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Original Article

Effects of neurofeedback and computer-assisted cognitive rehabilitation on relative brain wave ratios and activities of daily living of stroke patients: a randomized control trial

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Abstract. [Purpose] This study investigated the effects of neurofeedback (NFB) and computer-assisted cognitive rehabilitation (CACR) on the relative brain wave ratios and activities of daily living (ADL) of stroke patients. [Subjects and Methods] Forty-four participants were randomly allocated to the NFB (n=14), CACR (n=14), or control (CON) (n=16) groups. Two expert therapists provided the NFB, CACR, and CON groups with traditional rehabilitation therapy in 30-minute sessions, 5 times a week, for 6 weeks. NFB training was provided only to the NFB group and CACR training was provided only to the CACR group. The CON group received traditional rehabilitation therapy only. Before and after 6 weeks of intervention, brain wave and ADL evaluations were performed, and the results were analyzed. [Results] The relative ratio of beta waves, only showed a significant increase in the frontal and parietal areas of the NFB group. Significant changes in ADL were shown by all three groups after the intervention. However, there were no significant differences between the NFB and CACR groups and the CON group. [Conclusion] Our results suggest that CACR and NFB are effective at improving cognitive function and ADL of stroke patients.

Key words: Neurofeedback (NFB), Computer assisted cognitive rehabilitation (CACR), Brain wave

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INTRODUCTION

Rehabilitation improves the affected functions of patients and aims to maximize their roles as members of society. Patients develop the ability to perform higher stages of functional activity through repetitive and concentrated rehabilitative training, which results in the improvement of the sensory, motor, and cognitive abilities[1)].

Activities of daily living (ADL) are an important part of occupational performance together with work, productive activity, leisure, and play, and are also an important goal of rehabilitation. Should a cerebral infarction also affect the cognitive ability of a patient, independent performance of basic ADLs, such as eating, dressing, and toileting, may be disturbed[2)]. Improvements of attention, memory, visual perception, and sequencing through rehabilitation elicit improvements in functional ADL performance ability and in the quality of life of the patients and their families. Furthermore, it has a positive effect on learning ability, shortening the duration of the hospitalization period, and decreasing rates of depression, as well as other possible benefits[3)]. Thus, it is important to understand the interrelation between damage to the cognitive ability of stroke patients and subsequent restriction of activity, and to identify cognitive problems affecting the restoration of ADLs for recovery[4)].

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Strategies for cognitive therapy are widely used to improve cognition after stroke or other brain damage, but rarely for the acquisition of motor skills. Motor learning, however, is required for the re-acquisition of motor skills, and cognitive factors such as memory, perception, and problem solving play important roles[5)]. Computer assisted cognitive rehabilitation (CACR) training focuses on similar neuropsychological processes, but utilizes computer training of attention and concentration through the use of games or other programs to improve problem-solving ability[6)]. The task of traditional cognitive therapy involves tackling the problem of lost confidence or decreased interest due to increased difficulty of control, leading to failure to perform the task, whereas CACR allows increased possibility of control of the different levels of task difficulty for the patient[7, 8)].

More recently, cognitive rehabilitation therapies have tried various approaches including neurofeedback through electroencephalogram (EEG) training[9, 10)]. This process provides training for a certain period and is based on neural plasticity, it is based on the theory that effective learning of motor control requires a certain ratio of brain waves, the arousal level of patients reaches an optimum level activating the brain, therby influencing many functional factors[11)].

To date, there is insufficient research examining the relationship between improvements in ADL independence and changes in brain waves of stroke patients undergoing either NFB or CACR. Furthermore, despite the fact that it is important to demonstrate that rehabilitation for patients with brain injury involves the use of each brain area differently, using an objective evaluation like EEG[12)], this has seldom been attempted. The aim of this study was to identify the most effective rehabilitation method for stroke patients by comparing the effects of NFB and CACR on brain waves and ADLs during cognitive rehabilitation.

SUBJECTS AND METHODS

The participants were chosen from among 48 stroke inpatients who were undergoing physical and occupational therapy at an I hospital in Kyeongki-do. Participant selection criteria were: hemiplegic stroke patients with onset 3 months to 1 year before the study, and the abilities to follow verbal instructions and to communicate. The participants were chosen from among patients with a mild cognitive deficit who scored 18–23 on the mini mental state examination (MMSE) and were able to perform all the tests. Patients who had never attended school or had undergone NFB or CACR within the past year were excluded from the study. After being informed about the study, all subjects agreed to participate and signed a consent form. This study was approved by the Institutional Review Board of Gachon University.

The participants were randomly assigned to either the NFB, CACR, or control (CON) group. Participants were provided traditional rehabilitation therapy in 30-minute sessions, twice weekly for 6 weeks. After 6 weeks of intervention, a test was performed, and the results were analyzed. The general characteristics of the participants are shown in Table 1.

NFB training used the NeuroComp System (Neurocybernetics Company, Missouri, USA), and all electrodes were attached to the scalp at positions determined by the Standard International 10–20 system and oscillograph records[12)]. The patients sat on a comfortable chair, and one electrode was attached at C5 or C6, on the side of scalp for mono polar training, while the other two electrodes were attached to each ear. A repeater switched the analog signal of the brainwave imported via each electrode into a digital signal separated by frequency. The monitor used for treatment showed the original brain wave of the patient and that of each frequency band, and the therapist chose which frequencies to compensate and restrict. Controlling the threshold voltage allowed the brainwaves of the patients to be conditioned.

The NFB training program of the study used the beta-SMR training mode, which was performed with open eyes and provided two types of compensation for feedback: acoustic and visual. The compensation brain wave was a 12–15 Hz SMR-wave, or a 15–18 Hz mid-beta wave at the selected location of the cerebral cortex. The restraining brain waves were applied simultaneously a 0.5–4 Hz delta-waves and 22–36 Hz high-beta waves[10)]. The experimental training time was 30 minutes within which 10 sets of 3 minute training mode periods were performed.

CACR was developed by RehaCom (Hospi, Seoul, Korea) for computer-based cognitive rehabilitation and is used clinically[13)]. Patients perform tasks while sitting, looking at a monitor, and respond using a keyboard. In this study, we chose the attention, concentration, and memory programs of RehaCom, running the tests for 30 minutes per period according to the functional level of the patient.

We collected brain wave data using QEEG-8 (Laxtha Inc., Daejeon, Korea). The patients were repeatedly informed about the electrode attachment, measuring equipment, application of the analysis program, and measuring process before the test. The brain waves were measured prior to the other tests executed in this study, with the patient in a comfortable condition and without any training to prevent interference from the other tests.

The brain waves were measured at a brain wave laboratory that had no windows, to maintain constant light and temperature, and no noise, since brainwaves are affected by internal and external environmental factors. The patients sat on a comfortable chair, and listened to the instructions and the method of the experiment with the electrodes attached to their scalp to verify the normal functioning of the equipment. After a 3-minute rest period, the patients were asked to look forward and their brain waves were measured for 3 minutes. During measurement, the patients were asked not to talk or move to improve accuracy.

The brainwaves were analyzed quantitatively using Complexity 2.0 (Laxtha Inc., Daejeon, Korea). One hundred eighty seconds of raw data, excluding the initial and final 10-second periods, of only the 4–50 Hz frequency bandwere selected for

Table 1. General characteristics of the subjects

	NFB	CACR	CON
Gender (male/female)	8/6	9/5	7/9
Age (years)	62.2 ± 6.2	63.0 ± 5.4	64.0 ± 8.8
Duration (months)	5.9 ± 2.2	5.1 ± 2.2	6.5 ± 1.5
MMSE (score)	16.9 ± 3.2	17.8 ± 3.8	18.6 ± 3.4

All variables are mean ± standard deviation (SD). NFB: neurofeedback training group, CACR: computer assisted cognitive rehabilitation training group, CON: control group, MMSE: mini-mental state examination

Table 2. Comparison of the relative beta waves of each group

Channel	NFB		CACR		CON	
	pre	post	pre	post	pre	post
Fp1	0.07 ± 0.03	0.10 ± 0.04*	0.08 ± 0.06	0.10 ± 0.05	0.07 ± 0.04	0.07 ± 0.03
Fp2	0.07 ± 0.03	0.11 ± 0.04*	0.08 ± 0.05	0.10 ± 0.05	0.06 ± 0.03	0.07 ± 0.03
F3	0.11 ± 0.03	0.15 ± 0.06*†	0.11 ± 0.05	0.12 ± 0.05	0.12 ± 0.03	0.11 ± 0.03
F4	0.12 ± 0.03	0.15 ± 0.05	0.11 ± 0.04	0.13 ± 0.04	0.11 ± 0.03	0.11 ± 0.03
T3	0.15 ± 0.05	0.17 ± 0.09	0.12 ± 0.03	0.14 ± 0.04	0.15 ± 0.04	0.16 ± 0.04
T4	0.14 ± 0.05	0.16 ± 0.05	0.11 ± 0.04	0.12 ± 0.03	0.15 ± 0.04	0.14 ± 0.04
P3	0.11 ± 0.06	0.15 ± 0.06**	0.11 ± 0.03	0.12 ± 0.04	0.12 ± 0.04	0.13 ± 0.03
P4	0.11 ± 0.05	0.15 ± 0.06*†	0.11 ± 0.04	0.12 ± 0.04	0.12 ± 0.03	0.12 ± 0.03

All variables are mean ± standard deviation (SD). NFB: neurofeedback training group, CACR: computer assisted cognitive rehabilitation training group, CON: control group, Fp1: Lt. Frontopolar, Fp2: Rt. Frontopolar, F3: Lt. Frontal, F4: Rt. Frontal, T3: Lt. Temporal, T4: Rt. Temporal, P3: Lt. Parietal, P4: Rt. Parietal. *p<0.05, **p<0.01 †: comparison of NFB group and control group, p<0.05

the analysis, since the 0.5–4 Hz delta wave is often corrupted by noise arising from instability of posture or eye-blinking. The raw data was transformed using the fast Fourier transform, which expresses the contribution by the frequency property on the frequency space, with the value calculated as the amplitude of the sine raised to the 2nd power or as the absolute band power. The relative band power was calculated as the ratio of the absolute power rate of a certain frequency band to the absolute band power and has a value between 0 and 1. Relative power analysis is used to identify factors leading to personal brainwave differences, such as skull thickness or level of tension at the time of measuring. The frequencied determined by the relative power analysis analyzed as a relative theta wave (4–8 Hz/4–50 Hz), relative alpha wave (8–13 Hz/4–50 Hz), relative beta wave (13–20 Hz/4–50 Hz), and relative gamma wave (30–50 Hz/4–50 Hz).

The functional independence measure (FIM) assesses three functional performances of self-care, motor skill, and cognition, and consists of 18 items of basic ADLs which are scored on a 7-point scale. The scores range from 18 to 126, with the lowest score reflecting complete dependence, and the highest score reflecting complete independence. FIM scores correlate well with motor skills (r=0.77) and cognition (r=0.83)[14]. This study analyzed the FIM total score, and the motor and cognitive subtotal scores.

All statistical analyses were performed using SPSS 17.0. The Shapiro-Wilk test showed the data was normally distributed. Student's t-test was performed to examine the significance of within the group differences between before and after training. One-way ANOVA was performed to examine the significance of differences in the dependent variable among the 3 groups with the Scheffe method as the post-hoc test. Results were considered statistically significant for values of p<0.05.

RESULTS

The brainwave and ADL values before and after NFB or CACR are shown in Tables 2 and 3. The relative beta wave values showed significant differences between before and after training at Fp1, Fp2, F3, P3, and P4 in the NFB group (p<0.05). In the parietal area, in the NFB group, brain waves at F3 and P4 showed significant differences between before and after training (p<0.05). All three groups showed significant improvements in motor and cognition FIM subscale scores, and the FIM total score (p<0.01). However, there was no significant difference aming the FIM scores of the three groups.

DISCUSSION

This study investigated relative brain wave and ADL changes hemiplegic stroke patients following NFB or CACR train-

Table 3. Comparison of activities of daily living (ADL) of the groups

FIM	NFB		CACR		CON	
	pre	post	pre	post	pre	post
Motor	58.0 ± 13.1	59.6 ± 13.1**	54.6 ± 18.6	56.9 ± 17.6***	50.9 ± 13.6	53.0 ± 12.7***
Cog	24.4 ± 5.2	25.8 ± 4.5**	24.5 ± 5.3	25.4 ± 5.2***	25.8 ± 4.1	26.6 ± 4.1**
Total	82.4 ± 17.6	85.5 ± 16.2***	79.1 ± 21.8	82.3 ± 21.0***	76.8 ± 16.3	79.6 ± 15.5***

All variables are mean ± standard deviation (SD). NFB: neurofeedback training group, CACR: computer assisted cognitive rehabilitation training group, CON: control group, FIM: functional independent measure, Motor: motor subscale score, Cog: cognition subscale score, Total: functional independent measure total score. **p<0.01, ***p<0.001

ing. Attention and judgment related tasks mainly activate the frontal area of the brain, and tasks requiring language and spatiotemporal information mainly activate the parietal region[15]. The prefrontal area of the brain is mainly involved in cognitive activities, such as direct attention on new situations, and the frontoparietal area is involved in attention for space and control of intentional movement[16].

In this study, the relative beta wave values showed a significant difference (p<0.05) between before and after training at Fp1, Fp2, and F3 in the frontal area of the NFB group, and between F3 of the NFB group and the control group at post-test (p<0.05). In the parietal area of the NFB group, brain waves at F3 and P4 showed significant differences (p<0.05) between before and after training and a significant difference from the control group at P4 post-test (p<0.01).

Kim et al. evaluated patients with brain injury and normal controls after CACR cognitive training using 10 ComCog attention ability tasks, which activate the frontal area and temporoparietal area more than the front area of the temporo-occipital area, supplementary motor area, and cingulate gyrus as determined by fMRI, and compared them with a control group[17]. Their results showed NFB training improved the spatiotemporal attention of patients with brain injury. They proposed that NFB training may induce spread of brain activity to other brain areas eliciting long-term improvement. Furthermore, the brain activity differed in the injured area and they also suggested that further research was required in this area.

Cederfeldt et al. explored the effect of cognitive functions on the restoration of ADLs 1 year after discharge of stroke patients. They reported that the patients with cognitive functional impairment showed a difference in the restoration speed of ADLs compared to the normal group, and that understanding the relationship between cognitive damage and activity restraint is necessary, since it is very important to identify the cognitive problem influencing ADL restoration and to rectify this[4]. Likewise, the improvement of the cognitive-recognition function is related to ADL performance in stroke patients, and cognition-recognition training of certain areas appropriate to the patient's condition is necessary for independent ADL performance, as well as for a functional training approach in rehabilitation. In addition to hospital treatment, constant stimulation of cognitive functions by family and the surrounding environment may also be a motivating factor leading to successful rehabilitation.

This study found that in terms of ADL performance, as measured by the FIM score, all three groups showed significant improvements in motor and cognition subtotal scores, and their FIM total score, and that self-care showed especially significant improvement as part of the motor skill area (p<0.01). Walker et al. examined the effect of intervention using QEEG in patients with mild brain damage and found that 88% of patients showed an overall improvement in ADLs, and all of them returned to their occupations[15]. Kado et al. revealed that CACR therapy for brain damaged patients improved ADLs such as activity at home, occupational performance, and driving ability[3].

There was no difference in the FIM values among the three training methods. This seems to result from the fact that NFB, CACR, and traditional rehabilitation therapy aim to be performed independently from ADLs such as self-care, dressing, or mobility. Traditional rehabilitation therapy, as well as NFB or CACR, are all considered to be able to lead to improvement of cognitive function. More rapid rehabilitation seems to be possible, and NFB and CACR, which are beneficial for stroke patients with cognitive impairment, It is also necessary to develop and activate NFB and CACR programs and to conduct further research on the damaged brain areas in patients with cognitive impairments.

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