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Investigation of the effect of a cognitive rehabilitation program on neuroplasticity in stroke patients

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Abstract
This review aims to examine the effectiveness of various cognitive rehabilitation approaches used in stroke-related cognitive dysfunctions, with a particular emphasis on their impact on neuroplasticity, thereby contributing to increased awareness in this field. This study is an integrative review, referring to the retrospective systematic scanning of articles on the subject. The PICOS criteria have structured the study design to ensure methodological standards. An electronic search strategy was used to determine identify the studies targeted by the research. A search was conducted using six electronic databases: PubMed, Cochrane Library, Google Scholar, ResearchGate, Web of Science, and Scopus. All studies conducted between 2014 and 2024 were included. We only included articles with full text. Only articles with full texts available were included. Stroke is a leading cause of illness and death globally. Many survivors face cognitive issues that lower their quality of life. This review examines strategies to enhance neuroplasticity in stroke rehabilitation. Interventions such as computer-assisted cognitive training (CACT), physical exercise, virtual reality (VR), transcranial direct current stimulation (tDCS), and transcranial magnetic stimulation (TMS) have demonstrated potential in therapeutic applications. When combined with physical exercise, their efficacy is further enhanced. Non-invasive brain stimulation has been shown to facilitate improvements in executive functions and daily activities, while VR-based training contributes to rehabilitation. Overall, a multimodal approach that promotes neuroplasticity can significantly enhance cognitive functions and overall quality of life. Future research should focus on evaluating these interventions across diverse populations to optimize and refine treatment strategies.

Keywords: stroke, cognitive rehabilitation, recovery, neuroplasticity

1. Introduction

Stroke is a leading cause of death and disability, affecting 116.4 million people globally. Up to 80% of stroke survivors face physical, motor, language, sensory, behavioral, visual, and cognitive challenges (1,2). These include difficulties with memory, attention, and awareness. Delays in rehabilitation can worsen recovery. Treatments administered during periods of high neuroplasticity yield better results. A key question is whether we can extend the natural neuroplasticity boost after a stroke. Cognitive exercises may aid individuals with mild cognitive impairment and help prevent decline in healthy seniors (3). These exercises include computer training, memory techniques, puzzles, strategy games, and physical activity. Regular practice is crucial.

Previously, it was believed brain cells couldn't renew after birth. However, 20th-century studies have shown that brain cells can repair, form new connections, and even create new neurons, albeit in limited quantities (4). Neuroplasticity refers to the changes in neurons and their connections that occur due to environmental factors. It has two types: functional and structural. Functional neuroplasticity enables undamaged areas of the brain to assume the functions of damaged areas. Structural neuroplasticity involves changes in neuron networks due to learning or experience. Such changes can include alterations in dendrite structures, the formation or elimination of synapses, and even the birth or death of neurons (5).

Stroke is a common neurological disorder characterized by loss of brain function (6). Stroke is the third most common cause of death in developed countries after coronary heart disease and cancer (7,8). Its incidence is increasing worldwide, and its economic burden is also increasing (9). According to estimates, by 2030, approximately 80% of all stroke cases will occur in low- and middle-income countries (10). The prevalence of stroke in low and middle-income countries varies between 0.3% and 2.1%. In a developing middle-income country like Turkey, there is no definitive nationwide registry for stroke, and precise prevalence data are not available

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(11,12). Accurate data on stroke are limited, and there are only two published studies in Turkey, which determined that the prevalence of stroke in the ≥45 age group ranged between 0.9% and 4.1% (13,14). Although clinical symptoms are diverse (15), permanent motor deficits (including weakness, lack of coordination, and decreased mobility) and cognitive disorders (such as impairments in information processing and executive function) are typically observed (16,17). Stroke, a leading cause of disability worldwide, can impact all levels of the International Classification of Functioning; that is, it can affect body structures and functions, activity, and participation domains (18,19).

A review of the literature reveals that studies conducted with individuals who have experienced a stroke predominantly focus on the effectiveness of physical rehabilitation interventions targeting functional abilities such as gait, fine and gross motor skills, balance, and coordination. However, in addition to motor impairments, stroke survivors frequently experience deficits in cognitive functions, including executive functions, attention, and memory. In this context, this review aims to examine the effectiveness of various cognitive rehabilitation approaches used in stroke-related cognitive dysfunctions, with a particular emphasis on their impact on neuroplasticity, thereby contributing to increased awareness in this field.

1.1. Neuroplasticity

The concept of plasticity is derived from the Greek word "plastics," meaning "to shape" or "to give shape." Livingston first defined the concept of neuroplasticity in this way (24,25). In the past, it was thought that neural cells were not renewed after birth and diminished over time. However, research conducted in the 1900s revealed that brain cells can repair themselves throughout life, that new neurons can be formed, albeit to a limited extent, and that this process occurs in various brain regions. The discovery in 1998 that the adult human brain can produce new brain cells altered our understanding of the human brain. It sparked a renewed interest in the brain's plasticity throughout life (25,26). Neuroplasticity refers to the brain’s ability to alter its structure and function in response to internal or external stimuli. Through neuroplasticity, individuals can acquire new cognitive or physical skills throughout their lives and regain lost abilities. The brain's inherent capacity primarily drives the effectiveness of both physical and mental rehabilitation. While neuroplasticity is often more pronounced in younger individuals, it persists throughout life. Even in older adults, this capacity can help prevent both physical and cognitive decline (20,21).

The extent of neuroplasticity varies among individuals due to genetic differences. A key factor in neuroplasticity is the brain’s ability to produce neurotrophic factors, which support neuronal growth and function. In particular, research has shown that the production of brain-derived neurotrophic factor (BDNF) increases with aerobic exercise, thereby enhancing motor learning and memory (34, 22). Consequently, it is now well-established that physical activity enhances cognition, while cognitive activity can improve motor function. Given that stroke patients often experience both mental and physical impairments, they are ideal candidates for rehabilitation. The role of neuroplasticity in restoring lost function has been demonstrated in various studies employing different rehabilitation strategies in this patient population (35,23). However, the effective integration of cognitive rehabilitation into traditional motor rehabilitation remains unclear. This section will discuss the key mechanisms underlying neuroplasticity that contribute to functional recovery.

Rehabilitation-based Neuroplasticity Mechanisms

Neurogenesis

Neurogenesis is considered a component of structural neuroplasticity. Neurogenesis is the process by which stem cells differentiate into neurons. It primarily occurs in the hippocampus of the brain. Here, stem cells develop into new neurons and support cells, particularly with the acquisition of new experiences. The hippocampus is crucial for enabling the brain to adapt to cognitive demands. In adults, this process shows remarkable flexibility (26). Neurons are formed and selected to survive in a small brain area. Neurogenesis primarily occurs in the subventricular zone and the subgranular zone of the hippocampus. Environmental factors regulate it. Enriched environments, exercise, learning, and antidepressants boost neurogenesis. However, chronic stress and aging hinder it (27).

Changes in Axonal and Dendritic Branches

Neuronal circuits grow and shrink through changes in axonal and dendritic morphology. New dendritic branches form "trial synapses." Only the ones with proper input survive. Neuroplasticity enhances dendrites, forms new synapses, and adjusts existing ones. It can even create new neurons, aiding stress resistance. Dendrites are the most adaptable part of a neuron. Their changes indicate neuroplastic development. Synaptic connections drive these changes, which are further enhanced by environmental cues (28).

Synaptic Connections

In early development, synapse density in the human cortex increases to approximately twice that of adults. Brain growth later reduces this density. Synaptic pruning continues into the third decade, ensuring that only the most effective synapses remain. This process is vital for adapting to stimuli. Brain connections are dynamic, adjusting to needs. Activities that promote neuroplasticity enhance synaptic connections and communication pathways (30).

Re-learning after Brain Damage

Brain injury recovery methods fall into two main types:

1. Preventing further loss of function.
2. Restoring or compensating for lost function.

The first method is crucial. Early treatment might not entirely prevent long-term issues. Thus, understanding post-injury brain changes is vital. The brain forms new connections through learning (31). It adapts by coding experiences and altering circuits. Learning requires specific changes in the nervous system. These changes, known as neuroplasticity, depend on behavior, sensory input, and thought. Healthy brains adapt by reorganizing. In damaged brains, undamaged areas take over. Learning helps adapt after injury (32). People develop new strategies to cope with lost functions.

Use and Improve

Animal studies have shown that long-term training enhances brain plasticity. For example, monkeys learned to use their fingers to obtain food, increasing the finger area of the motor cortex. Likewise, mice that reached for food showed increased activity in the distal forepaw areas of the motor cortex. Post-injury training also aids recovery. It enhances performance and brain plasticity. Research now targets intentional training (33).

Repetition of Learned Experiences

Learning a new behavior requires repetition for lasting brain changes. Firstly, you need to learn a skill and then keep practicing it. This repetition makes the behavior stick, even when not in use. It's crucial for rehab. It helps patients maintain what they've gained in therapy and continue to improve (39).

Density of Repetitions

Both the duration and intensity of training affect brain plasticity. In tests, animals doing 400 reaching tasks daily had more synapses in the motor cortex. In contrast, those doing just 60 tasks showed no such increase (40).

1.2. Cognitive Rehabilitation

Cognitive rehabilitation is a therapeutic approach aimed at restoring lost cognitive functions or slowing progressive decline in individuals with neurological conditions such as traumatic brain injury, stroke, Alzheimer’s disease, Parkinson’s disease, or multiple sclerosis (36). Cognitive rehabilitation can be categorized into two types: compensatory and restorative (reference). In stroke patients, deficits in attention, long-term memory, executive functions, and visuospatial abilities are commonly observed (37). Additionally, emotional lability, depression, and anxiety are significant psychosocial challenges. Cognitive rehabilitation plays a crucial role in addressing these deficits in stroke patients. Moreover, improvements in these mental functions can enhance participation in motor rehabilitation and increase motivation, ultimately contributing to overall health and the recovery of daily functional abilities (41). After a stroke, the brain can repair itself. This relies on the plasticity of the remaining nervous systems. Such adaptations aid recovery and are essential in rehabilitation. Boosting this adaptability is crucial in post-stroke rehab (42).

With these objectives in mind, we aimed to write a review by examining research articles that investigate the effectiveness and application of cognitive rehabilitation methods in stroke. Specifically, we focused on approaches considered adequate through neuroplasticity, including virtual reality (VR), transcranial direct current stimulation (tDCS), transcranial magnetic stimulation (TMS), computer-assisted cognitive training (CACT), and cognitive rehabilitation combined with exercise.

2. METHOD

This study is an integrative review that involves a retrospective systematic review of articles on the subject.

2.1. Study design

PICOS (Population, Intervention, Comparison, Outcomes, Study design) standards were used to determine the study design (Table 1).

Table 1. PICOS Method in Determining Study Design

P Population	Participants with stroke
I Intervention	Cognitif rehabilitation (CACT, tDCS, TMS, virtual reality, cognitive exercises)
C Comparison	of Groups Pre-test-post-test without a control group, comparative with a control group, comparative without a control group
O Outcomes	Cognitive functions
S Study design	Interventional study, single and double blind randomized controlled trials

2.2. Search strategy

An electronic search strategy was used to determine the studies targeted by the research. A search was conducted using six electronic databases: PubMed, Cochrane Library, Google Scholar, ResearchGate, Web of Science, and Scopus. All studies conducted between 2014 and 2024 were included. We only included articles with full text. The search yielded 36 studies. Seven randomized controlled trials met our criteria. The keywords "cognitive exercise," "stroke," "rehabilitation, "recovery," and "neuroplasticity" were used as search terms. The search terms were related to cognitive rehabilitation, which was the central theme of the study. The second stage consisted of associating with neuroplasticity. In these stages, the words "and," "not," and "or" were used to ensure that studies combining the topics were addressed.

2.3. Study selection and data collection process

Four researchers (BÜ, YY, GA, SGÖ) independently reviewed the titles and abstracts of the studies to determine whether the studies met the inclusion criteria. The studies that met the requirements were recorded, and the full texts were evaluated.

3. Neuroplasticity in post-stroke cognitive rehabilitation

3.1. Computer-Assisted Cognitive Training (CACT)

CACT, using computers, tablets, and phones, has surpassed traditional methods. It enhances skills like memory and problem-solving through interactive exercises. Unlike other methods, CACT is accessible, comprehensive, and personalized (43). Its game-like structure makes it engaging. It's also safe, affordable, and scalable, crucial for preserving cognitive functions in older adults (44). CACT is vital in treating post-stroke cognitive impairment. A review by Fava-Felix et al. (2022) found it boosts recovery, especially in more educated patients. Gil-Pagés et al. (2022) reported that supervised home CACT improves recovery in patients with chronic stroke (45). Fava-Felix et al. (2022) reported that the 'Reh@Task' program was implemented three times per week for one month, whereas in another study, the 'BrainHQ' program was administered two or three times per week for a duration ranging from 12 to 18 months. These interventions demonstrated that computer-based cognitive training (CACT) particularly supports cognitive improvement in patients with higher educational levels. Similarly, Gil-Pagés et al. (2022) utilized the 'Guttmann, NeuroPersonalTrainer' application once daily over six weeks in their randomized, double-blind study. They reported that home-based, supervised CACT supports functional recovery in patients with chronic stroke. CACT focuses on enhancing cognitive skills, such as memory and problem-solving, through practice and repetition using engaging and interactive exercises. Distinguishing itself from other cognitive training approaches, CACT is notable for being accessible, comprehensive, and adaptable to individual needs. With its game-like structure, CACT provides a motivating experience for participants and is considered a safe, cost-effective, and scalable method. Therefore, it plays a significant role in preserving cognitive functions, particularly in older adults.

3.2. Combining Physical and Cognitive Training

Combining physical and cognitive training is more effective than either alone. Yeh et al. (2022) demonstrated that combining aerobic exercise with CACT significantly enhances cognitive functions. Bo et al. conducted a study with 225 stroke patients, randomly assigning participants into four groups: an exercise group, a cognitive training group, a combined exercise and cognitive training group, and a control group. The combined group demonstrated significantly better results in the mental rotation test compared to the other groups. Similarly, Bo et al. (2019) found significant cognitive improvements in stroke patients with vascular cognitive impairment when using this combination (46, 47).

3.3. Combination of Transcranial Direct Current Stimulation (tDCS) and Cognitive Training

Transcranial Direct Current Stimulation (tDCS) is a noninvasive method that adjusts brain activity. Developed in 2000 for clinical use, it shows promise in treating neurological conditions. tDCS works by altering neuronal activity. It affects sodium and calcium channels and boosts NMDA receptor activity (48). This process changes neural activity and increases cortical excitability. Liu et al. (2021) found that tDCS, combined with cognitive training, improved executive functions and daily living skills in individuals who had experienced a stroke (49). Similarly, Chen et al. (2024) reported that tDCS, along with mental training, helped stroke patients with unilateral neglect (50). When applying tDCS in patients with stroke, potential physiological side effects should be carefully considered. These side effects may include mild skin redness, itching, a burning sensation, headache, dizziness, and fatigue. Furthermore, contraindications must be considered, such as a history of epilepsy, the presence of a pacemaker or other implanted electronic devices, and active skin infections or open wounds (48).

3.4. Combination of rTMS and Cognitive Training

Repetitive transcranial magnetic stimulation (rTMS) is a noninvasive brain treatment. It uses magnetic pulses to stimulate or inhibit specific neurons. Typically, rTMS sessions occur daily or weekly. The duration depends on the patient's condition and response. This study focused on brain areas associated with cognition, including the dorsolateral prefrontal cortex, motor cortex, and parietal cortex. Treatment varies in frequency (e.g., 1 Hz, 10 Hz), intensity, and number of sessions based on individual needs. Li et al. (2023) demonstrated that combining rTMS with cognitive training benefits individuals with post-stroke cognitive impairment. It enhances cognition, executive functions, and working memory. However, further research is needed to confirm these results and clarify the role of rTMS (51). When applying repetitive transcranial magnetic stimulation (rTMS) in patients with stroke, potential adverse effects should be carefully considered. Common physiological side effects may include headache, dizziness, and discomfort at the site of stimulation. Additionally, contraindications must be considered, such as a history of epilepsy or seizures, the presence of metal implants in the brain, pacemakers or other implanted electronic devices, and severe anxiety disorders or other significant psychiatric conditions (51).

3.5. Combination of Virtual Reality and Cognitive Training

VR, as one of the new technological alternatives to traditional rehabilitation methods, offers an interactive and experiential environment that can be utilized to practice activities of daily living. Additionally, the fully immersive or augmented reality environments provided by VR enable individuals to engage in both physical and cognitive tasks in a safe setting. For example, VR facilitates the simultaneous practice of motor skills such as walking, stepping, and grasping, along with cognitive functions like attention, memory, and executive functions, making it a preferred rehabilitation tool. VR is used in conjunction with traditional methods to treat cognitive disorders following a stroke. It creates interactive environments that help train cognitive skills. A study by Huang (2022) found that VR training improved the active range of motion and daily activities in stroke patients compared to conventional occupational therapy alone. These sessions consisted of 16 intervention sessions, each lasting 60 minutes per day, 2 to 3 days a week. In addition, they used the commercial immersive VR headset developed by HTC VIVE (HTC Corporation) in this study (52,53). VR-based rehabilitation approaches are increasingly being utilized to support motor and cognitive recovery in individuals with stroke. The cost-effectiveness of VR systems is attributed to their potential to reduce overall healthcare expenditures in long-term rehabilitation processes. Home-based VR systems,

in particular, can minimize the need for frequent hospital and clinic visits, offering economic benefits for both healthcare systems and patients. However, the initial investment costs associated with advanced VR devices and software can be relatively high (38).

In terms of accessibility, the development of portable and user-friendly VR devices has facilitated their use among individuals from diverse socioeconomic backgrounds. Nevertheless, regional and economic disparities in access to technology persist as significant barriers to the widespread implementation of this technology (52). In conclusion, the primary advantages of using VR for cognitive and motor rehabilitation are its engaging nature, the ability to motivate patients through real-time feedback, which ensures sustained patient participation, and the provision of a safe environment.

The studies conducted on cognitive rehabilitation in individuals with stroke are summarized in Table 2.

Table 2. Summary table of studies referenced in the review about cognitive rehabilitation

Study	Participants	Intervention Group(s)	Comparison Group(s)	Outcomes	Primer Outcome
Yeh et al. (2022) Single blind randomized controlled trial	56 stroke patients	Computerized cognitive training (n = 18) 60 min/day, 3 days/week, for a total of 12 weeks	Aerobic exercise training (n = 18) Sequential combination of aerobic exercise and computerized cognitive training (n = 20) group	1. MoCA 2. Wechsler Memory 3. Scale-Third Edition 4. The Stroop color-word test 5. Timed Up and Go test 6.6-Minute Walk Test 7.Functional Independence Measure	The combined training group showed significant improvement in MoCA (*P* < .05) two sub-tests in WMS-III (both Ps < 0.05)
Gil-Pagés et al. (2022) Double-blind, randomized, crossover clinical trial	40 stroke patients	Computerized cognitive training (CCT) (n=18) A set of 1-h sessions, five sessions per week for 6 weeks. A series of cognitive exercises focusing on attention, memory, and executive functions was conducted in each session.	sham intervention (n=22)	1. Patient Competency Rating Scale (PCRS) 2. Rating Scale for Attentional Behavior (RSAB) 3. Prospective and Retrospective Memory Questionnaire (PRMQ) 4. Behavior Rating Inventory of Executive Function – Adult Version (BRIEF-A)	Significant mean differences in intervention group PCRS (p = 0.02) PRMQ (p = 0.01
Bo et al. (2019) Single-blind Randomized controlled trial	225 stroke patients	Groups (1): Physical exercise (n=56; 50-minute session) Group (2): Cognitive training (n=57; 60-minute session) Group (3): Combined intervention of physical exercise and cognitive training (n = 55; 50-minute session)	Group (4) control groups (n=57; 45-minute session) All participants received training for 36 sessions, three days per week, for 12 weeks.	1. Trail Making Part B, 2. Stroop, forward digit span 3. Mental rotation tests	The combined training group (e.g., mental rotation, 17.36% vs. 0.87%, *P* = 0.002)
Liu et al. (2021) Randomized controlled trial	50 stroke patients	Group 1: real tDCS (n=25) Left dorsolateral prefrontal cortex (DLPFC): tDCS was applied continuously at an intensity of 2.0 mA. 5 sessions per week for 4 weeks (20 min)	Group 2: sham tDCS (n=25)	1. Wisconsin Card Sorting Test (WCST) 2. Stroop Color-Word Test (SCWT) 3. Digital Symbol Test (DST) 4. Montreal Cognitive Assessment (MoCA) 5. Mini-mental State Examination (MMSE)	WCST, SCWT, DST, MMSE, and MoCA in the real-tDCS group were significantly higher than the sham-tDCS group (p<0.05)

Chen et al. (2024)	72 stroke patients	tDCS group (n = 18) CACT combined with tDCS group (n = 18) 20-minute treatment 15 times a week for three consecutive weeks	Conventional cognitive training (CCT) group (n = 18) CACT group (n = 18) 20-minute treatment 15 times a week for three consecutive weeks	1. MoCA 2.Instrumental Activities of Daily Living Scale (IADL) 3.Transcranial Doppler ultrasound (TCD) 4. Breath-holding index (BHI)	MoCA and IADL scores significantly increased after treatment (P< 0.01) in each group.
Huang et al. (2022) Single-blind Randomized controlled trial	30 stroke patients	Virtual reality training (VRT) (n=15) 16 sessions of intervention for 60 min/day, 3 days/week (HTC VIVE)	Conventional occupational therapy (COT) (n=15) 16 sessions of intervention for 60 min/day, 2 to 3 days/week	1.İnterleukin 6 (IL-6) 2.Brain-derived neurotrophic factor (BDNF) 3.Active range of motion of the upper limb 4.Fugl-Meyer Assessment for upper extremity (FMA-UE)	Signifcant time efects in serum IL-6 (p =0.010) Clinical assessments FMA-UE(p<0.05) in VRT group
Li W. et al. (2022) Double blind randomized controlled trial	58 stroke patients	TMS group (n=28) Left dorsolateral prefrontal cortex: 100MT TMS 50 Hz burst repeated 5 Hz (On/Off time) 5 days of the week Total 10 sessions	Sham group (n=30)	1.Mini-mental state examination (MMSE) 2.Oxford cognitive screen 3.Event-related potential P300	The TMS group exhibits more significant changes in semantic comprehension and executive function (p < .05).

4. Discussion

This review examines methods that promote brain recovery after a stroke. It was found that CACT, physical exercise, tDCS, rTMS, and VR can all be beneficial. CACT is the most popular and accessible method, especially helpful for educated patients. Combining CACT with physical exercise may enhance cognitive functions. Brain stimulation methods, such as tDCS and rTMS, can improve specific cognitive issues when combined with mental training. VR offers a more engaging environment for cognitive training post-stroke (44,52). In terms of cost, CACT is the most affordable method (44). tDCS and rTMS are more expensive and require specialized training. VR is also costly due to its equipment needs. Each method has its pros and cons. CACT is easy to access and motivating, but its effects might be limited. Physical exercise enhances health and cognitive functions, but it may not be suitable for everyone. tDCS and rTMS target specific brain areas and aid recovery but may have side effects. VR is interactive and immersive, increasing motivation, but is limited by cost and accessibility (52). Effective cognitive rehabilitation after a stroke needs teamwork. Physiotherapists are key players. They blend cognitive and physical exercises, plan programs, oversee tDCS and rTMS treatments, and design VR exercises. While neuroplasticity-based methods show promise, they can be hard to implement. Ongoing education is crucial. Therapies must be tailored using assessment techniques. Regular sessions are essential for recovery. Addressing ethical issues and maximizing therapy benefits is vital as neurorehabilitation evolves (46, 49, 50).

The lack of standardized protocols across clinical studies complicates the interpretation of treatment efficacy. To address these challenges, it is essential to provide comprehensive training for healthcare professionals, ensure individualized treatment approaches tailored to patients' needs, and develop cost-effective and user-friendly systems. Multidisciplinary collaboration and adherence to ethical standards, particularly regarding data privacy in remote applications, are also critical for the effective integration of these technologies into clinical practice.

Furthermore, existing studies have not specified which rehabilitation methods are more effective for different stroke subtypes (e.g., left vs. right hemisphere, anterior vs. posterior circulation, minor vs. significant stroke). It is well known that motor and cognitive impairments vary across different stroke groups. There are gaps in the literature regarding the optimal dosage and application of these interventions. Additionally, the long-term outcomes of cognitive rehabilitation have not been thoroughly addressed. These observed gaps in the literature could serve as a guide for future research, providing valuable insights for clinicians and academics working in this field.

Utilizing neuroplasticity-based methods in post-stroke rehabilitation can improve cognition and enhance quality of life. Techniques such as computer training, exercise, and specific brain stimulation aid recovery, either alone or in combination. Each has its pros and cons. The best choice depends on the patient's unique needs. In stroke rehabilitation, the application of advanced neurorehabilitation techniques such as VR, TMS, tDCS, and CACT presents several challenges. High initial costs, limited accessibility in low-resource settings, and the need for technical expertise can hinder the widespread adoption of these technologies. Additionally, patient-related factors such as age, cognitive impairments, and acceptance of technology may impact usability and adherence. Potential side effects, including headache, dizziness, and skin irritation, particularly with TMS and tDCS, necessitate careful patient selection and monitoring. Most studies focus on specific cognitive skills. Future research should aim for broader programs that enhance various cognitive areas and relate to daily life. Examining diverse patients and methods will refine understanding and treatment plans.

A team approach is vital in stroke rehab. Experts from different fields should collaborate. They ensure cognitive exercises are included, keep patients motivated, and follow treatment plans. Neuroplasticity-based methods show promise in improving cognition and quality of life. Further research could lead to more effective, personalized treatments.

Conflict of interest

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Authors' contributions

Concept: S.G.Ö., B.Ü., Y.Ş., G.A., Design: S.G.Ö., B.Ü., Y.Ş., G.A., Data Collection or Processing: B.Ü., Y.Ş., G.A., Analysis or Interpretation: S.G.Ö., B.Ü., Y.Ş., G.A., Literature Search: B.Ü., Y.Ş., G.A., Writing: S.G.Ö., B.Ü., Y.Ş., G.A.

Ethical statement

The study employed a review design. Ethics committee approval is not required for reviews. The studies included in the evaluation were cited in the article.

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