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Effectiveness of Neurofeedback Training in Poststroke Cognitive Impairment

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Abstract

Introduction. Poststroke cognitive impairment (PSCI), characterized by cognitive deficits occurring up to 3 months after stroke, poses a substantial burden because this condition can persist and get worse over time. There has been no recommended conventional cognitive rehabilitation method that has a significant effect on cognitive improvement. Neurofeedback training (NFT) based on quantitative electroencephalogram (qEEG), emerges as a promising intervention for PSCI. However, research remains limited, necessitating further investigation into its effectiveness and clinical utility. **Methods**. This study assesses the efficacy of NFT in eight PSCI patients over 10 sessions (30 min/session) across 2 weeks with protocol based on qEEG for each patient. **Results**. Significant improvements were observed in total MoCA-Ina scores (mean increase of 2.63 points), particularly in visuospatial/executive, naming, attention, language, delayed recall, and orientation domains. Wilcoxon test indicated a significant improvement (p = .019, effect size: −0, 828) post-NFT. Multivariate analysis revealed no confounding influence of demographic and clinical factors on cognitive improvement. **Conclusion**. These findings highlight NFT's potential as an adjunctive therapy in PSCI rehabilitation, warranting further investigation for efficacy of NFT in larger studies and explore its long-term effects on cognitive function and quality of life for PSCI patients.

Keywords: poststroke cognitive impairment; neurofeedback training; quantitative electroencephalogram; MoCA-Ina

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Introduction

Poststroke cognitive impairment (PSCI), defined as cognitive deficits occurring up to 3 months after stroke, with a minimum duration of 6 months, is unrelated to any other conditions or diseases such as metabolic, endocrine, vasculitis, or depression (Danovska et al., 2012). PSCI is also defined as all problems in cognitive function that occur following a stroke, irrespective of the (stroke) etiology (Rost et al., 2022). This condition can result from all types of strokes (ischemic stroke, intracerebral hemorrhage, or subarachnoid hemorrhage). While stroke patients may experience improvement in physical function over time, cognitive impairment can remain a cause of disability and dependency (Hernández & González-Gálvez, 2021). These impairments can significantly affect the patient's quality of life and rehabilitation process, adding a substantial burden to both families and society (Chen et al., 2015).

Until now there has been no recommended conventional cognitive rehabilitation method that has a significant effect on cognitive improvement. New cognitive rehabilitation strategies using human-computer interface have been studied and reported to offer promising new treatment. These methods modulate brain waves using neurofeedback training (NFT) based on quantitative electroencephalogram (qEEG; Kober et al., 2015). NFT is type of biofeedback therapy which aims to adjust brain waves within specific ranges, and optimal brain wave adjustments can affect various functional aspects of the patient (Cho et al., 2015). In NFT, EEG activity and brain waves are provided as visual or auditory feedback to the patients, allowing them to consciously adjust their brain wave activities with some repetitive training session (one session/days) to reach targeted training thresholds (Renton et al., 2017). NFT relies on operant conditioning to stimulate brain neuroplasticity and normalize the abnormal brain waveform. Such training can accelerate functional reorganization in poststroke brain, indicating the significant potential value of NFT in cognitive rehabilitation (Hammond, 2006; Kleim & Jones, 2008).

Research by Kober et al. (2015) reported that stroke patients with cognitive deficits, such as memory impairment, experienced improvement post-NFT with sensorimotor rhythm (SMR) and upper alpha protocols. Similarly, Cho et al. (2015) reported similar result, showing that NFT effectively enhances concentration and visual perception in poststroke patients. Meta-analysis conducted by Jackson et al. (2023) shows that NFT have a promising effect in episodic memory improvement. Objectively, Jang et al. (2019) found that MCI patients who received NFT therapy experienced an improvement in Montreal Cognitive Assessment (MoCA) scores of 4.4 points after 8 therapies and 6.2 points after 16 sessions. Research conducted by Marlats et al. (2019) involving 20 patients with mild cognitive impairment who underwent NFT therapy with the SMR protocol for 30 sessions, 2–3 times a week, showed an increase in the MoCA score of 1.9 points. Unfortunately, studies related to the effectiveness of NFT as cognitive rehabilitation in stroke patients are limited to single case studies, and adequate studies regarding its effectiveness and clinical utility have not been widely conducted. This study represents the first research in Indonesia assessing cognitive function improvement through NFT with the improvement parameter of the Indonesian version of the MoCA (MoCA-Ina) mean scores.

Methods

This study was a preexperimental design with one group pretest–posttest conducted at the Memory Clinic and Neurofeedback Clinic of Dr. Mohammad Hoesin Palembang Teaching Hospital from May to August 2023. The sample population consisted of patients diagnosed with PSCI based on comprehensive neurocognitive assessments (MMSE, MoCA-INA, *Clock Drawing Test* [CDT], *forward digit span, backward digit span,* CERAD, TMT A, TMT B, and *Clinical Dementia Rate* [CDR]) at the Memory Clinic, supervised and interpreted by a neurobehavior consultant, selected using consecutive sampling method. Inclusion criteria were patients aged ≥ 18 years with onset of cognitive impairment occurring ≥ 3 months poststroke, experiencing their first-time stroke, and having good vision and hearing function. Exclusion criteria were: patients with dementia, preexisting cognitive impairment before stroke (based on history taking and AD-8 test), psychiatric disorders such as depression, anxiety, aphasia, or concurrent neurological disorders (such as Parkinson’s Disease, etc.), which can affect patients’ cognitive function and cognitive test, and a history of medications affecting vigilance state. Dropout criteria included discontinuation of participation before study completion or death before completing the study.

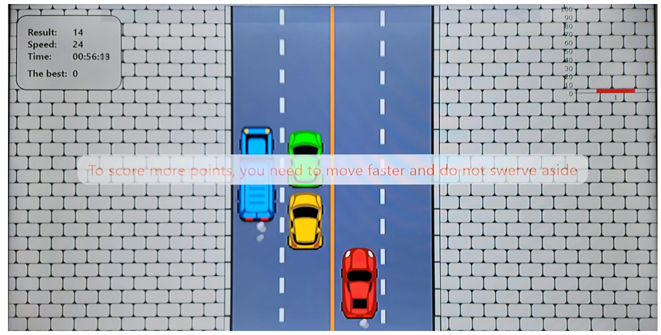
Written informed consent was obtained from all participants before their inclusion and after getting the full explanation of the study procedures, risks, and benefits. The study protocol was approved by the Ethics Committee of Dr. Mohammad Hoesin Palembang Teaching Hospital (No. DP.04.03/D.XVIII.6.11/ETIK/55/2023). The researcher ensured patient confidentiality in accordance with applicable research ethics.

Patients first underwent a baseline assessment using the MoCA-Ina, followed by qEEG examination. Subsequently, they received NFT using Neurosoft-Neuron-Spectrum-61, consisting of 10 consecutive sessions over 2 weeks, with each session lasting 30 min. The treatment protocols used were based on initial qEEG results: three patients exhibiting low alpha wave activity received the alpha protocol, and five patients with low SMR wave activity received the SMR protocol.

In the alpha protocol, patients are asked to relax and focus on looking at the monitor containing images of mushrooms. Therapy is achieved if the size of the mushroom image increases compared to the initial size. In the SMR protocol the patient is asked to focus and concentrate on the monitor with several modalities such as racing a car or plane. If concentration is achieved, the patient's car will overtake other cars. Post-NFT, patients underwent a repeat assessment using the MoCA-Ina.

Figure 1. *Example of Visual Feedback (A) Alpha Protocol Therapy and (B) SMR Protocol Therapy*.

(A)



(B)

Collected data were entered into SPSS version 22. Changes in mean MoCA-Ina scores and mean scores per cognitive domain were compared before and after therapy using paired simple *t*-tests for normally distributed data and Wilcoxon tests for nonnormally distributed data. The selected test has such shortcomings such as discards some information about the magnitude of differences between pairs. Furthermore, multivariate analysis was conducted to determine the influence of confounding variables on the change in mean MoCA-Ina scores. Significance was set at $p < .05$.

Results

In this study, eight participants meeting inclusion criteria and having no exclusion criteria were enrolled. All subjects completed the study protocol without any reported adverse effects of NFT. The baseline characteristics of the participants are presented in Table 1.

Based on the distribution characteristic data, most patients were under the age of 65 (75%), predominantly male (62.5%), with the highest level of education being high school (50%). Eight patients (75%) had lesions in the subcortical area, and the time since stroke, until the diagnosis of PSCI was established, was mostly over 6 months, accounting for 62.5%.

Table 1
Distribution of Characteristics of Poststroke Cognitive Impairment Patients

Variable	Frequency (*n*)	Percentage (%)
Age		
≤ 65 years	6	75%
> 65 years	2	25%
Gender		
Male	5	62.5%
Female	3	37.5%
Education Level		
Informal education/no schooling	0	0%
Elementary school	1	12.5%
Junior high school	1	12.5%
Senior high school	4	50%
College/university	2	25%

Table 1
Distribution of Characteristics of Poststroke Cognitive Impairment Patients

Variable	Frequency (*n*)	Percentage (%)
Lesion Location		
Cortical	2	25%
Subcortical	6	75%
Both	0	0%
Time Since Stroke		
≤ 6 months	3	37.5%
> 6 months	5	62.5%
Modified ranking scale (mRS)		
mRS 0	1	12.5%
mRS 1	2	25%
mRS 2	2	25%
mRS 3	1	12.5%
mRS 4	2	25%
mRS 5	0	0%

In Table 2, the results of the MoCA-Ina examination are presented. The baseline mean MoCA-Ina score was 14.75 ± 8.464, with a maximum score of 25 and a minimum score of 5. In each domain of the MoCA-Ina, the mean scores were as follows: 2.63 ± 1.847 for the visuospatial/executive domain, 1.75 ± 1.389 for the naming domain, 3.25 ± 2.121 for the attention domain, 1.13 ± 0.835 for the language domain, 0.88 ± 0.991 for the abstraction domain, 0.75 ± 0.886 for the delayed recall domain, and 4 ± 1.773 for orientation. Based on these data, the abstraction and delayed recall domains were the most affected, with four out of eight patients scoring 0 during the test.

Table 2
Baseline Scores of MoCa-Ina Total and Per Domain

	Mean Score	± *SD*
Moca-Ina Total	14.75	8.464
Visuospatial/Executive	2.63	1.847
Naming	1.75	1.389
Attention	3.25	2.121
Language	1.13	0.835
Abstraction	0.88	0.991
Delayed Recall	0.75	0.886
Orientation	4.00	1.773

Bivariate analysis in Table 3 and 4 reveals a comparison of MoCA-Ina scores before and after NFT intervention. Most patients showed improvement with an increase in MoCA-Ina scores, with only one patient experiencing a decrease of 1 point in MoCA-Ina score after completing NFT. There was an average improvement of 2.63 points in MoCA-Ina scores with a *p*-value of .019 ($p < .05$) (effect size: −0, 828), indicating that NFT therapy leads to an improvement in average MoCA-Ina scores. Education level also influenced MoCA-Ina scores, where those with less than 12 years of education had 1 point added to their total MoCA-Ina score. Analysis of improvement in pre and post values based on adjustments to MoCA-Ina scores was also conducted, and based on the Wilcoxon test, statistically significant results were obtained ($p = .019$), indicating no significant difference in improvement between baseline MoCA-Ina scores and those adjusted for education.

Table 3
Comparison of Mean MoCA-Ina Score Before and After NFT

	Neurofeedback Training		
	Before	After	*p*-value
Mean score of Moca-Ina	14.75 ± 8.464	17.38 ± 9.606	.019

Note. *p*-value using Wilcoxon test.

Table 4
Comparison of Mean MoCA-Ina Score Per Cognitive Domain Before and After NFT

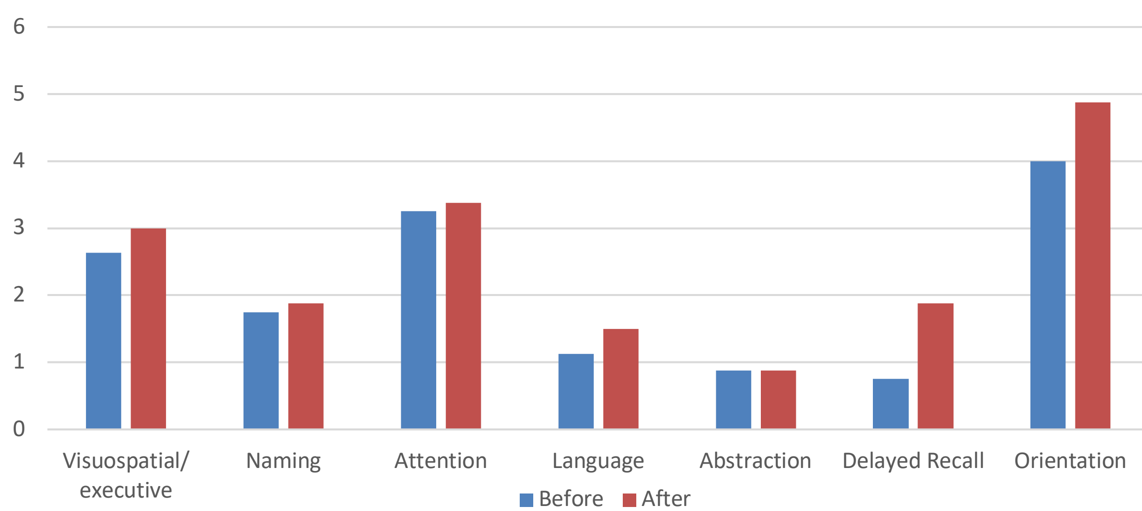
Cognitive Domain	Neurofeedback Training		
	Before	After	*p*-value
Visuospatial/Executive	2.63 ± 1.847	3.0 ± 2.070	.476[a]
Naming	1.75 ± 1.389	1.88 ± 1.356	.564[b]
Attention	3.25 ± 2.121	3.38 ± 2.134	.685[a]
Language	1.13 ± 0.835	1.5 ± 1.069	.197[a]
Abstraction	0.88 ± 0.991	0.88 ± 0.991	1.00[b]
Delayed Recall	0.75 ± 0.886	1.88 ± 1.959	.071[b]
Orientation	4.00 ± 1.773	4.88 ± 1.642	.131[b]

[a]Paired sample *t*-test; [b]Wilcoxon test

Upon analysis of cognitive domains, an increase in scores was observed in all domains except abstraction. Based on domain-specific analysis, it was found that after receiving 10 sessions of NFT, patients experienced improvement in MoCA-Ina scores with increases in visuospatial/executive function by 0.37 points, naming by 0.13 points, attention by 0.13 points, language by 0.37 points, delayed recall by 1.13 points, and orientation by 0.88 points. Statistical analysis was then performed to assess improvement using a one-sample paired *t*-test for the visuospatial/executive, attention, and language domains, and Wilcoxon test for naming, abstraction, delayed recall, and orientation domains. In each domain, no statistically significant differences were found ($p > .05$). This may be due to the small range of values per MoCA-Ina domain so that they do not show significant differences.

Multivariate analysis was conducted to examine the influence of confounding factors such as age, gender, educational level, lesion location, and time since stroke on the improvement of MoCA-Ina scores after receiving NFT. Patients were considered to have improved if there was an increase in MoCA-Ina score of greater than 2 points from baseline, and based on this criterion, six out of a total of eight samples (75%) showed improvement. According to the multivariate analysis, none of these variables were found to significantly affect the improvement of patient's MoCA-Ina scores ($p > .05$), as outlined in Figure 2.

Figure 2. *Comparison of Mean MoCA-Ina Scores Per Cognitive Domain Before and After NFT*.



Discussion

The finding of this study indicates that the use of NFT as an adjunct therapy in patients suffering from PSCIs can enhance overall cognitive function. There was significant improvement in mean MoCA-Ina score by 2.63 points (p = .019) following 10 sessions NFT intervention with tailored protocols based on qEEG. This result is in line with a previous study which reported that improvement in MoCA-Ina score occurs with an increase of ≥ 2 points (Zuo et al., 2022). Based on this finding, NFT can be a cognitive rehabilitation therapy modality that has benefits compared to other traditional modalities.

Several other studies also corroborate similar findings; for instance, Jang et al. (2019) reported that patients with MCI undergoing NFT experienced improvements in MoCA scores by 4.4 points after eight sessions and 6.2 points after 16 sessions. Additionally, improvements were noted in the complex memory domain, cognitive flexibility, attention, reaction time, and executive function (Jang et al., 2019). Similarly, Marlats et al. (2019) demonstrated a 1.9-point increase in MoCA scores (p < .012) along with enhanced alpha and theta waves in qEEG examination following NFT. Instead of MoCA-Ina, various other neurocognitive assessment parameters such as MMSE, Benton Visual Retention Test (BVRT), and Color Trails Test (CTT-1, CTT-2) have been extensively used concerning cognitive function improvement post-NFT (Jang et al., 2019; Marlats et al., 2019; Mroczkowska et al., 2014; Surmeli et al., 2016; Zuo et al., 2022). Unfortunately, there are still few studies regarding improvement of cognitive function using NFT in groups of patients diagnosed with PSCI, making this initial research one of the most useful studies.

NFT exhibits positive effects on memory enhancement and triggers neuronal plasticity in chronic stroke patients. This highlights NFT as a feasible alternative cognitive rehabilitation therapy that directly influences brain electrical activity. However, it is imperative to note that NFT outcomes may vary and are influenced by factors such as brain structural variances, interindividual differences in neuropsychological and psychological factors, as well as cognitive strategies used (Lecomte & Juhel, 2011).

Kober et al.'s 2015 study using SMR (12–15Hz) and upper alpha/UA (10–12 Hz) protocols found that SMR protocol enhances long-term memory function, visuospatial abilities, short-term memory, and learning efficiency, whereas UA protocol improves long-term memory, short-term memory, and working memory (Kleih-Dahms & Botrel, 2023; Kober et al., 2017). Furthermore, Cho et al. (2015) conducted a study on poststroke patients with cognitive impairments using beta-SMR protocol in 13 patients, with five 30-min sessions per week for 6 weeks, revealing improvements in visual discrimination, visual memory, and spatial relations (Cho et al., 2015).

This study shows a positive influence of NFT on increasing the mean MoCA-Ina scores, although these results did not achieve statistical significance when analyzed separately for each cognitive domain. This is in contrast to previous studies where improvements were predominantly observed in memory and executive function. This variance may be attributed to the limited sample size and the limitations of the MoCA-Ina instrument, which assesses delayed memory exclusively without specifically examining working memory and long-term memory. Conversely, many other studies combine various neuropsychological tests to evaluate overall cognitive function improvement.

Although statistically may not be significant, from a subjective impression, patients who have undergone NFT tend to report significant improvements in concentration, attention, and memory, even in patients who do not show improvement in overall scores. Most studies indicate that NFT has the potential to enhance cognitive function. However, not all studies find statistically significant improvements in all aspects of cognitive function. Sociodemographic and clinical factors did not have significant influence on the improvement of Moca-Ina scores. Based on theory, younger age, higher level of education, and earlier initiation of therapy are usually associated with more meaningful improvements. However, this study did not find any significant relationship, possibly due to the relatively small sample size and mostly having at least a high school education and younger age (< 65 years). Sociodemographic data shows that patients with lower education (under senior high school) have lower mean baseline MoCA-Ina scores, which is in line with the hypothesis of "cognitive reserve" usually associated with higher educational levels. Thus, it can be concluded that NFT in this study, consistent with other research, is a beneficial therapy for improving cognitive function in patients with PSCI.

The aim of NFB is to enable the subject to become aware of particular patterns of cortical activity that are associated with more optimal behavior or state (Lecomte & Juhel, 2011). NFT therapy can induce changes in brain electrical activity that synergize with cognitive function improvement through the patient's ability to modulate their brain electrical activity independently. Increased alpha waves are associated with improvement in working memory function and short-term memory. Alpha waves also play a role in inhibiting irrelevant or interfering processes, facilitating attention and memory processes through the suppression of distracting stimuli. Thus, it can be concluded that NFT can accelerate functional improvement and even improve patient functionality that cannot be achieved with other therapies. NFT primarily affects cognitive and personality improvement (Hammond, 2006; Kober et al., 2015). This can be a consideration and recommendation for neurologists in implementing the use of NFT as a cognitive rehabilitation therapy modality in addition to other modalities in poststroke patients. The NFT protocol was tailored based on qEEG abnormality (e.g., alpha, beta, theta, or SMR).

In NFT, EEG activity and brain waves are provided as visual or auditory feedback to the patient so that the patient can consciously adjust their brain wave activity to reach the targeted training threshold (Renton et al., 2017). NFT relies on operant conditioning to stimulate neuroplasticity (Hammond, 2006; Kleim & Jones, 2008). Additionally, NFT can also suppress excessive slow-wave activity typically found in stroke patients.

This study has several limitations. First, the small sample size can be attributed to several factors: difficulty in scheduling patients for 10 sessions of NFT, particularly since many patients come from rural areas; a majority of participants being diagnosed with poststroke dementia rather than mild cognitive impairment; and a limited number of visits by first-time stroke patients after 3 months of onset due to the hospital's role as a tertiary referral center. Second, the outcome was based solely on the patient's clinical condition without using other objective parameters, such as qEEG changes, which could provide more comprehensive insights into alterations in the brain wave spectrum. Third, the short follow-up period where the assessment was only carried out after 10 sessions over 2 weeks of NFT intervention so that the long-term effect of NFT was unknown. We suggest future research to address the limitations identified in this current study with a larger scale and longer follow-up period to assess the long-term effectiveness of NFT in PSCI rehabilitation.

Conclusion

NFT has shown efficacy in improving cognitive function among individuals with PSCI, as indicated by MoCA-Ina scores. Importantly, these improvements were not influenced by sociodemographic and clinical factors, suggesting that NFT may be considered as an adjunctive therapy to aid cognitive function recovery.

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