Vol. 7, No. 1, 2026, pp. 415-426
DOI: https://doi.org/10.29210/992220

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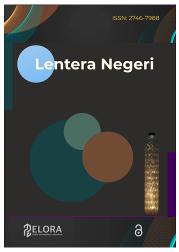

Visual stimulus training and brain function enhancement

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Article Info

Article history:
Received May 12th, 2026
Revised Jun 10th, 2026
Accepted Jun 19th, 2026

Keyword:
Visual stimulus training;
Brain function;
Cognitive enhancement;
Neuroplasticity;
Reaction time;
EEG;
Executive function.

ABSTRACT

Visual stimulus training has recently gained increasing attention as a non-pharmacological approach for enhancing cognitive performance and neural efficiency. Modern lifestyles characterized by cognitive overload, prolonged digital exposure, and reduced attentional capacity have contributed to declining cognitive performance among young adults. Visual stimulus interventions are believed to improve attentional control, visuomotor coordination, reaction speed, and executive functioning through neuroplastic adaptation mechanisms. Therefore, this study aimed to investigate the effects of visual stimulus training on brain function enhancement among healthy young adults. This study employed a randomized controlled experimental design involving 40 healthy participants aged 18–25 years. Participants were randomly divided into an experimental group (n = 20) and a control group (n = 20). The intervention consisted of an eight-week visual stimulus training program performed three times per week. Cognitive variables assessed included attention, working memory, reaction time, and executive functioning using standardized computerized cognitive tests. Neurophysiological adaptation was evaluated using electroencephalography (EEG). Data were analyzed using paired sample t-tests and repeated-measures ANOVA with a significance level of $p < 0.05$. The results demonstrated significant improvements in the experimental group following the intervention. Attention scores increased from 78.40 ± 6.28 to 87.15 ± 5.74 ($p = 0.001$), while working memory scores improved from 71.85 ± 5.76 to 80.90 ± 5.28 ($p = 0.001$). Reaction time decreased significantly from 312.25 ± 21.67 ms to 276.10 ± 18.44 ms ($p = 0.001$). Executive function scores also improved significantly from 74.20 ± 6.12 to 83.45 ± 5.87 ($p = 0.001$). EEG analysis revealed increased beta wave activity and reduced alpha wave activity after the intervention. In conclusion, visual stimulus training significantly enhanced cognitive performance and neural activation among healthy young adults. The findings suggest that visual stimulus training may serve as an effective and practical strategy for brain function enhancement.

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Introduction

Brain function enhancement has become an increasingly important topic in neuroscience, sports science, cognitive psychology, and rehabilitation research. The rapid growth of technology, higher cognitive demands in daily activities, and lifestyle changes have encouraged researchers to explore non-pharmacological methods capable of improving cognitive performance and neural efficiency. Among various approaches currently being developed, visual stimulus training has gained considerable attention because the visual system plays a dominant role in human information processing. The brain allocates a substantial portion of cortical activity to visual perception, making visual stimulation highly relevant to cognitive adaptation and neuroplasticity processes (Bavelier & Green, 2019). Recent technological advances, including virtual reality systems, computerized cognitive training, and neurofeedback devices, have further expanded the implementation of visual stimulus training in educational, clinical, and sports settings.

Young adults are increasingly exposed to sustained visual-cognitive demands associated with prolonged digital device use, academic multitasking, and rapid information processing requirements. These conditions may negatively affect attentional regulation, reaction speed, working memory efficiency, and executive control, particularly when cognitive recovery and attentional resources are insufficient. Consequently, interventions capable of improving attentional efficiency and visuomotor processing have become increasingly relevant within cognitive enhancement research (Do & Hill, 2023; Livingston et al., 2020).

Visual stimulus training involves repeated exposure to dynamic visual tasks designed to stimulate attentional processing, visuomotor coordination, peripheral awareness, and rapid sensory integration through structured visual-cognitive exercises. In the present study, visual stimulus training was operationalized as a structured eight-week intervention consisting of LED-based reaction drills, dynamic visual tracking exercises, peripheral awareness tasks, and dual-task visuomotor activities performed three times per week for approximately 45 minutes per session. The intervention intensity progressively increased by manipulating stimulus speed, spatial unpredictability, and cognitive task complexity throughout the training period. The present study specifically focused on healthy young adults aged 18–25 years because this population demonstrates relatively stable neurological maturation and high adaptability to cognitive training interventions. Furthermore, young adults are frequently exposed to sustained visual-cognitive demands associated with prolonged digital exposure and multitasking activities, making them an appropriate population for investigating visual stimulus training effects. To ensure adequate statistical sensitivity, participant recruitment was supported by an a priori statistical power analysis using repeated-measures ANOVA assumptions with a medium effect size, alpha level of 0.05, and statistical power of 0.80. The minimum required sample size was estimated at 34 participants, while 40 participants were ultimately recruited to account for potential attrition and maintain balanced group allocation (Greenwood & Parasuraman, 2010; Nguyen et al., 2019).

From a neurophysiological perspective, visual stimulus training activates multiple interconnected brain regions, including the occipital cortex, parietal cortex, cerebellum, and prefrontal cortex. These areas are responsible for visual perception, attention allocation, motor planning, and executive functioning. Enhanced interaction among these regions may contribute to faster information processing, improved reaction time, and better cognitive flexibility. Sensory integration theory also explains that optimized visual processing can positively influence broader cognitive and motor systems because visual input is essential for coordinating responses to environmental stimuli. Furthermore, dopaminergic pathways associated with attention and reward mechanisms may support long-term neural adaptation during repeated visual training sessions.

Several recent studies have demonstrated the positive effects of visual stimulus training on cognitive and neural performance. A recent controlled intervention study conducted by (Yu et al., 2024) involving 60 healthy participants reported that combined visual-motor response training performed over six weeks significantly improved attentional performance, visuomotor reaction speed, and cognitive flexibility as measured using computerized reaction tasks and executive function assessments. The study reported moderate effect sizes for attentional improvement and reaction time enhancement, suggesting that repeated visual-cognitive stimulation may induce measurable neuroplastic adaptation. Similarly, a systematic review by (Ren et al., 2025) concluded that stroboscopic visual training effectively enhances visual processing speed, attentional focus, hand-eye coordination, and motor responsiveness through neuroplastic adaptation mechanisms. In rehabilitation settings, visual cognitive training has also been shown to improve executive functioning and overall cognitive efficiency, particularly when interventions involve complex multisensory integration tasks (Fiorenzato et al., 2025; Mathew et al., 2025; Mehrinejad Khotbehsara et al., 2025; Niering & Seifert, 2024). These findings suggest that repeated visual stimulation may facilitate adaptive neural changes capable of enhancing both sensory and higher-order cognitive functions.

Neuroimaging and electrophysiological studies further support the neurological basis of visual stimulus training. Electroencephalography studies have demonstrated increased neural activation during attentional and sensory processing tasks following prolonged visual training interventions (S. Eldar & Bar-Haim, 2010; Gkintoni et al., 2025; Gupta et al., 2019; Nava et al., 2024; Ordikhani-Seyedlar et al., 2016). Such findings indicate that repeated visual stimulation may improve early sensory encoding as well as higher-level cognitive control mechanisms. Emerging evidence from brain-computer interface research has also shown that specific visual stimuli can generate measurable neural activation patterns detectable through EEG and functional imaging technologies. This evidence highlights the close relationship between visual processing and broader neural network adaptation.

Despite these promising findings, several limitations remain within the existing literature. Many previous studies involved relatively small sample sizes and short intervention durations, limiting the generalizability of their results. Considerable variation also exists regarding the type of visual stimuli, training intensity, intervention duration, and outcome measurements used across studies. Some investigations reported strong improvements in attention and reaction time, whereas others found inconsistent effects on executive functioning and working memory. Furthermore, most studies have focused primarily on athletes, older adults, or rehabilitation populations, while limited research has examined healthy young adults and educational contexts. Longitudinal studies exploring sustained neuroplastic adaptation following visual stimulus training are also still limited.

Another important limitation concerns the lack of standardized neurophysiological assessment methods. Although some studies have incorporated EEG, neurofeedback, and functional imaging approaches, many investigations continue to rely mainly on behavioral cognitive assessments without directly examining neural adaptation mechanisms. External factors such as sleep quality, physical activity, nutritional status, and psychological stress are also often insufficiently controlled, potentially influencing cognitive outcomes. Therefore, more comprehensive studies integrating behavioral assessments with neurophysiological measurements are necessary to better understand the mechanisms and effectiveness of visual stimulus training.

The increasing accessibility of visual training technologies further strengthens the rationale for investigating visual stimulus interventions. Modern LED-based reaction systems, immersive virtual reality platforms, and computerized cognitive applications provide practical and relatively affordable opportunities for cognitive enhancement. Unlike pharmacological interventions, visual stimulus training is generally non-invasive, adaptable, and applicable across diverse populations. These characteristics make visual stimulus training potentially valuable for improving academic performance, athletic performance, occupational productivity, cognitive rehabilitation, and healthy aging.

Based on the existing evidence and unresolved limitations, this study aims to investigate the effects of visual stimulus training on brain function enhancement. Specifically, this study seeks to evaluate changes in attention, working memory, reaction time, and executive functioning following structured visual stimulus interventions. In addition, the study aims to examine potential neurophysiological adaptations associated with repeated visual training exposure. It is hypothesized that visual stimulus training will significantly improve cognitive performance and neural efficiency compared with conventional or non-intervention conditions.

Method

Research Design

This study employed a quantitative experimental approach using a randomized controlled trial design to investigate the effects of visual stimulus training on brain function enhancement. The study applied a pre-test and post-test control group design in which participants were randomly assigned to either an experimental group receiving visual stimulus training or a control group performing conventional physical and cognitive activities without specific visual stimulation intervention. This design was selected to minimize bias and allow a direct comparison of cognitive and neurofunctional changes between groups following the intervention period.

Random allocation was conducted using a computerized random number generator administered by an independent researcher not involved in participant assessment or intervention delivery. Allocation concealment was maintained using sealed opaque envelopes containing group assignments, which were opened only after baseline assessments had been completed. This procedure was implemented to minimize selection bias and maintain allocation integrity throughout the recruitment process.

The intervention program was conducted over eight weeks with a training frequency of three sessions per week. Each session lasted approximately 45 minutes and consisted of progressive visual stimulus exercises designed to activate attentional, visuomotor, and executive processing systems. Baseline assessments were conducted one week before the intervention, while post-intervention measurements were performed within one week after the completion of the training program. The study design followed recommendations for cognitive intervention research emphasizing controlled training exposure and repeated measurements to evaluate neuroplastic adaptation.

Participants

The participants consisted of 40 healthy young adults aged between 18 and 25 years recruited from university populations through purposive sampling techniques. The target population was selected because young adults demonstrate relatively stable cognitive performance and high adaptability to visual-cognitive interventions. Participants were randomly allocated into two groups consisting of 20 individuals in the experimental group and 20 individuals in the control group.

An a priori statistical power analysis was conducted using G*Power version 3.1 for repeated-measures ANOVA with within–between interaction effects. Assuming a medium effect size ($f = 0.25$), significance level of 0.05, statistical power of 0.80, two groups, and two repeated measurements, the minimum required sample size was estimated at 34 participants. To compensate for potential attrition and maintain statistical stability, the final sample size was increased to 40 participants with equal allocation between groups.

Several inclusion criteria were established to ensure participant homogeneity and reduce potential confounding variables. Participants were required to have normal or corrected-to-normal vision, no history of neurological disorders, no diagnosed cognitive impairments, and no current use of neuroactive medications. Participants were also required to maintain regular sleep patterns and refrain from consuming substances that could affect cognitive performance, including alcohol and stimulant medications, during the intervention period. Exclusion criteria included a history of traumatic brain injury, epilepsy, severe visual impairment, psychiatric disorders, or participation in other cognitive training programs within the previous six months.

Prior to participation, all individuals received a detailed explanation regarding the objectives, procedures, benefits, and potential risks associated with the study. Written informed consent was obtained from all participants before data collection began. Ethical approval for the study was granted by the institutional research ethics committee in accordance with the Declaration of Helsinki principles regarding human research ethics.

A priori statistical power analysis was conducted using G*Power version 3.1 to determine the minimum required sample size for repeated-measures ANOVA with within–between interaction effects. Assuming a medium effect size ($f = 0.25$), alpha level of 0.05, statistical power of 0.80, two groups, and two measurement points, the minimum required sample size was calculated as 34 participants. To account for potential attrition during the intervention period, the sample size was increased to 40 participants, with 20 participants allocated to each group.

Instruments and Measurements

Attention performance was assessed using the Stroop Color and Word Test, which evaluates selective attention and inhibitory control. Previous studies have demonstrated acceptable validity and reliability for the Stroop Test, with test–retest reliability coefficients ranging from 0.80 to 0.91 in healthy adult populations.

Working memory capacity was measured using the computerized N-Back Test, which is widely used in cognitive neuroscience research to evaluate memory updating and information retention processes. The N-Back task has demonstrated strong construct validity and internal consistency, with reliability coefficients reported between 0.78 and 0.88.

Reaction time performance was assessed using a computerized visual reaction time test involving randomized visual stimulus presentations. The computerized reaction time assessment has shown high temporal accuracy and test–retest reliability above 0.85 in cognitive performance studies.

Executive functioning was evaluated using the Trail Making Test and task-switching assessments to examine cognitive flexibility and processing efficiency. The Trail Making Test has demonstrated strong psychometric properties with reliability coefficients ranging from 0.76 to 0.89 and established validity for assessing executive control and cognitive flexibility.

To examine neurophysiological adaptation, electroencephalography (EEG) recordings were conducted before and after the intervention period. EEG data were collected using a portable 32-channel wireless EEG system (sampling rate: 500 Hz) based on the international 10–20 electrode placement system. Electrode impedance was maintained below 10 kΩ throughout the recording sessions. EEG measurements focused on alpha (8–12 Hz) and beta (13–30 Hz) frequency bands associated with attentional processing and cognitive engagement.

Artifact rejection procedures were conducted prior to data analysis to minimize noise contamination caused by eye blinking, muscle movement, and electrical interference. Raw EEG signals were filtered using a band-pass filter of 0.5–40 Hz, and independent component analysis (ICA) was applied to remove ocular and movement-related artifacts. Only artifact-free EEG segments were included in the final analysis.

Prior to data collection, all cognitive assessment instruments underwent pilot testing to confirm procedural consistency and measurement stability. Internal consistency reliability for the computerized cognitive assessments ranged from Cronbach's alpha = 0.81 to 0.89. Calibration procedures were also performed for EEG equipment and visual stimulus devices before each testing session to ensure signal accuracy and measurement consistency throughout the intervention period.

The Stroop Color and Word Test demonstrated test–retest reliability coefficients ranging from 0.80 to 0.91 and established convergent validity for attentional and inhibitory control assessment. The computerized N-Back Test has shown internal consistency reliability coefficients between 0.78 and 0.88 with strong construct validity for working memory evaluation. The computerized visual reaction time assessment demonstrated temporal reliability above 0.85 and high measurement sensitivity for visuomotor response detection. The Trail Making Test demonstrated reliability coefficients ranging from 0.76 to 0.89 and has been extensively validated for executive function and cognitive flexibility assessment in healthy adult populations.

Research Procedure

The research procedure consisted of three major phases: baseline assessment, intervention implementation, and post-intervention evaluation. During the baseline phase, participants attended the laboratory for initial cognitive and neurophysiological assessments. Demographic data including age, sex, physical activity level, sleep duration, and visual health status were also recorded.

Following baseline testing, participants were randomly assigned to either the experimental or control group using a computerized randomization procedure. The experimental group participated in structured visual stimulus training sessions three times per week for eight weeks. Each session consisted of warm-up activities, dynamic visual reaction drills, peripheral awareness exercises, visual tracking tasks, and visuomotor coordination activities. Training intensity and complexity gradually increased over time to stimulate progressive neural adaptation and prevent training monotony.

Visual reaction drills involved responding to rapidly changing LED stimuli appearing at different spatial locations. Peripheral awareness exercises required participants to identify visual targets presented simultaneously across multiple visual fields. Visual tracking tasks involved following moving objects displayed on digital screens while maintaining attentional accuracy. Additional dual-task exercises combining visual and cognitive demands were included to stimulate executive control and working memory systems.

The control group participated in general stretching and low-intensity physical activities without exposure to structured visual stimulus interventions. This approach was implemented to control for general physical engagement and participant interaction effects.

To ensure procedural consistency, all training sessions were supervised by trained researchers following standardized protocols. Environmental conditions such as room lighting, temperature, and noise levels were controlled throughout the intervention period. Participants were instructed to maintain consistent sleep schedules and avoid excessive caffeine intake before testing sessions.

Several strategies were applied to minimize potential bias during the study. Random allocation procedures reduced selection bias, while standardized testing instructions minimized measurement variability. Researchers conducting post-test assessments were blinded to group allocation to reduce observer bias. Participant attendance and compliance were monitored throughout the intervention period, and individuals missing more than 15% of training sessions were excluded from the final analysis.

Data Analysis

Data analysis was performed using IBM SPSS Statistics version 26. Descriptive statistics including mean, standard deviation, minimum score, maximum score, and percentage changes were calculated for all study variables. Preliminary assumption testing was conducted before inferential analysis. Data normality was examined using the Shapiro–Wilk test, while homogeneity of variance was assessed using Levene's test.

To evaluate within-group changes between pre-test and post-test measurements, paired sample t-tests were conducted for each variable. Between-group differences were analyzed using repeated-measures analysis of variance (ANOVA) to examine the interaction effects between group and time. Effect size values were calculated using Cohen's d and partial eta squared to determine the magnitude of intervention effects.

Statistical significance was established at $p < 0.05$. In addition to quantitative statistical analysis, graphical visualization of cognitive and neurophysiological changes was performed to facilitate interpretation of intervention outcomes. The overall analytical approach was designed to comprehensively examine the effectiveness of visual stimulus training on cognitive performance and neural adaptation.

Results and Discussions

Participant Characteristics

A total of 40 participants successfully completed the intervention program and were included in the final analysis. The participants were randomly divided into the experimental group (n = 20) and the control group (n = 20). Baseline demographic characteristics including age, body mass index (BMI), and baseline cognitive scores were analyzed to determine the homogeneity of both groups prior to the intervention. The descriptive analysis showed that there were no substantial differences between groups at baseline. Table 1 presents the demographic characteristics of participants in both groups.

Table 1. Participant Characteristics

Variable	Experimental Group (n = 20)	Control Group (n = 20)	p-value
Age (years)	21.35 ± 1.72	21.10 ± 1.89	0.684
Body Mass Index (kg/m²)	22.14 ± 2.31	21.88 ± 2.46	0.751
Male/Female	11/9	10/10	0.752
Baseline Attention Score	78.40 ± 6.28	77.95 ± 5.91	0.823
Baseline Working Memory Score	71.85 ± 5.76	72.10 ± 5.48	0.887
Baseline Reaction Time (ms)	312.25 ± 21.67	315.40 ± 20.83	0.657

The homogeneity analysis demonstrated that all baseline variables were statistically comparable between the experimental and control groups ($p > 0.05$), indicating that both groups had similar initial characteristics before the intervention.

Normality and Homogeneity Testing

Prior to hypothesis testing, assumption analyses were conducted to evaluate data distribution and variance homogeneity. The Shapiro–Wilk test was used to assess normality, while Levene's test was applied to examine homogeneity of variance across groups. The results indicated that all variables were normally distributed and fulfilled the assumptions required for parametric statistical analysis.

Table 2. Results of Normality and Homogeneity Tests

Variable	Shapiro–Wilk p-value	Levene's Test p-value	Interpretation
Attention Score	0.214	0.337	Normal and Homogeneous
Working Memory Score	0.189	0.421	Normal and Homogeneous
Reaction Time	0.276	0.398	Normal and Homogeneous
Executive Function Score	0.241	0.355	Normal and Homogeneous

The statistical findings confirmed that all study variables met the assumptions for repeated-measures ANOVA and paired sample t-test analyses.

Changes in Cognitive Performance Variables

Following the eight-week intervention program, improvements were observed in several cognitive performance variables within the experimental group. Participants who received visual stimulus training demonstrated increased attention scores, improved working memory performance, faster reaction times, and enhanced executive functioning compared with the control group. Table 3 presents the pre-test and post-test results for all cognitive variables.

Table 3. Pre-test and Post-test Cognitive Performance Results

Variable	Group	Pre-test	Post-test	Mean Difference	p-value
Attention Score	Experimental	78.40 ± 6.28	87.15 ± 5.74	+8.75	0.001*
	Control	77.95 ± 5.91	79.20 ± 5.66	+1.25	0.218
Working Memory Score	Experimental	71.85 ± 5.76	80.90 ± 5.28	+9.05	0.001*
	Control	72.10 ± 5.48	73.25 ± 5.31	+1.15	0.301
Reaction Time (ms)	Experimental	312.25 ± 21.67	276.10 ± 18.44	-36.15	0.001*
	Control	315.40 ± 20.83	309.95 ± 19.72	-5.45	0.174
Executive Function Score	Experimental	74.20 ± 6.12	83.45 ± 5.87	+9.25	0.001*
	Control	73.90 ± 5.95	75.10 ± 5.76	+1.20	0.267

*Significant at $p < 0.05$

The results demonstrated statistically significant improvements in all cognitive variables within the experimental group after visual stimulus training ($p < 0.05$). In contrast, the control group showed only minimal non-significant changes across all measured variables.

Additional between-group comparisons using post-test adjusted mean analyses demonstrated that the experimental group maintained significantly superior cognitive performance outcomes compared with the control group after controlling for baseline differences. These findings further support the effectiveness of the visual stimulus training intervention in enhancing cognitive and neurofunctional performance.

Neurophysiological Outcomes

Electroencephalography (EEG) analysis was conducted to examine neural adaptation associated with the intervention. The experimental group demonstrated increased beta wave activity and reduced excessive alpha activity during cognitive processing tasks following the training period. These changes were associated with improved attentional focus and cognitive engagement. Table 4 summarizes the EEG findings before and after the intervention.

Table 4. EEG Activity Changes Following Intervention

EEG Variable	Group	Pre-test	Post-test	p-value
Beta Wave Activity (μV^2)	Experimental	14.25 ± 2.11	18.90 ± 2.34	0.001*
	Control	14.48 ± 2.25	15.02 ± 2.17	0.241
Alpha Wave Activity (μV^2)	Experimental	21.74 ± 3.42	18.12 ± 3.01	0.003*
	Control	22.10 ± 3.36	21.55 ± 3.20	0.378

*Significant at $p < 0.05$

The EEG findings indicated greater neural activation and attentional engagement in the experimental group following visual stimulus training.

Comparative Analysis Between Groups

Repeated-measures ANOVA was performed to examine the interaction effect between group and time. The analysis revealed significant interaction effects for all primary cognitive variables, indicating that the improvements observed were associated with the visual stimulus training intervention.

Table 5. Repeated-Measures ANOVA Results

Variable	F-value	p-value	Partial Eta Squared
Attention Score	18.72	0.001*	0.331
Working Memory Score	21.45	0.001*	0.361
Reaction Time	24.16	0.001*	0.389
Executive Function Score	19.88	0.001*	0.344

*Significant at $p < 0.05$

The effect size analysis demonstrated moderate-to-large intervention effects across all variables, suggesting that visual stimulus training produced meaningful improvements in cognitive and neurofunctional performance.

Post-intervention comparisons demonstrated that participants in the experimental group achieved significantly greater improvements in attentional performance, working memory capacity, reaction speed, and executive functioning compared with the control group. Repeated-measures ANOVA revealed statistically significant group × time interaction effects across all primary outcome variables, indicating that the observed improvements were attributable to the visual stimulus training intervention rather than natural performance variation.

Effect size analysis demonstrated moderate-to-large intervention effects, with partial eta-squared values ranging from 0.331 to 0.389. Reaction time demonstrated the largest intervention effect, indicating substantial enhancement in visuomotor processing efficiency following repeated visual-cognitive stimulation. Statistical power analysis conducted post hoc demonstrated achieved power values above 0.80 for all primary outcome variables, indicating adequate sensitivity for detecting intervention-related cognitive changes.

Overall, the findings indicated that the eight-week visual stimulus training program significantly enhanced attention, working memory, reaction time, executive functioning, and neural activation compared with conventional activity conditions.

The present study investigated the effects of visual stimulus training on brain function enhancement among healthy young adults. The findings demonstrated that participants who received the eight-week visual stimulus intervention experienced significant improvements in attention, working memory, reaction time, executive functioning, and neurophysiological activation compared with the control group. These results indicate that repeated visual stimulation may positively influence cognitive processing efficiency and neural adaptation. The significant interaction effects identified through repeated-measures ANOVA further suggest that the observed cognitive improvements were strongly associated with the intervention rather than natural performance variation over time.

One of the most important findings of this study was the substantial improvement in attentional performance following visual stimulus training. Attention is a fundamental cognitive process responsible for selecting, maintaining, and regulating relevant sensory information during task execution. The improvement observed in the experimental group may be explained by the repeated exposure to dynamic visual stimuli requiring continuous focus, rapid perceptual discrimination, and fast visuomotor responses. Repeated attentional engagement likely strengthened neural pathways associated with selective attention and sensory processing. This finding is consistent with previous studies reporting that visual-cognitive training can improve attentional control and perceptual processing efficiency through adaptive neuroplastic changes (Chen & Hao, 2025; Mukhtar & Iftikhar, 2025).

The construct validity of the present findings is strengthened by the use of multiple standardized cognitive assessments targeting distinct but interrelated cognitive domains. Attention, working memory, reaction speed, and executive functioning were evaluated using validated neurocognitive instruments with established psychometric properties, reducing the likelihood that the observed improvements merely reflected generalized testing familiarity. Furthermore, the consistency between behavioral improvements and EEG-based neurophysiological adaptation provides convergent evidence supporting the validity of the intervention effects on cognitive processing efficiency and neural activation.

The enhancement in working memory performance also represents an important outcome of the present study. Working memory is closely associated with information retention, cognitive manipulation, and executive regulation during complex tasks. The visual stimulus training used in this study incorporated dual-task activities, spatial tracking, and rapid visual processing demands that may have stimulated memory updating and information integration processes. Repeated activation of these cognitive systems may have promoted stronger neural connectivity within frontoparietal brain networks involved in working memory regulation. Similar findings were reported by (D. Eldar et al., 2026; Ikefuama et al., 2022; Tataranu & Rizea, 2025), who explained that repetitive cognitive stimulation can facilitate synaptic strengthening and improve cognitive efficiency through neuroplastic adaptation mechanisms.

Reaction time demonstrated one of the largest improvements following the intervention. Participants in the experimental group showed faster visual response speed after completing the training program. This improvement may be explained by enhanced sensorimotor integration and more efficient processing of visual information within cortical and subcortical neural pathways. Visual stimulus training requires rapid interpretation of sensory input followed by immediate motor responses, which may improve communication efficiency between visual processing regions and motor planning areas. Previous research has shown that visual reaction training enhances perceptual speed, decision-making accuracy, and motor responsiveness in both athletes and non-athlete populations (Bernárdez-Vilaboa et al., 2026; Jothi et al., 2025; Luo et al., 2025; Wang et al., 2025). Faster reaction performance is particularly important because it contributes not only to athletic performance but also to cognitive functioning in educational and occupational settings where rapid information processing is essential.

The improvement in executive functioning observed in this study further supports the effectiveness of visual stimulus training as a cognitive enhancement strategy. Executive functions involve higher-order cognitive processes such as cognitive flexibility, inhibitory control, and decision-making. During the intervention, participants were required to continuously adapt to unpredictable visual stimuli while maintaining attentional accuracy and response precision. These task demands may have stimulated prefrontal cortical activity and strengthened executive control systems. According to (Ardestani et al., 2016; Gazzaley & Nobre, 2012), repeated attentional and cognitive engagement can improve top-down control mechanisms responsible for executive regulation and cognitive coordination.

The neurophysiological findings obtained through EEG analysis also provide important evidence regarding neural adaptation following visual stimulus training. Increased beta wave activity and reduced alpha wave activity were observed in the experimental group after the intervention. Beta wave activity is commonly associated with heightened attentional focus, active cognitive engagement, and information processing efficiency, whereas excessive alpha activity is often related to reduced cognitive activation. The observed EEG changes suggest that visual stimulus training enhanced neural activation and attentional readiness during cognitive tasks. These findings align with previous electrophysiological studies demonstrating that repeated sensory and attentional training can alter cortical activation patterns and improve neural efficiency (Foldal et al., 2020, 2023; Huang et al., 2024; Pervin et al., 2026).

The present findings are also consistent with the neuroplasticity framework underlying cognitive training interventions. Neuroplasticity refers to the brain's capacity to reorganize neural pathways and strengthen synaptic communication in response to repeated stimulation and learning experiences. Visual stimulus training likely induced repeated activation within visual-attentional networks, promoting adaptive neural changes over the intervention period. Hebbian learning theory explains that frequently activated neural circuits become increasingly efficient over time, contributing to improved cognitive performance and sensory processing efficiency. The combination of visual, attentional, and motor demands included in the intervention may therefore have accelerated functional adaptation across multiple brain systems simultaneously.

Although the findings of this study support the effectiveness of visual stimulus training, several limitations should be acknowledged. First, the sample size was relatively small, which may limit the generalizability of the findings to broader populations. Second, the intervention duration was limited to eight weeks, making it difficult to determine whether the observed cognitive improvements would persist over longer periods. Third, although EEG analysis provided valuable neurophysiological information, the study did not include more advanced neuroimaging techniques such as functional magnetic resonance imaging (fMRI) or diffusion tensor imaging that could provide more detailed insights into structural and functional brain adaptation.

Additional external factors may also have influenced the outcomes of this study. Variables such as sleep quality, nutritional status, psychological stress, and daily physical activity were monitored through self-report but were not fully controlled experimentally. These factors are known to influence cognitive performance and neural functioning. Future studies should therefore incorporate stricter control of lifestyle-related variables to improve internal validity.

Several additional threats to internal validity should also be considered when interpreting the present findings. Repeated exposure to computerized cognitive assessments may have introduced potential practice effects that contributed to performance improvement independent of the intervention. Although both groups underwent identical testing procedures, some degree of test familiarity cannot be entirely excluded. Expectancy bias may also have influenced participant motivation and engagement because individuals assigned to the experimental group were aware of their participation in a structured cognitive enhancement program. To minimize these threats, blinded post-test assessment procedures and standardized testing protocols were implemented throughout the study.

Despite these limitations, the present study provides important practical implications. Visual stimulus training may serve as an effective non-pharmacological intervention for improving cognitive performance in educational, athletic, occupational, and rehabilitation settings. In educational contexts, visual stimulus exercises may help improve concentration, attentional control, and learning efficiency among students. In sports environments, improved reaction time and visuomotor coordination may enhance athletic performance and decision-making under pressure. Furthermore, visual stimulus interventions may have potential applications in cognitive rehabilitation programs for older adults and individuals with mild cognitive impairment.

Future research should explore longer intervention durations, larger sample populations, and the integration of advanced neuroimaging methods to better understand the long-term neural mechanisms associated with visual stimulus training. Comparative studies examining different types of visual training approaches, including virtual reality-based systems and traditional visual exercises, would also provide valuable insights into the most effective intervention models for cognitive enhancement.

Conclusions

This study examined the effects of visual stimulus training on brain function enhancement among healthy young adults. The findings demonstrated that the eight-week visual stimulus training program significantly improved several cognitive and neurofunctional variables, including attention, working memory, reaction time, executive functioning, and neural activation patterns. Participants who received the intervention showed greater cognitive improvements compared with the control group, indicating that repeated visual stimulation may effectively enhance cognitive processing efficiency and sensory-motor integration. The neurophysiological findings obtained through EEG analysis further supported the behavioral outcomes of the study. Increased beta wave activity and reduced alpha wave activity following the intervention suggested improved attentional engagement and neural efficiency during cognitive tasks. These results reinforce the concept that structured visual stimulus exposure can facilitate adaptive neuroplastic changes within brain networks associated with attention, executive control, and visuomotor processing. The findings of this study provide important implications for the application of visual stimulus training in various fields. In educational settings, visual stimulus exercises may support concentration and learning performance. In sports science, improved reaction speed and cognitive responsiveness may contribute to better athletic performance. Additionally, visual stimulus training may have potential benefits for occupational performance and cognitive rehabilitation programs. Despite several limitations related to sample size and intervention duration, the study provides evidence that visual stimulus training is a promising non-pharmacological strategy for enhancing brain function. Future research involving larger populations, longer intervention periods, and advanced neuroimaging approaches is recommended to further clarify the long-term effectiveness and underlying neural mechanisms of visual stimulus training.

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