed as follows.

$$D_{ij} = \sqrt{\sum_{k=1}^m w_k (X_{ik} - X_{jk})^2} \quad (1)$$

where, D_{ij} represents the baseline difference distance between candidate object i in the experimental group and candidate object j in the control group, X_{ik} and X_{jk} represent the standardized values of the two subjects on the KTH baseline variable, w_k is the weight of the variable, and m is the number of matching variables. Matching variables could include age, gender, years of education, baseline executive function score, frequency of electronic device use, and previous gaming experience. When D_{ij} is smaller, it means that the baseline characteristics of the two groups of objects are closer, and the comparability after grouping is stronger.

After grouping, the two baseline variables should be tested for balance. Continuous variables can be determined by standardized mean difference:

$$\text{SMD} = \frac{\bar{X}_T - \bar{X}_C}{\sqrt{(S_T^2 + S_C^2)/2}} \quad (2)$$

Here, \bar{X}_T and \bar{X}_C denote the variable mean between the training group and the control group, and S_T^2 and S_C^2 denote the variance between the two groups, respectively. It is generally believed that when $|\text{SMD}| < 0.1$, the difference between groups is small and the sample is well balanced. Through the process of "inclusion and exclusion screening - baseline information collection - random grouping - matching distance correction - balance test", the analysis of the training effect of electronic brain games can be guaranteed not to be interfered by obvious initial differences of samples, and the reliability of subsequent assessment of executive function changes and verification of neural plasticity mechanisms can be improved.

3.2 Design of training module for Electronic Brain games

The electronic brain game training module should carry out task mapping around the core structure of the executive function of the elderly, so that each type of game task corresponds to a clear cognitive processing goal. Four training modules including working memory, inhibition control, cognitive flexibility and attention control can be set up in the system, and the task stimulus, response rule, feedback mode and difficulty progression parameters are configured in the module. Figure 2 shows the design of the electronic brain game training module.

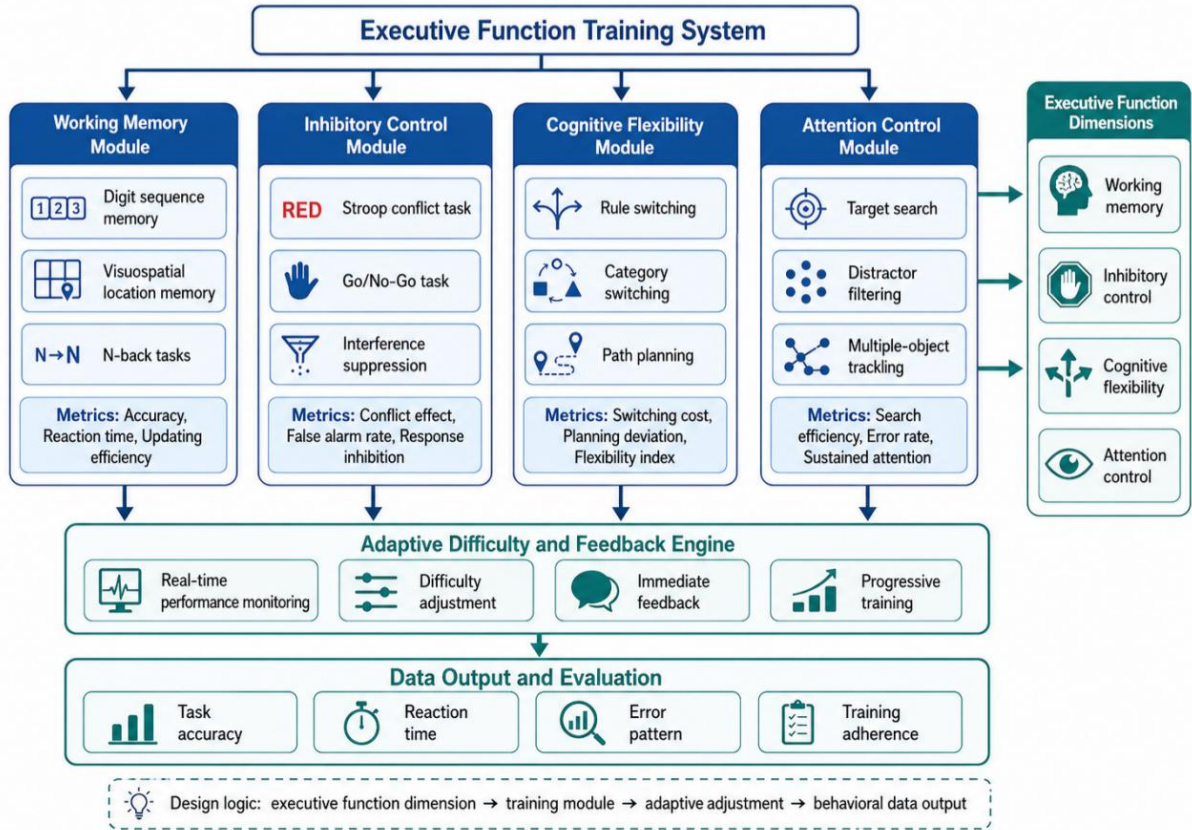


Figure 2: Design of training module for electronic brain games

The working memory module mainly uses digit sequence memory, figure location memory and N-back type tasks, requiring subjects to complete information retention, update and re-extract in a short time. Its task performance can be described by both accuracy rate and reaction time. Suppose that the i th task accuracy is marked as c_i , the accuracy is 1, and the error is 0, then the working memory accuracy is:

$$A_{wm} = \frac{1}{n} \sum_{i=1}^n c_i \quad (3)$$

In order to avoid the problem of simple accuracy masking the reaction delay, the working memory efficiency index can be further constructed as follows.

$$E_{wm} = \frac{A_{wm}}{\overline{RT}_{wm}} \quad (4)$$

Here, \overline{RT}_{wm} represents the working memory task average reaction time. A higher index indicates that the subject has a faster ability to update information while maintaining a higher correct rate.

The inhibition control module can use color-meaning conflict judgment, Go/No-Go response task and interference stimulus exclusion task, focusing on the inhibition ability of subjects to dominant response. Taking Stroop tasks as an example, the conflict effect can be calculated:

$$IC = \overline{RT}_{incon} - \overline{RT}_{con} \quad (5)$$

Here, $\overline{RT}_{\text{incon}}$ represents the average reaction time in the inconsistent condition and $\overline{RT}_{\text{con}}$ represents the average reaction time in the consistent condition. A smaller IC value indicates that subjects are more efficient in suppressing conflicting stimuli. The false response rate can also be calculated for the Go/No-Go task:

$$\text{FAR} = \frac{N_{\text{false}}}{N_{\text{nogo}}} \quad (6)$$

Here, N_{false} represents the number of incorrect keystrokes in the No-Go condition, and N_{nogo} represents the total number of No-Go stimuli. This index can be used to judge the change of impulse response control ability in the elderly.

The cognitive flexibility module can design tasks for rule switching, category switching, and path planning, requiring subjects to quickly change judgment rules based on color, shape, spatial location, or task cues. The core evaluation index is task switching cost:

$$\text{SC} = \overline{RT}_{\text{switch}} - \overline{RT}_{\text{repeat}} \quad (7)$$

Here, $\overline{RT}_{\text{switch}}$ represents the average reaction time in the rule switching condition, and $\overline{RT}_{\text{repeat}}$ represents the average reaction time in the rule repeating condition. If SC decreases after training, it indicates that subjects have enhanced cognitive flexibility in rule updating, strategy adjustment, and multi-task switching. The path planning task can also introduce the shortest path deviation rate:

$$\text{PDR} = \frac{L_{\text{actual}} - L_{\text{opt}}}{L_{\text{opt}}} \times 100 \quad (8)$$

Here, L_{actual} represents the actual path length completed by the subject, and L_{opt} represents the optimal path length calculated by the system. This index can reflect the planning ability and problem solving efficiency.

The attention control module can use target search, interference elimination and multi-target tracking tasks, and focus on training selective attention, sustained attention and distributive attention. The target search efficiency can be expressed as follows.

$$E_{\text{att}} = \frac{N_{\text{target}}}{T_{\text{search}} + \lambda N_{\text{error}}} \quad (9)$$

where N_{target} represents the number of correctly identified targets, T_{search} represents the total search time, N_{error} represents the number of incorrect clicks, and λ is the error penalty coefficient. The formula can reflect the search speed, recognition accuracy and anti-interference ability at the same time.

In order to ensure that the training intensity of each module is consistent with the executive function goal, a comprehensive training load function can be constructed as follows.

$$L_t = \sum_{q=1}^4 \omega_q D_{q,t} \cdot C_{q,t} \quad (10)$$

Here, L_t represents the comprehensive load of the TTH training, q corresponds to the four

modules of working memory, inhibitory control, cognitive flexibility and attention control, ω_q is the module weight, $D_{q,t}$ is the module difficulty level, $C_{q,t}$ is the task completion coefficient. The system adjusts the difficulty of the next round of the task based on the subject's real-time performance:

$$D_{q,t+1} = D_{q,t} + \alpha(A_{q,t} - \theta) - \beta FAR_{q,t} - \gamma CV_{RT} \quad (11)$$

Here, $A_{q,t}$ represents the current correct rate of the QTH task, θ is the target correct rate threshold, $FAR_{q,t}$ represents the error response rate, CV_{RT} represents the reaction time variation coefficient, and α , β , γ are the adjustment parameters. Through this mechanism, the system can increase the difficulty of the task when the subject's performance is stable, reduce the cognitive load when the error rate increases or the response fluctuation increases, and avoid training too easy or too hard. Therefore, electronic brain game training is no longer a simple entertainment operation, but a technical closed loop of "executive function dimension - game task type - process index - difficulty adjustment", which provides a quantifiable basis for subsequent training effect analysis and neural plasticity mechanism verification.

3.3 Training process and difficulty adaptation mechanism

The training process was carried out in a closed-loop mode of "baseline evaluation - sub-module training - dynamic parameter adjustment - stage retest - result feedback". The intervention period can be set as 8 weeks, 3 times a week, 30-40 min each time, and the total number of training is 24 times. Each training consisted of warm-up task, core training task and feedback task, and the core training task covered four modules of working memory, inhibitory control, cognitive flexibility and attention control. In order to avoid fatigue caused by repetition of a single task, the system can be combined in the way of "2 core modules +1 auxiliary module". For example, working memory and attention control are mainly used in the first and second weeks, inhibition control tasks are added in the third and fourth weeks, and rule conversion, dual-task processing and path planning tasks are increased in the fifth and eighth weeks. The training load was gradually transitioned from low cognitive load to high executive control load. The training flow is shown in Figure 3.

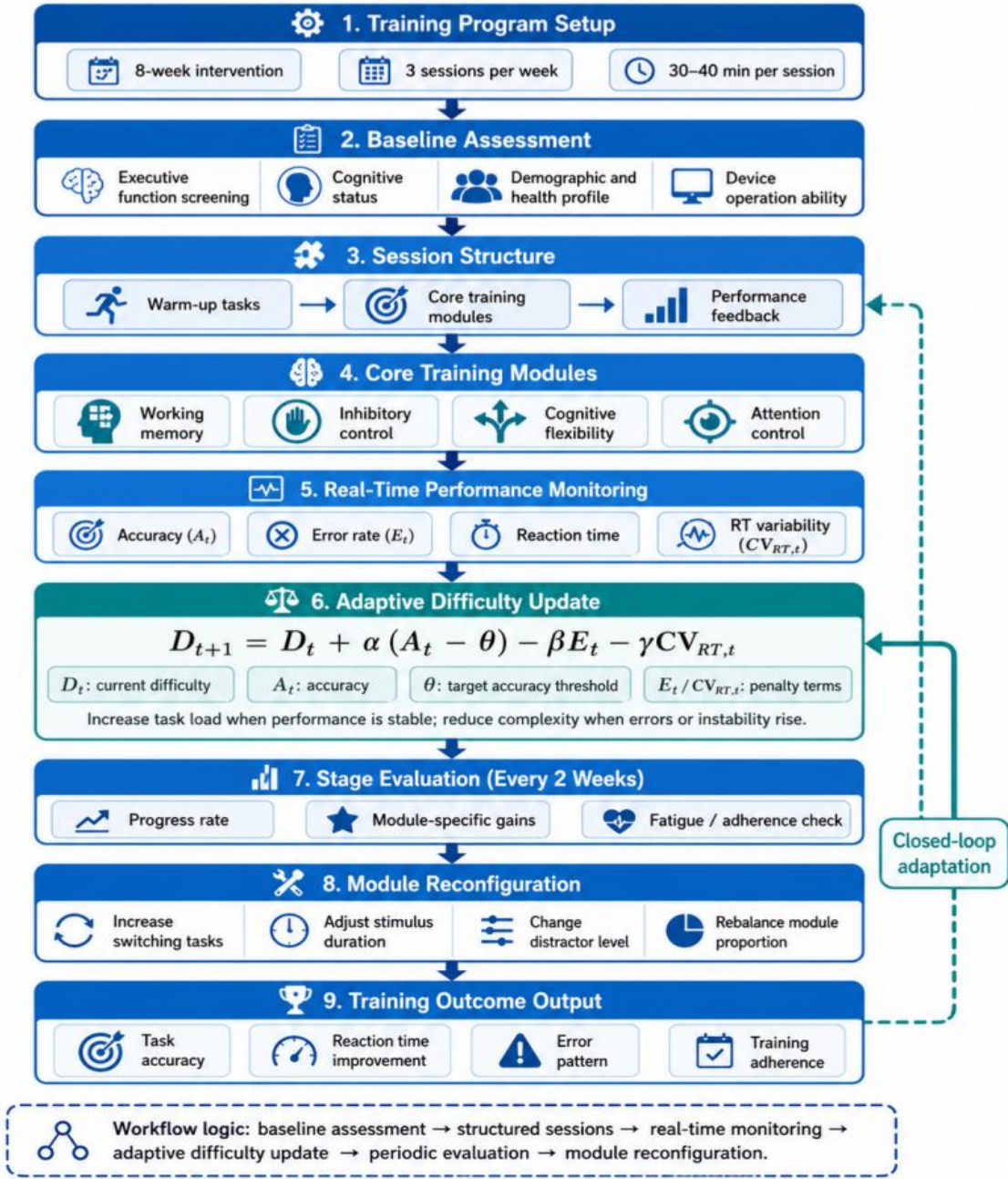


Figure 3: Training flow

The difficulty adaptation mechanism is mainly adjusted according to accuracy rate, error rate, reaction time and task completion stability. Let the TTH training difficulty be D_t , the current accuracy is A_t , the target accuracy threshold is θ , and the error rate is E_t . Then the next training difficulty can be expressed as follows.

$$D_{t+1} = D_t + \alpha(A_t - \theta) - \beta E_t \quad (12)$$

Here, α represents the adjustment coefficient of correct rate to difficulty increase, and β represents the penalty coefficient of error rate to difficulty decrease. When $A_t > \theta$ and E_t is low, the system increases the number of stimuli, reduces the presentation time, or increases the distractor term. When $A_t < \theta$ or E_t is elevated, the system reduces the task complexity to prevent subjects from training frustration due to successive failures.

Considering that the reaction speed of the elderly is quite different, only relying on the correct rate to adjust the difficulty may cause judgment bias, so the reaction time fluctuation coefficient can be further introduced:

$$CV_{RT,t} = \frac{\sigma_{RT,t}}{\mu_{RT,t}} \quad (13)$$

Here, $\sigma_{RT,t}$ represents the standard deviation of the t-th training reaction time, and $\mu_{RT,t}$ represents the average reaction time. The larger the $CV_{RT,t}$, the less stable the responses of the subjects. After integrating accuracy, error, and response stability, the difficulty update model can be extended as follows.

$$D_{t+1} = D_t + \alpha(A_t - \theta) - \beta E_t - \gamma CV_{RT,t} \quad (14)$$

Here, γ is the reaction fluctuation penalty coefficient. This model can limit the difficulty to increase too quickly when the subjects' correct rate is high but their response is extremely unstable, so that the training intensity is more in line with the real executive control level of the elderly.

In order to control the training rhythm, it is also necessary to establish a single training load evaluation index. Let the task difficulty of the QTH training module be $D_{q,t}$, the task completion rate be $C_{q,t}$, the average reaction time be $\overline{RT}_{q,t}$, and the module weight be ω_q , then the comprehensive training load can be expressed as follows.

$$L_t = \sum_{q=1}^4 \omega_q \cdot D_{q,t} \cdot C_{q,t} \cdot \frac{1}{\overline{RT}_{q,t}} \quad (15)$$

Here, $q=1,2,3$, and 4 correspond to working memory, inhibitory control, cognitive flexibility, and attentional control modules, respectively. If L_t increases continuously and the error rate does not increase significantly, it means that the subject can adapt to the current training intensity. A decrease in L_t accompanied by an increase in error rate suggests that the training load is beyond its current cognitive tolerance and that stimulus complexity needs to be reduced or the response time window extended.

The training system should also have a periodic feedback mechanism to calculate the training progress rate every two weeks:

$$P = \frac{S_{\text{phase}} - S_{\text{base}}}{S_{\text{base}}} \times 100 \quad (16)$$

Among them, S_{base} represents the baseline stage comprehensive training performance, and S_{phase} represents the stage training performance. The system judges the individual progress according to the p-value and adjusts the proportion of subsequent modules. If the working memory was significantly improved but the task switching cost was insufficient, the rule switching and classification switching tasks were added. If the correct rate is high but the reaction time is long, time-critical judgment and target search tasks are added. Through this dynamic adjustment method, the electronic brain game training can form an adaptive closed loop of "real-time monitoring, difficulty update, stage feedback and module reconfiguration", so that the training stimulus is always maintained in the acceptable but challenging interval of the subjects, so as to improve the intensity of neuroplasticity activation and the improvement effect of executive function.

3.4 Data collection and feature extraction during training

The data collection of the training process should be completed automatically by the electronic brain game system, and the longitudinal data structure with "subject-training numbers-task module-behavioral response" as the basic unit should be formed. For each training, variables such as subject number, training date, task type, task level, stimulus presentation duration, reaction time, accuracy rate, error rate, completion rate, number of prompts, number of consecutive correct times, task completion time, number of interruptions and system feedback results were recorded. The training process data collection is shown in Figure 4.

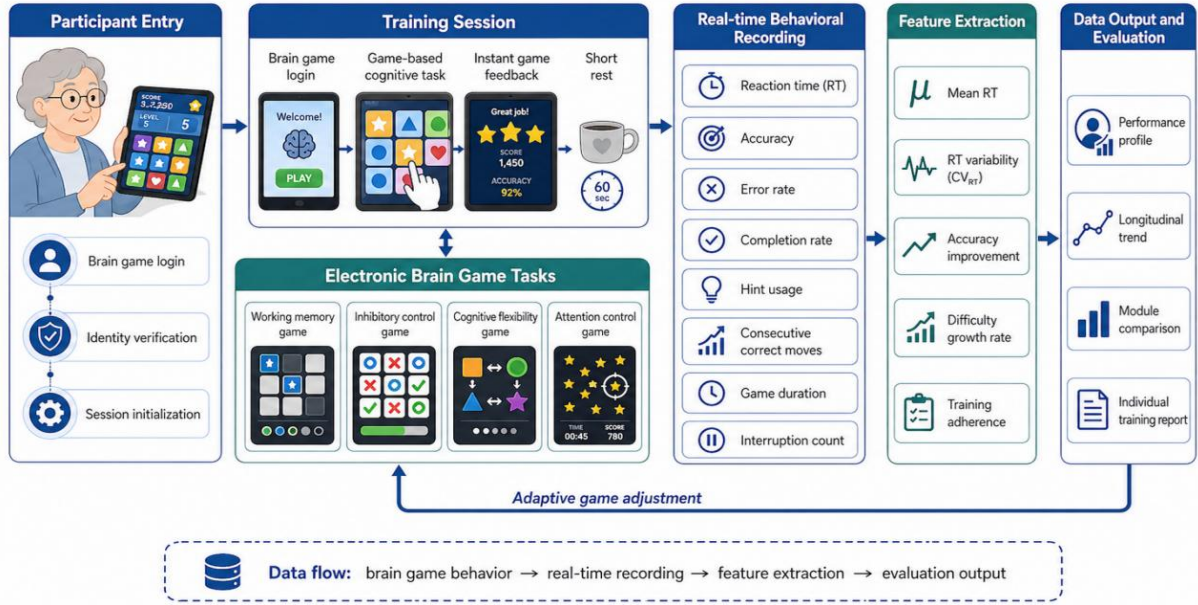


Figure 4: Data acquisition during training

To ensure data analyzability, the process data of the i th subject in the TTH training session can be expressed as follows.

$$X_{i,t} = \{RT_{i,t}, A_{i,t}, E_{i,t}, C_{i,t}, D_{i,t}, H_{i,t}, S_{i,t}, T_{i,t}, B_{i,t}\} \quad (17)$$

Here, $RT_{i,t}$ represents reaction time, $A_{i,t}$ represents accuracy rate, $E_{i,t}$ represents error rate, $C_{i,t}$ represents completion rate, $D_{i,t}$ represents task difficulty level, $H_{i,t}$ represents prompt times, $S_{i,t}$ represents consecutive correct times, $T_{i,t}$ represents task completion time, $B_{i,t}$ represents interruption times. Through this data structure, the training process of electronic brain games can be transformed from a single performance record to a traceable and modelable dynamic behavior data.

In feature extraction, the average reaction time is used to reflect the information processing speed, which can be expressed as follows.

$$\mu_{RT} = \frac{1}{n} \sum_{j=1}^n RT_j \quad (18)$$

Here, RT_j denotes the J TH effective reaction time, and n denotes the number of effective reactions. It's easy to overlook performance stability when looking only at the average

reaction time, so we also need to calculate the reaction time volatility coefficient:

$$CV_{RT} = \frac{\sigma_{RT}}{\mu_{RT}} \quad (19)$$

Here, σ_{RT} is the standard deviation of reaction time and μ_{RT} is the mean reaction time. The smaller the CV_{RT} , the more stable the response, the better the attention maintenance and task control ability of the subjects. If the average reaction time decreases and the CV_{RT} synchronization decreases after training, it indicates that the subject not only improves the reaction speed, but also performs the control process more stably.

The rate of improvement can be used to measure the change in task recognition ability before and after training:

$$IR_A = \frac{A_{post} - A_{pre}}{A_{pre}} \times 100 \quad (20)$$

Here, A_{pre} and A_{post} represent the average correct rate in the early and late training stages, respectively. The difficulty growth rate can be used to reflect the adaptability of the subjects to the training load:

$$GR_D = \frac{D_{last} - D_{first}}{D_{first}} \times 100 \quad (21)$$

where D_{first} represents the average task level in the initial stage and D_{last} represents the average task level in the final stage. If the correct rate remains stable and the difficulty increase rate is high, it indicates that the subjects can maintain better performance under higher cognitive load, reflecting a strong training adaptability.

Training compliance is an important index to evaluate the executability of the electronic brain game intervention, which can be expressed by the ratio of the actual completed training times to the planned training times:

$$Adh = \frac{N_{complete}}{N_{plan}} \times 100 \quad (22)$$

Here, $N_{complete}$ represents the actual number of completed training, and N_{plan} represents the number of planned training. Considering that the number of interruptions and task completion quality also affect compliance judgment, a modified compliance index can be further constructed as follows.

$$Adh^* = Adh \cdot C - \lambda \frac{B}{N_{complete}} \quad (23)$$

Here, C represents the average task completion rate, B represents the total number of training interruptions, and λ is the interruption penalty coefficient. This index can avoid evaluating compliance only by "whether to participate in training", and can better reflect the real investment degree of subjects in the training process.

In the comprehensive feature modeling, speed, accuracy, stability, difficulty adaptation and compliance can be integrated into the training performance index:

$$TPI = w_1A + w_2C + w_3GR_D - w_4CV_{RT} - w_5E \quad (24)$$

where TPI is the training performance index, A is the average accuracy rate, C is the average completion rate, GR_D is the difficulty growth rate, CV_{RT} is the reaction time fluctuation coefficient, E is the error rate, and w_1 to w_5 are the weight coefficients. This index can be used to compare the training benefit levels of different subjects, and can also be used as a key explanatory variable in subsequent regression analysis, correlation analysis, or structural equation models. Through the above data collection and feature extraction, the training process of electronic brain games can be transformed into quantitative evidence reflecting the changes in executive function, which provides technical support for judging the training effect, analyzing individual differences and verifying the mechanism of neural plasticity.

3.5 Assessment of executive function and neuroplasticity indicators

The joint measurement method of "behavioral test-training process data-neural signal index" should be used to evaluate the executive function and neuroplasticity indicators, so as to improve the accuracy of interpretation of the training effect of electronic brain games. At the behavioral level, Stroop Test, N-back test, Trail Making Test and digit span test can be implemented before and after training. The Stroop test was used to evaluate the inhibitory control ability, which could reflect the interference inhibition level by the reaction time difference between the conflict condition and the consistent condition. The N-back test was used to evaluate the updating ability of working memory, focusing on recording accuracy and reaction time. Trail Making Test was used to evaluate cognitive flexibility, task switching ability and processing speed. The digit span test is used to analyze short-term memory capacity and attention maintenance level. In order to form a unified evaluation result, the scores of each test can be standardized and the comprehensive score of executive function can be constructed:

$$S = \sum_{k=1}^n w_k Z_k \quad (25)$$

Among them, S represents the comprehensive score of executive function, Z_k represents the standardized score of the KTH test, w_k represents the weight of the index, and n represents the number of evaluation indicators. The comprehensive improvement rate before and after training can be expressed as follows.

$$I = \frac{S_{\text{post}} - S_{\text{pre}}}{S_{\text{pre}}} \times 100 \quad (26)$$

Among them, S_{pre} and S_{post} represent the comprehensive scores of executive function before and after training, respectively.

Neuroplasticity indicators can be collected in combination with EEG or fNIRS. EEG can mainly analyze the θ/β band power change, the amplitude of event-related potentials and the functional connectivity strength of brain regions in the prefrontal region. fNIRS can record the change of prefrontal oxygenated hemoglobin concentration and reflect the brain activation level induced by the training task. Functional connectivity strength can be expressed as follows.

$$FC_{ij} = \text{corr}(x_i, x_j) \quad (27)$$

Here, x_i and x_j represent the neural signal sequences of the two brain regions, respectively, and a higher FC_{ij} indicates a stronger synergistic activity of the brain regions.

Through correlation analysis or regression modeling of the improvement rate of executive function, training performance index and neuroplasticity index, it can be further determined whether electronic brain game training promotes the improvement of executive function in the elderly by enhancing prefrontal activation and optimizing functional connectivity.

4 Training effect analysis and mechanism verification of electronic brain games

4.1 Experimental design

This study used a quasi-experimental design of pre-test and post-test combined with control group to test the intervention effect of electronic brain game training on executive function and its neuroplasticity pathway in the elderly. Eighty community elderly people aged 60 to 80 years old were selected. According to the inclusion and exclusion criteria, they were randomly divided into an electronic brain game training group and a routine activity control group, with 40 people in each group. The training group received electronic brain game training for 8 weeks, 30 to 40 minutes each time, 3 times a week, covering four modules of working memory, inhibitory control, cognitive flexibility and attention control. The control group maintained the original daily activities, and health education, reading or regular leisure activities were arranged to avoid systematic cognitive training intervention.

The experimental process included five stages: baseline evaluation, training intervention, mid-term monitoring, post-test evaluation and data modeling. At baseline, the information of age, gender, years of education, basic cognitive level, and experience in using electronic devices were collected, and the Stroop Test, N-back test, Trail Making Test and digit span test were completed. In the intervention phase, process data such as reaction time, accuracy rate, error rate, completion rate, difficulty level and training compliance were automatically recorded by the system. After the training, the executive function assessment was completed again, and the EEG or fNIRS indicators were collected simultaneously to analyze the changes of prefrontal activation, functional connectivity and neural signal stability. The main points of the experimental design are shown in Table 2.

Table 2: Experimental design of electronic brain game training

Item	Training Group	Control Group	Observed Indicators
Sample size	40 participants	40 participants	Age, gender, years of education, baseline cognitive level
Intervention method	Electronic brain game training	Routine activities	Training engagement, activity completion
Intervention period	8 weeks, 3 sessions per week	Synchronous observation for 8 weeks	Compliance, completion rate, number of interruptions
Duration per session	30–40 min	30–40 min	Reaction time, accuracy, error rate
Assessment time	Before and after training	Before and after training	Executive function score, neuroplasticity indicators
Analytical methods	Pre-post comparison, between-group comparison, regression analysis	Used as reference	Intervention effect and mechanism pathway

In order to improve the rigor of the interpretation of the results, the repeated measures model of "group \times time" can be used to analyze the training effect:

$$Y_{it} = \beta_0 + \beta_1 \text{Group}_i + \beta_2 \text{Time}_t + \beta_3 (\text{Group}_i \times \text{Time}_t) + \beta_4 \text{Cov}_i + \varepsilon_{it} \quad (28)$$

Among them, Y_{it} represents the executive function score of the i th subject at the T th time point, Group_i represents the group, Time_t represents the evaluation time, $\text{Group}_i \times \text{Time}_t$ is the interaction term, Cov_i represents the covariates such as age, education years, and basic cognitive level, and ε_{it} is the random error term. If the interaction term β_3 is significant, it means that the training group has a more significant improvement in executive function changes compared with the control group. Through this experimental design, the association between the behavioral effect of electronic brain game training, the characteristics of the training process and the neuroplastic response can be verified at the same time.

4.2 Effect analysis of executive function training in the elderly

After training, the pre-test results of the experimental group and the control group were compared. The results showed that the experimental group was better than the control group in the comprehensive score of executive function, reaction speed, correct rate, error rate and each dimension performance. Specifically, the comprehensive score of executive function in the experimental group increased from 68.4 points to 82.9 points, while the control group only increased from 67.9 points to 70.3 points, indicating that the electronic brain game training had a significant promotion effect on the overall executive function. The comprehensive score change is shown in Figure 5.

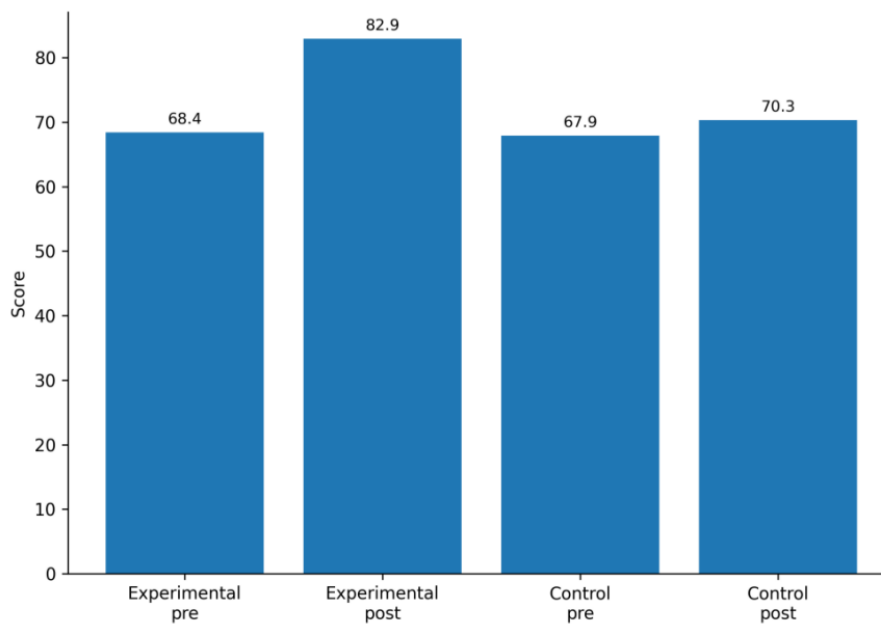


Figure 5: Changes in Composite Executive Function Score Before and After Training

At the same time, the average response time of the experimental group decreased from 845 ms to 706 ms, while that of the control group only decreased from 838 ms to 812 ms, indicating that the training group improved more significantly in information processing speed and task response efficiency, as shown in Figure 6.

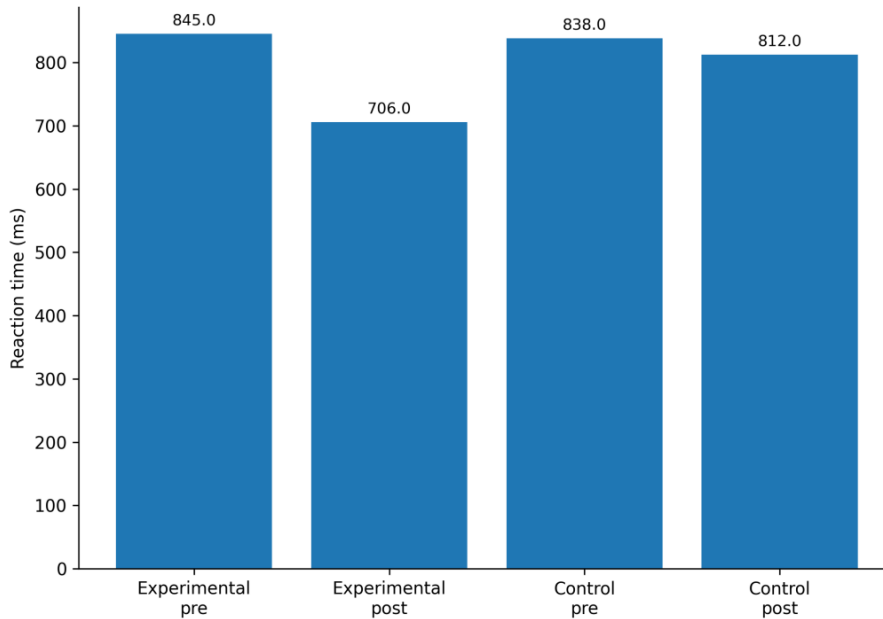


Figure 6: Changes in Mean Reaction Time Before and After Training

From the perspective of task performance indicators, the accuracy of the experimental group increased from 78.6% to 89.4%, while the control group only increased from 79.1% to 81.0%, indicating that the electronic brain game training can effectively enhance the accuracy of the elderly in task judgment and information update, as shown in Figure 7.

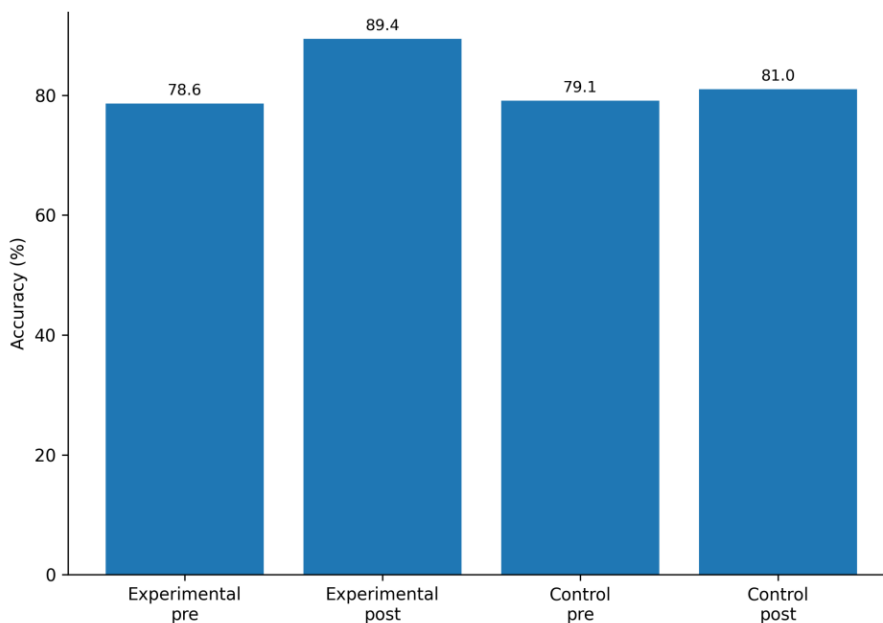


Figure 7: Changes in Task Accuracy Before and After Training

In terms of error rate, the experimental group decreased from 18.7% to 10.2%, and the control group decreased from 18.4% to 16.9%, indicating that the training group had more obvious advantages in suppressing irrelevant responses and reducing errors, as shown in Figure 8.

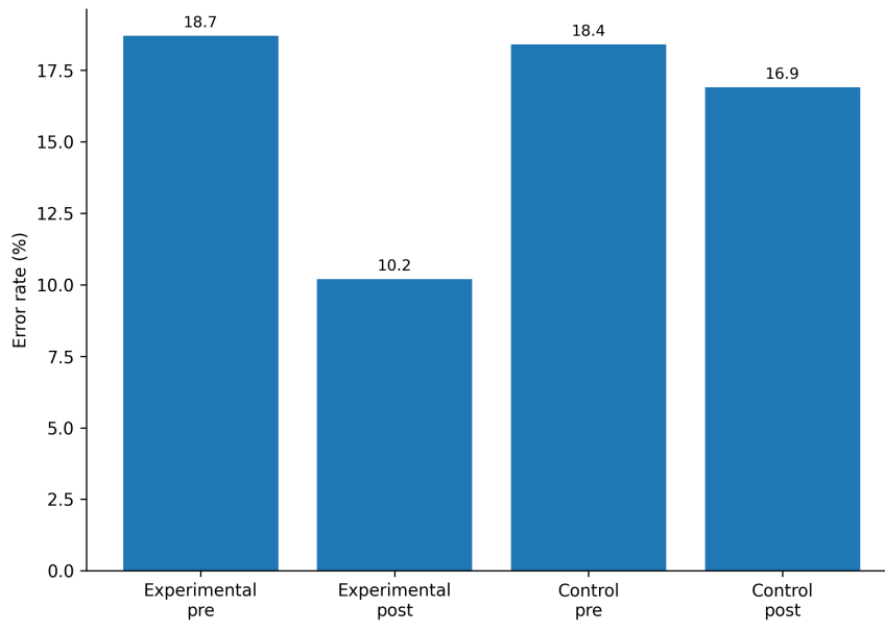


Figure 8: Changes in Task Error Rate Before and After Training

By further comparing the improvement ranges of the four dimensions of working memory, inhibitory control, cognitive flexibility and attention control, it can be seen that the improvement of the experimental group in all dimensions is higher than that of the control group, and the improvement of working memory and attention control is the most prominent, while cognitive flexibility and inhibitory control also show a stable growth trend. The dimension differences are shown in Figure 9.

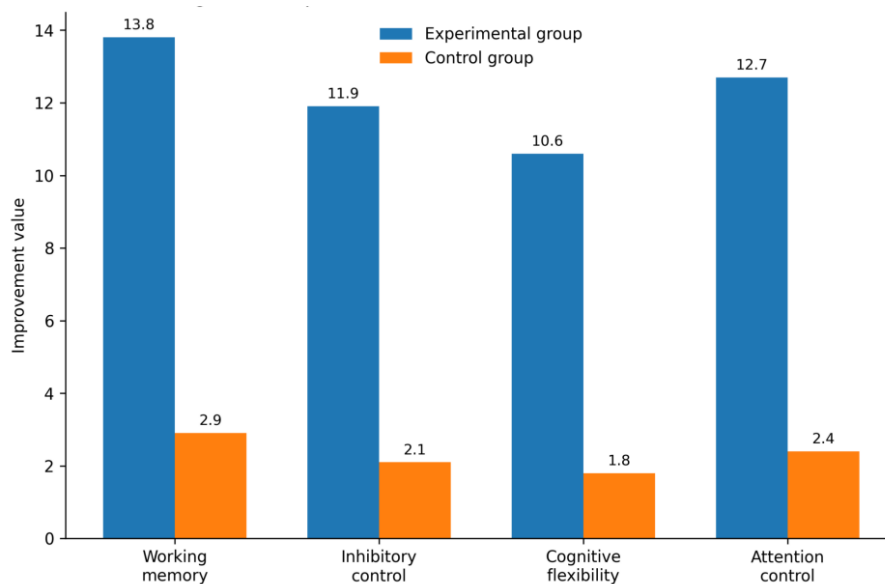


Figure 9: Comparison of Improvement Across Executive Function Dimensions

In general, electronic brain game training can produce a stable intervention effect on the executive function of the elderly, and show a good promotion effect on multiple core cognitive dimensions.

4.3 Validation of neural plasticity mechanisms and influencing pathways

In order to further verify the neuroplasticity mechanism of electronic brain game training on the improvement of executive function in the elderly, this study analyzed the relationship between prefrontal activation level, functional connectivity strength of brain regions and neuroplasticity response before and after training and the improvement of executive function. The experimental results showed that the average amplitude of prefrontal HbO activation increased from 0.31 to 0.48 in the training group, and only increased from 0.30 to 0.33 in the control group, indicating that electronic brain game training can enhance the level of prefrontal neural activity in the elderly during executive control tasks. The prefrontal HbO activation changes before and after training are shown in Figure 10.

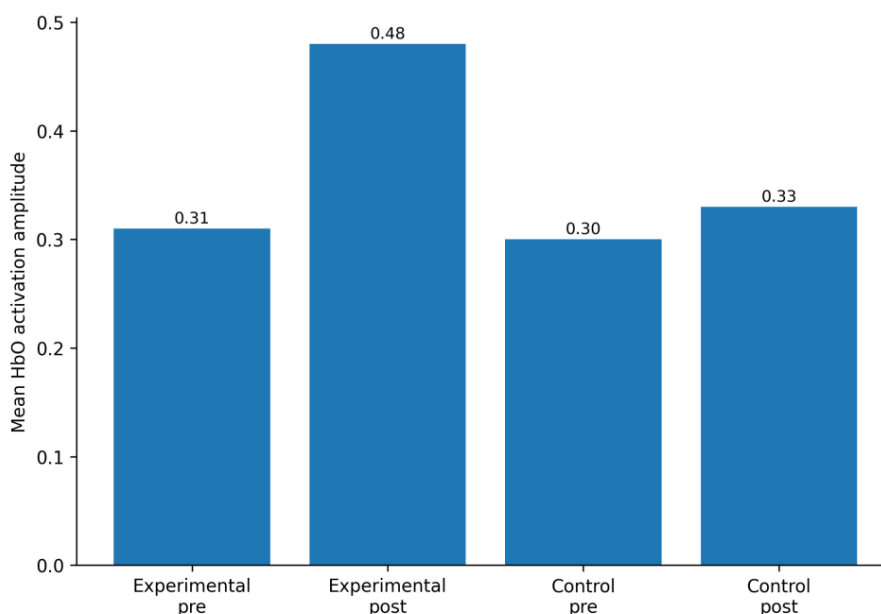


Figure 10: Changes in Prefrontal HbO Activation Before and After Training

Further analysis of the functional connectivity changes of brain regions in the training group showed that the connection strength of the left and right dorsolateral prefrontal cortex increased from 0.42 to 0.57, the connection strength of the dorsolateral prefrontal cortex and the frontal pole area increased from 0.38 to 0.51, and the connection strength of the dorsolateral prefrontal cortex and the anterior cingulate area increased from 0.35 to 0.48. The connection strength between frontal polar region and anterior cingulate region increased from 0.33 to 0.45. The results show that the electronic brain game training not only improves the activation level of local brain regions, but also enhances the information cooperation ability between brain regions related to executive control. The functional connectivity changes in the training group are shown in Figure 11.

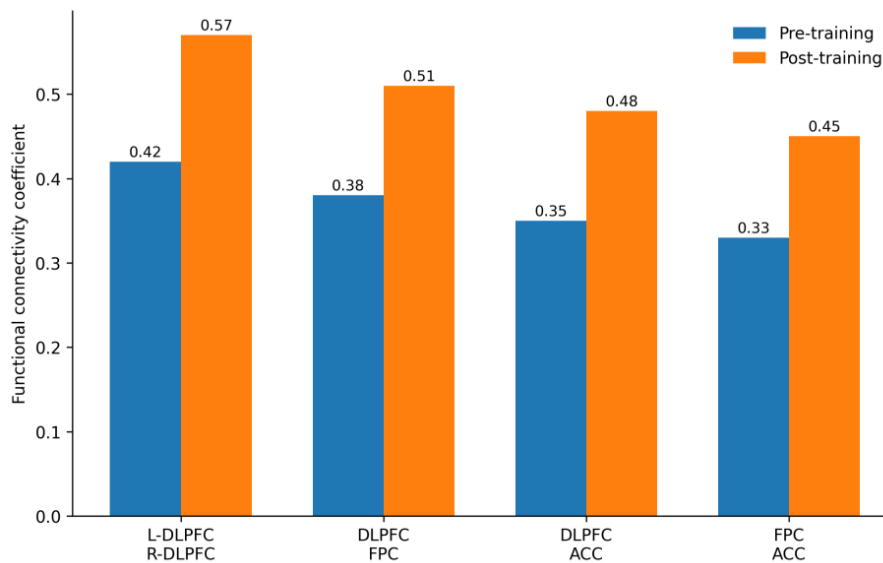


Figure 11: Changes in Functional Connectivity in the Experimental Group

In the verification of influence pathways, the change of prefrontal activation, the enhancement of functional connectivity and the improvement of reaction-time stability were integrated into the neuroplasticity response index, and the correlation analysis was performed with the improvement rate of executive function. The results showed that the neuroplasticity response index was significantly positively correlated with the improvement rate of executive function, and the correlation coefficient was 0.88, indicating that the more obvious the neural response of the elderly subjects, the greater the improvement of executive function. The relationship between them is shown in Figure 12.

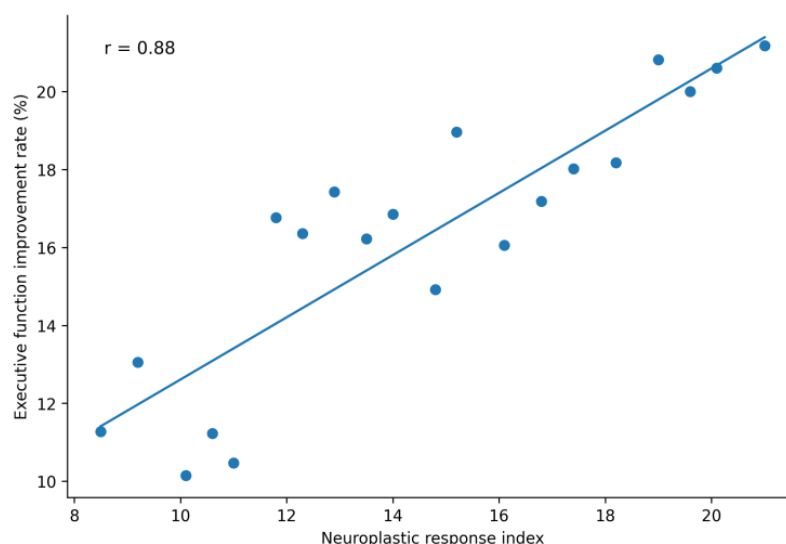


Figure 12: Relationship Between Neuroplastic Response and Executive Function Improvement

It can be seen that the promotion of electronic brain game training on executive function does not only come from task proficiency, but is closely related to the enhancement of prefrontal activation, the optimization of functional connectivity and the reallocation of neural resources, which basically verifies the mechanism pathway of "electronic brain game training-neuroplastic responsibility-executive function improvement".

4.4 Discussion

The experimental results show that electronic brain game training has a significant promotion effect on the improvement of executive function in the elderly. After training, the comprehensive score of executive function in the experimental group increased from 68.4 to 82.9, the reaction time decreased from 845 ms to 706 ms, the accuracy increased from 78.6% to 89.4%, and the error rate decreased from 18.7% to 10.2%. These changes indicate that electronic brain games do not only improve the operational proficiency of the elderly, but also have a comprehensive impact on information processing speed, task judgment accuracy, error suppression and execution efficiency. Compared with the control group, the improvement of the experimental group was greater, which also indicated that the regular activities had a limited effect on the promotion of executive function, and the electronic brain games with the characteristics of target tasks, immediate feedback and progressive difficulty were more likely to form sustained cognitive stimulation.

From the perspective of executive function, the improvement of working memory and attention control was more prominent, which were closely related to the number sequence memory, figure location memory, target search and interference exclusion in the training task. Such tasks require subjects to continuously maintain information, quickly identify targets, and exclude irrelevant stimuli, which can strengthen the ability to update information and allocate attention. Inhibitory control and cognitive flexibility also showed stable improvement, indicating that color-meaning conflict judgment, Go/No-Go response and rule switching tasks could reduce the cognitive cost of conflict processing and task switching in the elderly.

Neural metrics further explain the underlying mechanisms of behavioral improvement. After training, the amplitude of prefrontal HbO activation in the experimental group increased from 0.31 to 0.48, indicating that the prefrontal involvement induced by the executive control task was enhanced. The functional connectivity strength between the left and right dorsolateral prefrontal cortex, the dorsolateral prefrontal cortex, the frontal pole area, and the anterior cingulate area were significantly improved, indicating that the training promoted the information coordination of the brain regions related to executive control. The correlation coefficient between the neuroplasticity response index and the improvement rate of executive function reached 0.88, indicating that the more obvious the neural response, the more fully the improvement of executive function. It can be concluded that electronic brain game training promotes the enhancement of prefrontal activation, the optimization of brain area connectivity and the reallocation of cognitive resources through continuous task stimulation, adaptive difficulty adjustment and immediate feedback mechanism, and ultimately promotes the improvement of executive function in the elderly.

5 Conclusion

From the perspective of neuroplasticity, this paper focuses on the influence mechanism of electronic brain game training on executive function in the elderly, and constructs an analysis framework covering training module design, process data collection, executive function evaluation and neural index verification. The experimental results showed that 8-week electronic brain game training could effectively improve the executive function of the elderly. The comprehensive score of the experimental group increased from 68.4 to 82.9, which was significantly higher than that of the control group from 67.9 to 70.3. The average reaction time decreased from 845 ms to 706 ms, the correct rate increased from 78.6% to 89.4%, and the error rate decreased from 18.7% to 10.2%, indicating that training had a positive effect on improving processing speed, judgment accuracy and inhibitory control ability. The results of

neural index further showed that the activation amplitude of prefrontal HbO increased from 0.31 to 0.48 in the experimental group, and the functional connectivity strength of brain regions related to executive control was also significantly enhanced. The correlation coefficient between the neuroplasticity response index and the improvement rate of executive function reached 0.88. In conclusion, electronic brain game training can promote the enhancement of prefrontal activation, the optimization of functional connectivity and the reallocation of cognitive resources through continuous cognitive stimulation, adaptive adjustment of difficulty and immediate feedback mechanism, thereby promoting the improvement of executive function in the elderly. Follow-up studies can further expand the sample size, extend the follow-up period, and combine EEG, fNIRS and other multimodal data to verify the long-term intervention effect.

Funding

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