J. Phys. Ther. Sci.
27: 673–676, 2015

Original Article

The effect of neurofeedback on a brain wave and visual perception in stroke: a randomized control trial

Hwi-Young Cho, PhD, PT[1)], Kitae Kim, PhD, KMD[2)], Byounghee Lee, PhD, PT[3)a], Jinhwa Jung, PhD, OT[4)*a]

[1)] *Department of Physical Therapy, College of Health Science, Gachon University, Republic of Korea*
[2)] *Department of Korean Medicine, Semyung University, Republic of Korea*
[3)] *Department of Physical Therapy, Sahmyook University, Republic of Korea*
[4)] *Department of Occupational Therapy, Semyung University: 65 Semyung-ro, Jecheon-si, Chungbuk 390-711, Republic of Korea*

Abstract. [Purpose] This study investigated a brain wave and visual perception changes in stroke subjects using neurofeedback (NFB) training. [Subjects] Twenty-seven stroke subjects were randomly allocated to the NFB (n = 13) group and the control group (n=14). [Methods] Two expert therapists provided the NFB and CON groups with traditional rehabilitation therapy in 30 thirst-minute sessions over the course of 6 weeks. NFB training was provided only to the NFB group. The CON group received traditional rehabilitation therapy only. Before and after the 6-week intervention, a brain wave test and motor free visual perception test (MVPT) were performed. [Results] Both groups showed significant differences in their relative beta wave values and attention concentration quotients. Moreover, the NFB group showed a significant difference in MVPT visual discrimination, form constancy, visual memory, visual closure, spatial relation, raw score, and processing time. [Conclusion] This study demonstrated that NFB training is more effective for increasing concentration and visual perception changes than traditional rehabilitation. In further studies, detailed and diverse investigations should be performed considering the number and characteristics of subjects, and the NFB training period.

Key words: Neurofeedback (NFB), Brain wave, Visual perception

(This article was submitted Aug. 25, 2014, and was accepted Oct. 10, 2014)

INTRODUCTION

Cognition is defined as information processing in one's brain and ability to judge and make decisions, and it covers various concepts such as attention, memory, executive planning, insight, and problem solving[1, 2)]. For normal cognitive function, the integration of sensory information, visual perception, and language ability is required first, and loss of attention and of memory impair cognitive function, such as problem solving and reasoning ability[3)].

In rehabilitation training program, the adaptive approach, which focuses on recovery of damaged cognitive function in the brain, is one of the common approaches in cognitive rehabilitation. It is based on the theory that neuroplasticity reorganizes the damaged cerebral cortex, and it focuses on recovery of the damaged cognitive function and minimizing the effects of the damage[4)].

As a method of functional brain imaging for brain wave testing, many different innovative methods of radiological examination including the electroencephalogram, positron emission tomography, magnetic resonance imaging, functional magnetic resonance imaging, and single-photon emission computerized tomography have been used, and these methods can be used to confirm the brain's functional changes by comparison with normal brains[5)]. Compared with other experimental brain imaging methods, brain wave measurement is a commonly used as a noninvasive method for analyzing the changes in brain functions directly within a short period of time, and providing a variety of useful information with data from a short examination[6)]. It is also an electronic neurophysiological experiment method that can be used to investigate the brain's functional status in real-time while focusing on a specific assignment. This is applicable to various patients suffering from brain damage, alcoholism, and/or depression, and it can be used to analyze brain functions objectively. It makes it especially easy to observe the process of spatiotemporal changes, and therefore, it is very useful for measuring cognitive load in real time[7)].

Neurofeedback (NFB) brain wave training based on the principle of brain plasticity is a relatively novel method for cognitive rehabilitation. This method involves training to adjust brain waves within a specific range, and the optimum brain wave adjustment improves the level of awakening and affects various functional elements of the patient. Therefore, understanding brain waves should be among the highest research priorities[8, 9)].

*Corresponding author. Jinhwa Jung (E-mail: otsalt@nate.com) [a]These two authors contributed equally to this work.

The beta wave improves concentration and reaction time when activated with a brain wave between 12–35 Hz. Through beta wave activation, NFB training aims to improve cerebral function by enabling patients to activate this brain wave by reinforcing or suppressing certain frequencies based on visual and auditory feedback[7, 10]. Previous research has shown that NFB is effective in improving cognitive functions including visual perception, memory, and concentration in patients with brain injuries, such as traumatic brain injury or stroke[11, 12]. However, research on cognitive rehabilitation through NFB on existing stroke patients has been limited to single case studies, and sufficient studies on its effectiveness and clinical usability have not been conducted.

This study investigated the changes of a brain wave and visual perception following NFB and the manner in which these changes affect daily life in stoke patients. Also, we aimed to indicate the effective therapeutic method to clinicians engaged in the cognitive rehabilitation of patients with stroke.

SUBJECTS AND METHODS

The participants were recruited from among 28 stroke patients who received occupational and physical therapy and were hospitalized at a General Hospital in Kyeongki province, Republic of Korea, from June to July 2013. Participant selection criteria included that the patient should be hemiparalytic from a stroke within the previous 3 months to 1 year, be able to follow verbal instructions, and be able to communicate at a certain level. In addition, participants were chosen from among patients who were able to perform all the tests and had experienced light cognitive function failure that was scored between 18 and 23 on the mini-mental state examination (MMSE). A subject was eliminated if he/she had diplegia, never attended a school, was biased, or had experienced NFB within the past year. Furthermore, all subjects who participated in this trial provided a signed written consent form after having the expected result and the side effects fully explained. Randomization was performed by drawing an intervention from an envelope. A total of 27 subjects eventually completed the intervention and testing: 13 from the NFB group and 14 from the control group. NFB training was conducted over a period of 6 weeks, considering the hospitalization period. As the participants were recruited successively, the training was conducted over a 9-week period. The evaluation included measurement of brain waves and visual perception. The control group received occupational and physical therapy for half an hour 5 times a week for 6 weeks. The NFB group received the same number of traditional rehabilitation sessions as the control group with extra NFB training, respectively, for half an hour 5 times a week for 6 weeks. Exercise was prescribed and supervised by two experienced accredited physical therapists. All of the protocols used in this study were approved by Sahmyook University. Before participation, the procedures, risks, and benefits were explained to all of the participants, who gave their informed consent. The participants' rights were protected according to the guidelines of Sahmyook University.

To perform the NFB training, a NeuroComp System (Neurocybernetics Inc., Encino, CA, USA), composed of a repeater, a monitor for the clinician and the patient, computer, electroencephalography (EEG) sensor, cables, and poles, was used for NFB. The poles used in NFB training were attached to the scalp, and data were recorded on an oscillograph. The location of the poles followed the International 10–20 Electrode System, and the distance between each pole was 10–20% of the whole circumference[5, 13]. The NFB training method used in this research was a beta-SMR training method and was conducted with the patient's eyes open. The reward forms for the feedback were divided into auditory and visual rewards. The reward brain wave was set with either an SMR wave (12–15 Hz) or mid-beta wave (15–18 Hz) depending on the location of the cerebral cortex. The inhibitory brain wave was set with both a delta wave (0.5–4 Hz) and high-beta wave (22–36 Hz)[7, 8, 12]. The training time for a single trial was set at 30 minutes, during which a 3-minute training module was conducted 10 times.

For monopolar type training, a pole or NFB sensor was attached to a certain part of the scalp (C5 or C6) within the lesion area, and the remaining 2 poles were attached to both ears with the participant seated on a comfortable chair. The patient viewed games through a monitor for brain wave training. We used 4 games that had a low level of difficulty and were intriguing including Space Race, Mazes, Island, and Boxlight. Participants played the games by watching the monitor with the poles attached, and his/her awakening level was controlled. For the Space Race game, the spaceship was set to move forward and backward depending on his/her level of brain wave activation.

A quantitative analysis of the brain wave data was performed using the Complexity 2.0 software (Laxtha Inc., Daejeon, Republic of Korea). The measured brain wave pattern was checked for any artifact inflow, and data for 180 seconds obtained from pattern observation with the NFB system from the raw data of the measured brain excluding the first 10 seconds-were used for the analysis. Since delta waves between the 0.5–4 Hz are likely to be contaminated with noise such as eye blinking (2–4 Hz) and head movement due to an unstable body position (0.5–1 Hz), the range of 4–50 Hz from the entire brain wave domain was also extracted for the analysis. The fast Fourier transform (FFT) filtering method was conducted to convert the raw data into frequencies.

FFT shows the contributions of frequency components to the frequency domain. The X axis represents the frequency and Y axis represents the power value, which shows spectral analysis of evoked potentials in brain. The output value is the absolute band power, which is the square of the signal amplitude. The relative band power is the absolute power ratio of a particular frequency band on values of absolute band power between 0 and 1, and could be in percentage (0–100%). This relative band power analysis was used to adjust for the difference in skull thickness between test subjects and individual brain waves due to the degree of tension during measurement. The beta frequency band spans 12 to 30 Hz[14].

The motor-free visual perception test (MVPT) was used for visual perception evaluation. It contains a total of 36 items with four multiple-choice response options worth 1 point each, adding up to a maximum score of 36. The MVPT is a standardized evaluation tool for individuals 18–80 years of age and measures six different parts of visual perception functions. There are 5 items for visual discrimination (VD), 5 items for form constancy (FC), 8 items for visual memory (VM), 11 items for visual closure (VC), and 4 items for spatial relation (SR). Moreover, the processing time to complete each item is measured for all items (35 items) except for item 4. The MVPT can be used on patients with damaged physical function who have difficulty with writing, and the confidence level of test-retest reliability for the MVPT r=0.77–0.83[15].

SPSS ver. 12.0 was used to calculate the averages and standard deviations. The differences in the brain wave and visual perception within a group before and after the treatments were tested using the paired t-test, whereas differences between groups were tested using the independent t-test. For all data, statistical significance was accepted at values of $p < 0.05$.

RESULTS

The general characteristics of participants are shown in Table 1. The brain wave values and visual perception changes before and after NFB training are shown in Table 2. Brain wave measurement before and after NFB training revealed a statistically significant difference for the NFB group's relative beta wave value and attention concentration quotient (ACQ) ($p<0.05$). Comparison of the difference before and after the interventions between the two groups revealed that the NFB group's relative wave values and ACQs were significantly different ($p<0.05$). For the NFB group, there were differences in VD, FC, VM, VC, and SR before and after the experiment. Comparison of the differences before and after the interventions between the two groups revealed significant differences in MVPT raw score and processing time ($p<0.05$).

Table 1. General characteristics of the subjects

	NFB	CON
Gender (male/female)	8/5	11/3
Age (years)	62.9±7.2	63.6±9.3
Lesion side (right/left)	9/4	8/5
Duration (months)	10.6±3.2	12.5±2.7
MMSE (score)	19.8±2.5	20.5±3.7

All variables are presented as the mean±SD. NFB: neurofeedback training group; CON: control group; MMSE: mini-mental state examination

DISCUSSION

NFB is developing along with technical development of quantitative EEG, computer devices, and individual medical protocols. While performing assignments that require more attention than in a steady state, alpha waves are controlled and beta waves are increased; vitalization of beta wave reflects cognitive function improvement[14, 16]. The SMR waves in beta waves were found to be in an appropriately steady state and to maintain attention and wakefulness. Promotion of SMR wave activity is also used in a treatment to relieve impulsivity and involuntary movements[17]. SMR-beta wave training is an effective interventional approach for treatment of attention and cognitive impairment, whereas NFB training supports and improves the neurophysiological function level.

Performance of EEG before and after NFB training revealed statistically significant differences in the NFB group's relative beta wave value and ACQ ($p<0.05$). Comparison of the differences before and after the interventions between the two groups revealed significant differences in the NFB group's relative beta wave values and ACQs compared with

Table 2. Comparison of brain waves and MVPT in each group

Item	Subtest	NFB		CON	
		Pre	Post	Pre	Post
Brain wave (%)	Relative beta wave*	11.32±4.52	15.45±5.51*	8.58±3.80	11.32±7.37
	Relative mid-beta wave	2.17±1.02	2.81±1.32**	1.53±0.61	2.17±1.61
	Relative high beta wave*	4.22±1.71	6.08±2.03*	3.37±1.90	4.43±3.60
	ACQ* (Hz)	0.2085±0.0777	0.3417±0.2523	0.1917±0.0451	0.2922±0.2976
MVPT (score)	Raw score***	20.76±4.34	23.46±4.48**	24.00±5.43	25.21±5.17**
	VD	5.69±1.64	7.15±0.89**	5.85±1.79	6.00±1.70
	FC	2.53±0.96	3.15±0.80*	3.21±1.05	3.64±0.84*
	VM	4.30±1.79	4.69±1.93**	5.35±1.44	5.50±1.45
	VC	6.00±1.77	6.69±1.75**	6.57±1.60	6.92±1.89
	SR	2.23±1.01	2.69±0.85**	3.00±1.17	3.14±0.86
	Time (second)*	7.76±1.31	6.99±1.38***	7.22±2.06	6.87±2.07**

All variables are presented as mean±SD. *$p<0.05$; **$p<0.01$; ***$p<0.001$. NFB: neurofeedback training group; CON: control group; ACQ: attention concentration quotient; MVPT: motor-free visual perception test; VD: visual discrimination; FC: form constancy; VM: visual memory; VC: visual closure; SR: spatial relation; Time: visual perceptual processing time the control group (p<0.05). Relative beta wave value went up when attention increased, and ACQ reflects improvements in attention. The results of this study indicate that the increased relative beta wave value and ACO resulted in significant improvement compared with the control group. This was similar to earlier findings. Lopez-Larraz et al.[18] reported that NFB increased cognitive ability and concentration for various diseases, and Gevensleben et al.[19] claimed that NFB using the beta wave is effective for improvement of concentration, although their research was performed with ADHD patients. In this study, we observed that NFB led to notable differences in attention and concentration after the intervention. This difference may have been due to the neurobiological reaction to NFB, which affects the beta wave and the concentration brain waves. Thus, NFB would be a prevailing choice for patients who require attention and concentration training.

Visual perception is a process in which the central nervous system integrates visual information to adapt to the environment and converts the information to cognitive concepts for decision-making. This process has a hierarchical structure consisting of oculomotor control, visual fields, visual acuity, visual attention, visual scanning, pattern recognition, and visual memory, and the highest visual percptual process in the hierarchy is visual cognition[2]. Through training of visual scanning, visuospatial orientation, and visual judgment, the damaged visual perception functions of stroke patients can be improved to enhance recognition ability and activities of daily living.

Regarding visual perception before and after NFB, both the NFB group and control group showed statistically significant differences in MVPT raw score and processing time. For the NFB group, there were differences in VD, FC, VM, VC, and SR before and after the intervention. Comparison of the differences between the two groups revealed significant differences in the MVPT raw score and processing time (p<0.05). NFB training was found to be more effective in changing visual perception change compared with traditional rehabilitation training (p<0.05). The NFB program is considered to have been more effective in improving visual perception ability because the training was on watching and focusing with the eyes.

More research into the development of an attention and concentration training program that fits the rehabilitation purpose of not only stroke patients but also patients with other illnesses is necessary. In addition, post-test check-ups should be performed to determine how long the changes last. Standardized and more elaborate EEG measurement and analysis are required to provide sufficient evidence for neurofeedback brain wave training.

REFERENCES

1) Serruya MD, Kahana MJ: Techniques and devices to restore cognition. Behav Brain Res, 2008, 192: 149–165. [Medline] [CrossRef]
2) Pendleton HM, Schultz-krohn W: Pedretti's Occupational Therapy, 6th ed. San Jose: Mosby, 2006.
3) Stern H, Jeaco S, Millar T: Computers in neurorehabilitation: what role do they play? Part 1. Br J Occup Ther, 1999, 62: 549–553.
4) Adcock RA, Dale C, Fisher M, et al.: When top-down meets bottom-up: auditory training enhances verbal memory in schizophrenia. Schizophr Bull, 2009, 35: 1132–1141. [Medline] [CrossRef]
5) Thornton KE, Carmody DP: Electroencephalogram biofeedback for reading disability and traumatic brain injury. Child Adolesc Psychiatr Clin N Am, 2005, 14: 137–162, vii. [Medline] [CrossRef]
6) Stecklow MV, Infantosi AF, Cagy M: EEG changes during sequences of visual and kinesthetic motor imagery. Arq Neuropsiquiatr, 2010, 68: 556–561. [Medline] [CrossRef]
7) Sokhadze TM, Cannon RL, Trudeau DL: EEG biofeedback as a treatment for substance use disorders: review, rating of efficacy, and recommendations for further research. Appl Psychophysiol Biofeedback, 2008, 33: 1–28. [Medline] [CrossRef]
8) Sterman MB, Egner T: Foundation and practice of neurofeedback for the treatment of epilepsy. Appl Psychophysiol Biofeedback, 2006, 31: 21–35. [Medline] [CrossRef]
9) Nelson LA: The role of biofeedback in stroke rehabilitation: past and future directions. Top Stroke Rehabil, 2007, 14: 59–66. [Medline] [CrossRef]
10) Cortoos A, Verstraeten E, Cluydts R: Neurophysiological aspects of primary insomnia: implications for its treatment. Sleep Med Rev, 2006, 10: 255–266. [Medline] [CrossRef]
11) Egner T, Zech TF, Gruzelier JH: The effects of neurofeedback training on the spectral topography of the electroencephalogram. Clin Neurophysiol, 2004, 115: 2452–2460. [Medline] [CrossRef]
12) Scott WC, Kaiser D, Othmer S, et al.: Effects of an EEG biofeedback protocol on a mixed substance abusing population. Am J Drug Alcohol Abuse, 2005, 31: 455–469. [Medline] [CrossRef]
13) Wing K: Effect of neurofeedback on motor recovery of a patient with brain injury: a case study and its implications for stroke rehabilitation. Top Stroke Rehabil, 2001, 8: 45–53. [Medline] [CrossRef]
14) Machado DC, Lima GC, Souza Dos Santos R, et al.: Comparative analysis electroencephalographic of alpha, Beta and gamma bands of a healthy individual and one with hemiparesis. J Phys Ther Sci, 2014, 26: 801–804. [Medline] [CrossRef]
15) Korner-Bitensky N, Sofer S, Kaizer F, et al.: Assessing ability to drive following an acute neurological event: are we on the right road? Can J Occup Ther, 1994, 61: 141–148. [Medline] [CrossRef]
16) Fairclough SH, Venables L, Tattersall A: The influence of task demand and learning on the psychophysiological response. Int J Psychophysiol, 2005, 56: 171–184. [Medline] [CrossRef]
17) Thompson L, Thompson M: Neurofeedback combined with training in metacognitive strategies: effectiveness in students with ADD. Appl Psychophysiol Biofeedback, 1998, 23: 243–263. [Medline] [CrossRef]
18) López-Larraz E, Iterate I, Escolano C, et al.: Single-trial classification of feedback potentials within neurofeedback training with an EEG brain-computer interface. Conf Proc IEEE Eng Med Biol Soc, 2011, 2011: 4596–4599. [Medline]
19) Gevensleben H, Moll GH, Rothenberger A, et al.: [The usage of neurofeedback in children with ADHD: the method and its evaluation]. Prax Kinderpsychol Kinderpsychiatr, 2011, 60: 666–676. [Medline] [CrossRef]