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The Impact of Transcranial Brain Stimulation Combined with Cognitive Training on Attention and Working Memory: A Review of Literature

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Abstract

Studies conducted on both normal and abnormal samples have shown transcranial brain stimulation to be effective in improving cognitive functioning. Meanwhile, the behavioral training of cognitive skills has been found to be effective as well. To enhance or rehabilitate core cognitive processes, neuropsychologists and clinicians usually use either one of these or a combination of both. In this study, we reviewed the literature to investigate the effects of brain stimulation alone or combined with cognitive training on attention and working memory. It was concluded that the combined method can be more effective than brain stimulation alone. However, there is no sufficient evidence to make a conclusive statement.

Keywords: Transcranial Brain Stimulation; Cognitive Training; Attention; Working Memory.

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1. Introduction

The term cognitive rehabilitation refers to the improvement of cognitive or emotional functions in specific domains. Based on neuroplasticity mechanisms, cognitive rehabilitation changes the related structures of the brain by strengthening or weakening the connections between neurons. As a result, the related cognitive abilities improve [1]. In addition to improving the cognitive abilities of healthy individuals [2], cognitive rehabilitation can slow down normal cognitive decline in older adults [3], and can benefit patients with cognitive dysfunctions (e.g., Attention Deficit Hyperactivity Disorder (ADHD), mild cognitive impairment, Alzheimer's disease, etc. [4,5]) and groups with mental disorders (e.g., depression, anxiety [6], and obsessive-compulsive disorder [7]).

Cognitive rehabilitation involves various methods, including pharmacotherapy, Brain Stimulation (BS), and Cognitive Training (CT). The use of pharmacotherapy might result in health risks and side effects [8]. However, its prescription is more common in patients with severe post-traumatic cognitive dysfunctions [9]. Techniques for BS include electrical, magnetic, optical, and ultrasound stimulation. These techniques can be used for both cortical and deep brain stimulation purposes [10]. In clinical studies and practices, transcranial electrical and magnetic stimulations are more feasible and affordable options [11]. Also, among these two techniques, transcranial Electric Stimulation (tES) is used more often. Using Transcranial Magnetic Stimulation (TMS) has its own limitations. For example, despite the rarity of seizure induction under TMS, it is possible. Additionally, the device is not portable and the technique is often costly to use [12]. However, tES is an easy-to-use and pretty low-cost technique, and it has no considerable side effects [13]. CT is another common method to improve cognitive functions. CT is a behavioral intervention that consists of four primary components: (a) repeated practices, (b) focus on tasks with an inherent problem, (c) use of standardized tasks, and (d) target-specific cognitive domains [14]. It is assumed that, as the physical training can be transferred to other physical abilities (for example, running affects cycling), CT can also affect whole cognitive functions [15]. Therefore, by performing tasks that engage specific cognitive functions, one can improve these functions, as well as related functions, in everyday life, which is the aim of cognitive rehabilitation [16].

In reviewing the literature, it is evident that various cognitive functions have been enhanced or rehabilitated, whether through CT or BS. In clinical practice, transcranial brain stimulation and CT alone are widely used to improve cognitive functions. Meanwhile, some studies have combined these methods for clinical purposes. There is evidence that a combination of tES and CT may be more effective than either by itself [17]. It has been shown that tES has immediate but temporary effects. This is while CT affects cognition gradually but the effects may last for a longer time. Therefore, using a combined method can provide the advantages of both methods [18]. It is hypothesized that combining BS and CT can improve performance in a specific cognitive function and additionally may lead to an increase in the longevity of the effects. On the other hand, by influencing neuroplasticity through BS and CT, the effects are likely to extend to other areas and functions as well [19].

Currently, most CT programs focus on the two major cognitive functions of attention and working memory [20]. However, no proper synthesis of the available evidence exists to reflect how combining tES and CT techniques impacts these two cognitive functions. Additionally, there have been previous studies on the effects of combining TMS and CT on attention and working memory, the findings of which have not been reviewed yet. In this study, the findings of studies addressing the effectiveness of combining transcranial brain stimulation techniques and CT on attention and working memory have been reviewed.

2. Attention

Attention is a complex cognitive function, which refers to the ability to focus on relevant information and ignore irrelevant information. Mechanisms of attention consist of alerting, orienting, and executive control systems [21]. Attention is closely related to cognitive abilities such as perception and memory. When it comes to cognitive rehabilitation, working on attention is a priority [22].

Researchers have found that the combination of BS and CT improves patients' attention. Park *et al.* [23] performed a double-blind, controlled experiment with 11 stroke patients who suffered from functional impairments in attention and working memory. An anodal transcranial direct current stimulation (tDCS; 30 min, 2 mA) was applied on both sides of the prefrontal cortex simultaneously with a computer-assisted attention training

(15 min attention training and 15 min memory training) once a day for five times a week (a total of 12 sessions). The results showed that patients, compared with the control group, had a significant improvement in auditory and visual attention tasks after the treatment. Silva *et al.* [24] conducted a single-session experiment on alertness, orientation, and executive control abilities in female patients with fibromyalgia. In their study, one group received anodal tDCS (20 min, 1 mA) over DLPFC combined with an inhibitory control training task, while the other group received CT with sham stimulation. It was found that the performance of attentional networks in the combination group was significantly improved. Also, in a randomized controlled trial on a healthy sample in which participants received 10 sessions of CT (dual n-back) with active-tDCS (30 min, 2 mA) or Sham-tDCS, it was found that the combination of CT and tDCS improves attention performance at both the post-test and follow-up [17].

Besides pieces of evidence suggesting that combined treatment can improve attention, some studies have found these sorts of combination do not affect the improvement of patients' cognitive abilities. Fazeli *et al.* [25] studied the effectiveness of 10 one-hour sessions of CT (speed of processing cognitive remediation therapy) followed by 20 min of either active (2 mA) or sham tDCS on neurocognitive impairments in older adults with HIV, and assessed improvements in the cognitive performance among participants. It turns out that the treatment with active stimulation had no significant positive effects on attention compared with sham stimulation. In another study, Das *et al.* [26] recruited 22 patients with mild cognitive impairment and conducted a study on the effects of CT together with BS on cognitive abilities. Participants received offline anodal tDCS stimulation (20 min, 2 mA) over the left lower frontal gyrus and were trained via reasoning tasks. The experiment lasted for four weeks and was repeated twice a week. The results showed that the task performance (attention, inhibition, and memory) in the control group and the experimental group did not significantly improve. However, the combination of stimulation and training led to a significant increase in cerebral blood flow, indicating that anodal stimulation regulated neuroplasticity.

3. Working Memory

Working memory, formerly known as short-term or operant memory [27], is the ability to store and process information in a short period and is the main component of higher-order cognitive functions [28]. Working memory plays a crucial role in everyday life and is considered the core of human learning, comprehension, reasoning, and other advanced cognitive activities [29].

Studies of working memory with combined tDCS and CT are fairly common. Martin *et al.* [30] conducted a 5-week experiment on patients with mild cognitive impairment. Patients received either active-tDCS (30 min, 2 mA; 30 min, 0.016 mA) or sham stimulation (60 min, 0.016 mA) on the left DLPFC simultaneously with CT. It was shown that combining CT and tDCS resulted in a significant improvement in working memory performance. Additionally, their working memory performance was also at a higher level after a 3-month follow-up. In a double-blind, randomized controlled trial, 50 boys with ADHD received 15 treatments using either Sham or active tDCS (20 min, 2 mA) with video games. As compared to the CT group, the combined group showed an increase in working memory performance [31].

Au *et al.* [32] recruited 62 healthy college students and randomly assigned them to three groups (right prefrontal, left prefrontal, and sham) during seven sessions of training. The results showed that the effectiveness of tDCS (25 min, 2 mA) combined with CT remained even three months after the last session of intervention. Researchers observed greater effects if there was a two-day interval between stimulations. They also demonstrated a selective transfer into the right prefrontal group to untrained visual and spatial working memory tasks. These results indicate that tDCS stimulation can improve the efficiency of working memory training in healthy young people and increase the speed of learning during training. McKinley *et al.* [33] studied the memory ability of thirty-two air force military pilots receiving the primary motor cortex and DLPFC stimulation (10 min single-session; four groups: anodal right Dorsolateral Prefrontal Cortex (DLPFC), cathodal left motor cortex, anodal right DLPFC + cathodal left motor cortex, and Sham-tDCS). Participants first received a computerized CT and then received tDCS through an offline protocol. The results showed that the cathodal tDCS over DLPFC immediately after training has a beneficial effect on working memory and procedural learning. In a double-blind, randomized, crossover trial, it was examined whether anodal tDCS on working memory could improve the performance using a 2-back training protocol with different stimuli (either shapes or letters). It was found that tDCS (15 min, 1.5 mA) combined with CT can improve spatial working memory performance but not verbal working memory. This emphasizes the importance of using multiple methods to treat working memory [34].

While researchers are investigating the effects of combined CT and stimulation techniques on working memory, they are also looking for the stability of those effects. Ruf *et al.* [35] conducted anodal tDCS (20 min, 1 mA) over the left and right DLPFCs, combined with spatial and verbal working memory training in healthy adults. It was found that tDCS can enhance the effectiveness of CT, and this effect can even be transferred to untrained tasks lasting for nine months. The authors pointed out that the efficacy of BS depends on the baseline level before training. Participants with lower working memory ability benefit more from the stimulation, while participants with high ability benefit less.

Thirty healthy college students participated in a randomized control trial conducted by Ke *et al.* [36]. Participants were divided into two groups: active-tDCS (25, 1.5 mA) and sham, both combined with working memory training (letters and shapes n-back training). There was a significant improvement in the 3-back learning rate of letters and shapes in the active stimulation group compared with the sham stimulation group. Furthermore, the training benefits were negatively correlated with the baseline level of performance, and the benefit could be transferred to the untrained working memory tasks.

Although many researchers have found that combined protocols can enhance the working memory of healthy individuals and patients, some studies have reported inconsistent results. In the study by Park *et al.* [23]—mentioned in the attention section—it was found that the combination of tDCS and CT had no different effects on working memory. Ikeda *et al.* [37] applied anodal tDCS (2 × 13 min; 20 min interval; 2 mA) over the left DLPFC on 34 healthy adults. They performed a 3-back training before and after stimulation. In this study, the brain activity was recorded via Magnetoencephalography (MEG) for 10 min. The results suggest that offline anodal stimulation does not alter the accuracy and reaction times related to working memory performance. However, analysis of the MEG data revealed that tDCS had increased the gamma-band oscillations, indicating increased neural activity in the left DLPFC. Kolskar *et al.* [38] used magnetic resonance imaging to measure the effects of both CT and stimulation on stroke patients' working memory. In this double-blind, randomized controlled trial, the participants were divided into two groups. They received either CT (auditory and visual-spatial working memory) with tDCS (left DLPFC; 20 min, 1 mA) or CT with sham stimulation. Results showed that CT affected the cognitive abilities of stroke patients by itself, but there was no additional improvement in the combined group. An overview of additional information, including the demographic and methodological characteristics and findings of each of the mentioned studies regarding electrical stimulation is summarized in Table 1.

4. Magnetic Stimulation Combined with CT

According to a review of the literature, a search for "tES" and "CT" and "attention" or "working memory" with their synonyms or subsets in the MEDLINE and Web of Science, reveals 47 RCT records (before exclusion). On the other hand, a total of 13 RCT records are displayed before exclusion when searching the "TMS" instead of "tES" with other mentioned terms. This shows that studies on the combined effects of TMS-CT were much less frequent than studies on the combined effects of tES-CT. Most of the attention in the literature is paid to tES presumably due to its popularity and ease of use. It is therefore expected to find more studies on the combination of tES and CT. Despite the small number of TMS-CT studies, there are some remarkable findings. An interesting example is in a double-blind study by Liu *et al.* [39]. 60 stroke patients with attention dysfunction were evaluated in two groups of TMS-CT and CT (with sham TMS) interventions. Combined TMS and CT showed more improvement in visual attention than the CT group (lower reaction time and fewer errors in Trail Making Test), this improvement was observed across other aspects of attention (i.e., shifting attention, auditory attention). Similarly, the mentioned intervention significantly improved working memory. This study was one of the few that reported different effectiveness for the combined method.

Bakulin *et al.* [46] evaluated the enhancing effects of repetitive Transcranial Magnetic Stimulation (rTMS) (repetitive TMS) combined with CT on working memory in 12 healthy volunteers. The left DLPFC was stimulated with high-frequency rTMS (1600 pulses, 10 Hz). Under four protocols, BS and CT were applied to all participants, either together or alone, in a counterbalanced manner (online BS + CT, offline BS + CT, BS alone, and CT alone). In their study, each protocol consisted of one intervention session followed by one week interval. Working memory performance was assessed using an auditory-verbal n-back, ten minutes before and after the intervention. Results showed that combined CT does not necessarily increase TMS effects. A study by Fried *et al.* [47] examined the effects of TMS-CT on working memory in 20 healthy participants. They utilized n-back training (verbal and spatial), and TMS stimulation was applied to the DLPFC region (1200 pulses, 1 Hz). Results showed that the combined method did not lead to significant changes in working memory performance. A study on 27 healthy volunteers examined the combined effects of TMS and video game interventions. The video game was presented as a ten-session CT, followed by TMS applied to the DLPFC region (600 pulses, 5 Hz). Results showed that the combined protocol had no different effects on working memory compared to TMS alone [48]. According to the authors, the combined approach generally did not lead to significant differences in cognitive enhancement among participants. By studying confounding variables, it was found that participants with early gaming experiences performed better, and this performance was influenced by their working memory (measured by the 3-Back task). Nguyen *et al.* [49] in a single-arm trial, performed CT combined with TMS (25 sessions; 400 pulses, 10 Hz) on 10 Alzheimer's patients. The study examined selective attention and found no differences between baseline and post-intervention measurements (including follow-up).

An exploration of the literature reveals that direct effects of TMS on working memory have frequently been observed in both healthy and abnormal samples [50 – 54]. Similarly, many studies have reported the direct effects of TMS on selective attention [55 – 60]. There are, however, very few studies that have examined the effects of TMS combined with CT on attention and working memory. Since TMS's direct effect on these functions was prominent in the literature and its combination with CT proved less attractive, the small number of combined studies may be due to its low benefit-cost ratio. Due to the small number of studies, it is hardly possible to provide evidence of the extent and accuracy of the effect of the combined method on working memory and selective attention. An overview of additional information, including the demographic and methodological characteristics and results of each of the mentioned studies regarding magnetic stimulation is summarized in Table 2.

5. Discussion

According to the literature review, combining tES with CT can enhance attention and working memory, whereas such an effect cannot be observed in the combination of TMS and CT. This, at least in part, could be due to a lack of evidence. Combined BS and CT can be useful not only for patients with neurological conditions and/or psychiatric disorders (e.g., stroke, mild cognitive impairment, Alzheimer's disease, etc.) but for individuals without specific disabilities. If there are no practical or ethical barriers to using BS, clinicians are recommended to use it along with CT [61].

Research on the combined method, however, has some limitations. For example, its effectiveness among patients with cognitive impairments [62] and traumatic brain injury [63] are not yet clear enough. Another issue with using a combined method is its unclarity of the procedures and protocols. There are no very specified intervention protocols determining the type of combination (online or offline with CT), CT procedures, stimulation current, and other parameters of stimulation specific to the target function or type of problem. Although several studies have shown that the effects of the combined BS and CT can be maintained during long-term follow-ups [64, 65], it should be considered that many of those are pilot studies, and the sample sizes are too small to provide conclusive evidence. Further studies involving larger sample sizes may be more useful both for research and clinical purposes. There are still many ambiguous points regarding the combination of CT and BS methods that merit further investigation. Very few studies have examined this combination at present. It is especially difficult to support the effects of TMS and CT on attention and working memory. These studies can be conducted on both normal and abnormal samples through randomized controlled trial studies.

In conclusion, consistent with previous findings [4, 66], the current study argues that functions or dysfunctions of attention and working memory can be effectively enhanced or rehabilitated through the combination of tES and CT. Combining TMS and CT does not appear to be more effective than either alone.

Table 1. Characteristics of the included studies for transcranial electric stimulation (tES)

Study	Sample	Group	n	Age (SD)	% F	Type (area)	prod (size)	Design	CT	Min (mA)	Nr. of SESS	Results/Conclusion
Attention												
Martin *et al.* (2013)	Healthy	tDCS + CT	21	23.1 (2.8)	75	**tDCS:** A (left DLPFC), C (right deltoid muscle)	neuroConn DC-STIMULATOR (A: 5 × 7; C: 5 × 7)	randomized controlled trial	n-back training (verbal and spatial)	30 (2.0)	10	Significant improvement in attention under combined protocol
	Healthy	tDCS	10	21.7 (2.5)	50	**tDCS:** A (left DLPFC), C (right deltoid muscle)				30 (2.0)		
	Healthy	Sham + CT	21	23.2 (6.8)	61.5	**tDCS:** Sham				30 (DEF)		
Park et al (2013).	Stroke	EG	6	65.3 (14.3)	66.6	**tDCS:** A (bilateral PFC), C (non-dominant arm)	Iomed Phoresor II Auto PM850 (5 × 5)	double-blind, randomized controlled trial	CACR (39)	30 (2.0)	12	Significant improvement in auditory and visual attention
	stroke	CG	5	66.0 (10.8)	40.0	**tDCS:** Sham				30 (DEF)		
Silva *et al.* (2017)	Fibromyalgia	EG	20	51.3 (9.2)	100	**tDCS:** A (left DLPFC), C (right SO)	N/A (5 × 7)	double-blind, randomized controlled trial	Go/No-go task	20 (1)	1	Significant improvement in attentional networks
	Fibromyalgia	CG	20	4837 (9.9)	100	**tDCS:** Sham				20 (DEF)		
Fazeli *et al.* (2019)	HIV+	EG	17	56.0 (3.2)	35	**tDCS:** A (right IFG), C (contralateral upper arm)	Soterix 1x1 tDCS (5 × 7)	double-blind, randomized controlled trial	SOP-CRT (40)	20 (2.0)	10	No significant positive effects on attention
	HIV+	CG	16	55.6 (5.4)	31	**tDCS:** Sham				20 (DEF)		
Das *et al.* (2019)	MCI	EG	12	62.6 (8.4)	33.3	**tDCS:** A (left IFGG), C (contralateral shoulder)	neuroConn DC-STIMULATOR (3 × 5)	double-blind, randomized controlled trial	SMART (41)	20 (2.0)	8	No significant positive effects on attention, inhibition, and memory
	MCI	CG	10	63.3 (7.4)	20	**tDCS:** Sham				20 (DEF)		
Working memory												
Park et al (2013).	Stroke	EG	6	65.3 (14.3)	66.6	**tDCS:** A (bilateral PFC), C (non-dominant arm)	Iomed Phoresor II Auto PM850 (5 × 5)	double-blind, randomized controlled trial	CACR	30 (2.0)	12	No Significant positive effects on working memory
	stroke	CG	5	66.0 (10.8)	40.0	**tDCS:** Sham				30 (DEF)		
Au *et al.* (2016)	Healthy	EG	20	20.9 (2.3)	65	**tDCS:** A (right DLPFC), C (contralateral SO)	Soterix 1x1 tDCS (5 × 7)	single-blind, randomized controlled trial	n-back training	25 (2.0)	7	Significant improvement in working memory: Active right > Active left > Sham
	Healthy	EG	20	21.5 (2.9)	55	**tDCS:** A (left DLPFC), C (contralateral SO)				25 (2.0)		
	Healthy	CG	22	20.5 (1.9)	64	**tDCS:** Sham				25 (DEF)		

Study	Sample	Group	n	Age (SD)	% F	Type (area)	prod (size)	Design	CT	Min (mA)	Nr. of SESS	Results/Conclusion
Working memory												
McKinley *et al.* (2017)	Healthy	EG	8	N/A	N/A	**tDCS:** A (left motor cortex), C (N/A)	MagStim DC stimulator	randomized controlled trial	Warship Commander: Airspace Monitoring (42)	10 (N/A)	1	Significant improvement in working memory: DLPFC > motor > motor + DLPFC > CG
	Healthy	EG	8			**tDCS:** A (N/A), C (right DLPFC)				10 (N/A)		
	Healthy	EG	8			**tDCS:** A (left motor cortex), C (right DLPFC)				10 (N/A)		
	Healthy	CG	8			**tDCS:** Sham				10 (DEF)		
Ruf *et al.* (2017)	Healthy	EG (t | c)	36	23.5 (3.4)	83.3	**tDCS:** A (right DLPFC), C (contralateral deltoid muscle)	neuroConn DC-STIMULATOR (5 × 7)	randomized controlled, cross-over trial	3-back training (verbal and spatial)	20 (1.0)	5	Significant improvement in working memory in both groups compared with controls
	Healthy	EG (t | c)	35	25.4 (6.4)	77.1	**tDCS:** A (left DLPFC), C (contralateral deltoid muscle)				20 (1.0)		
Ikeda *et al.* (2019)	Healthy	EG (t | c)	12	21.3 (1.3)	0	**tDCS:** A (right DLPFC), C (left DLPFC)	neuroConn DC-STIMULATOR (5 × 7)	double-blind, randomized controlled, cross-over trial	*n*-back training	2 × 13, 20 rest (2.0)	2	No Significant positive effects on working memory
	Healthy	EG (t | c)	12			**tDCS:** A (left DLPFC), C (right DLPFC)				2 × 13, 20 rest (2.0)		
Ke *et al.* (2019)	Healthy	EG	15	N/A	40	**HD tDCS:** A (left DLPFC), Cs (right frontal pole, midline frontal, and left motor cortex)	Starstim tES-EEG systems (2.5 diameter)	randomized controlled trial	*n*-back training (verbal and shape)	25 (1.5)	7	Significant improvement in working memory
	Healthy	CG	15			**tDCS:** Sham				25 (DEF)		
Martin *et al.* (2019)	aMCI	EG	33	71.8 (6.4)	60.6	**tDCS:** A (left DLPFC), C (N/A)	neuroConn DC-STIMULATOR (5 × 7)	double-blind, randomized controlled, parallel groups trial	COGPACK (43)	30 (2.0)	15	Significant improvement in working memory at post-test; no significant difference at follow-up
	aMCI	CG	35	71.6 (6.3)	71.42	**tDCS:** Sham				30 (DEF)		
Kolskar *et al.* (2020)	Stroke	EG	27	69.1 (7.4)	26	**tDCS:** A (right DLPFC), C (right occipital/cerebellum)	neuroConn DC-STIMULATOR (5 × 7)	double-blind, randomized controlled trial	*n*-back training	20 (1.0)	17	No Significant positive effects on working memory
	Stroke	CG	27			**tDCS:** Sham				20 (DEF)		

Study	Sample	Group	n	Age (SD)	% F	Type (area)	prod (size)	Design	CT	Min (mA)	Nr. of SESS	Results/Conclusion
Working memory												
Ramaraju *et al.* (2020)	Healthy	t | c (counterbalanced)	20	30 (8.0)	0	**t: tDCS:** A (left DLPFC), C (right SO) | **c: tDCS:** Sham	neuroConn DC-STIMULATOR (5 × 7)	double-blind, randomized controlled, cross-over trial	2-back training (words and shapes)	**t:** 15 (1.5) | **c:** 15 (DEF)	**t:** 1 | **c:** 1	Significant improvement in spatial working memory
Westwood *et al.* (2021)	ADHD	EG	24	13.1 (1.1)	0	**tDCS:** A (left DLPFC), C (contralateral SO)	NovoStim (5 × 5)	double-blind, randomized controlled trial	ACTIVATE (44)	20 (2.0)	15	Significant improvement in working memory
	ADHD	CG	2 6	14.2 (2.1)	0	**tDCS:** Sham				20 (DEF)		

Abbreviations: F, female; EG, experimental group; CG, Control group; prod, product; SESS, sessions; PFC, prefrontal cortex; CACR, Korean computer-assisted cognitive rehabilitation program; DEF, default mode; IFG, inferior frontal gyrus; SOP-CRT, speed of processing cognitive remediation therapy; SO, supraorbital area; MCI, mild cognitive impairment; SMART, strategic memory and advanced reasoning training; aMCI, amnestic mild cognitive impairment; DLPFC, dorsolateral prefrontal cortex; t, treatment; c, control.

Table 2. Characteristics of the included studies for transcranial magnetic stimulation (TMS)

<table>
<tr><th>Study</th><th>Sample</th><th>Group</th><th>n</th><th>Age (SD)</th><th>% F</th><th>Type (area)</th><th>Prod: coil (size)</th><th>Design</th><th>CT</th><th>Nr. Of pulses (Hz)</th><th>Nr. of SESS¹</th><th>Results/Conclusion</th></tr>
<tr><td>Fried et al. (2014)</td><td>Healthy</td><td>F3 | F4 | Cz (counterbalanced)</td><td>20</td><td>20.8 (2.1)</td><td>85</td><td>rTMS: left DLPFC | rTMS: right DLPFC | rTMS: vertex of the scalp</td><td>Magstim: figure-of-8 (3.5 diameter each loop)</td><td>randomized controlled, cross-over trial</td><td>n-back training (verbal and spatial)</td><td>1200 (1)</td><td>3 (24 h interval)</td><td>No significant positive effects on working memory</td></tr>
<tr><td>Nguyen et al. (2017)</td><td>Alzheimer's</td><td>EG</td><td>10</td><td>73.0 (7.2)</td><td>50</td><td>rTMS: right and left PFC, right and left PC, and Broca's and Wernicke's</td><td>N/A: figure-of-8 (N/A)</td><td>single-arm trial</td><td>Naming, spatial attention, and syntax and grammar</td><td>400 (10)</td><td>25</td><td>No significant improvement in cognitive functioning (e.g., attention) at post-test; no significant difference at follow-up</td></tr>
<tr><td rowspan="2">Liu et al. (2020)</td><td>Stroke</td><td>EG</td><td>29</td><td>55.5 (6.2)</td><td>65.5</td><td>TMS: left PFC</td><td rowspan="2">Yiruide CCY-IA: figure-of-8 (3.5 diameter each loop)</td><td rowspan="2">double-blind, randomized controlled, parallel groups trial</td><td rowspan="2">comprehensive CT (attention, orientation, visual spatial, and logical reasoning)</td><td>700 (10)</td><td rowspan="2">20</td><td rowspan="2">Significant positive effect on visual and auditory attention</td></tr>
<tr><td>Stroke</td><td>CG</td><td>29</td><td>57.7 (7.2)</td><td>44.8</td><td>TMS: Sham</td><td>700 (10): held at a 90°angles to the scalp</td></tr>
<tr><td>Bakulin et al. (2020)</td><td>Healthy</td><td>HF rTMS + CT: online | HF rTMS + CT: offline | HF rTMS | CT (counterbalanced)</td><td>12</td><td>N/A</td><td>66.6</td><td>HF rTMS: left DLPFC</td><td>NBS eXimia Nexstim stimulator: figure-of-8 (N/A)</td><td>randomized controlled, cross-over trial</td><td>n-back training (verbal and spatial)</td><td>1600 (10)</td><td>4 (1 wk interval)</td><td>Significant improvement in working memory under HF rTMS not under combined protocols</td></tr>
<tr><td rowspan="2">Palaus et al. (2020)</td><td>Healthy</td><td>EG</td><td>14</td><td>29.9 (5.3)</td><td>50</td><td>TMS: right DLPFC</td><td rowspan="2">Magstim: figure-of-8 (3.5 diameter each loop)</td><td rowspan="2">randomized controlled, trial</td><td rowspan="2">Super Mario 64</td><td>600 (5)</td><td rowspan="2">10</td><td rowspan="2">No significant positive effects on working memory</td></tr>
<tr><td>Healthy</td><td>CG</td><td>13</td><td>29.0 (7.4)</td><td>53.8</td><td>TMS: Sham</td><td>600 (5): held at a 90°angles to the scalp</td></tr>
</table>

Abbreviations: F, female; EG, experimental group; CG, Control group; prod, product; SESS, sessions; PFC, prefrontal cortex; DLPFC, dorsolateral prefrontal cortex; wk,

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