

Effects of Neurofeedback on Brain Waves and Cognitive Functions of Children with Cerebral Palsy: a Randomized Control Trial

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Abstract. [Purpose] This study investigated brain wave and cognitive function changes in children with cerebral palsy (CP) using neurofeedback (NFB). [Subjects] Twenty-eight children with CP were randomly allocated to the NFB (n = 14) and control (CON) (n = 14) groups. [Methods] Two expert therapists provided the NFB and CON groups with traditional rehabilitation therapy in 30-minute sessions, semi-weekly, for 6 weeks. NFB training was provided only to the NFB group. The CON group received traditional rehabilitation therapy only. Before and after 6 weeks of intervention, electroencephalography and Loewenstein Occupational Therapy Cognitive Assessment (LOTCA) were performed, and the results were analyzed. [Results] Between before and after the intervention, both the NFB and CON groups showed significant differences in spectral edge frequency of 50%. Moreover, the NFB group showed a statistically significant difference in all LOTCA subtests, while the CON group showed a significant difference only in the LOTCA total score. [Conclusion] Detailed and diverse investigations should be performed considering the number and characteristics of subjects and the limitations influencing the NFB training period.

Key words: Cerebral palsy, Neurofeedback, Cognition

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INTRODUCTION

Cerebral palsy (CP) is defined as a permanent physical disability in posture and motor functions caused by cerebral dysfunction, which can occur before, during, or after birth¹⁾. Statistically, over the last 40 years, 2–2.5 out of every thousand individuals have CP, and 25–80% of these individuals exhibit additional posture and motor disorders²⁾. Other aspects of CP include impairment of sensory abilities, learning, socialization, communication, muscle tone, visual perception, and cognition²⁾.

Cognitive problem is caused not only by CP but also by various other conditions such as traumatic brain injury (TBI), autistic spectrum disorder, and attention deficit/hyperactivity disorder (ADHD)^{4, 5)}. Moreover, it may have a negative effect on mental and intellectual capacity development⁶⁾. Therefore, treatments that enhance the cognitive domains are of great interest, and diverse approaches are being used. Recently, the neurofeedback (NFB) approach was tested using EEG biofeedback training^{4, 5)}. Electroencephalography (EEG) is a valuable method for assessing the damaged brain parts of CP subjects who tend to have abnormal brain waves and a high incidence of epilepsy³⁾. In addition, early detection of these abnormal brain waves and provision of appropriate treatment are needed to lower the risk of learning disorder or mental retardation (MR)¹⁾.

NFB is a type of biofeedback that uses real-time computer displays to illustrate brain activity, with the goal of developing latent faculties in normal people and alleviating clinical symptoms in patients⁷⁾. The human brain can learn to control a certain range of brain waves with training over time, and remembers the results for a long time⁸⁾. NFB brain wave training uses monitoring devices to almost instantly provide information about a person's state of physiological functioning, and allows subjects to gain the ability to control their own brain waves intentionally⁹⁾. NFB therapy is a self-regulation method that aims to normalize brain waves by reinforcing or suppressing a certain frequency of the subject's own brain waves through visual and auditory feedback, and consequently to enhance cerebral functions¹⁰⁾. Two typical training methods used for NFB therapy are the beta/sensory motor rhythm and alpha-theta modes, and the kind of brain waves depends on the purpose of training. The training method for treatment depends on the patient's diseases and symptoms. Furthermore, the purpose of the training should be considered when deciding the reward band for reinforcement and the inhibition band for suppression¹¹⁾.

NFB brain wave training is effective at improving the memory of children and the rehabilitation of patients with brain injury¹²⁾. Furthermore, studies of various disorders such as epilepsy, depression, stroke, TBI, and ADHD have shown NFB training improves attention, cognition, motor function,

Table 1. The demographic characteristics (Mean \pm SD)

Item	NFB	CON
Gender (male/female)	8/6	9/5
Age (year)	9.49 \pm 0.41	9.52 \pm 0.45
Height (cm)	135.71 \pm 2.61	134.94 \pm 2.97
Weight (kg)	31.75 \pm 2.39	32.10 \pm 2.46

Note. NFB: Neurofeedback training group, CON: control group

hyperactivity control, and other brain functions^{8,9,13}).

Previous studies of brain waves report that various diseases are related to abnormal types of brain waves, and NFB training has beneficial effects for managing disease-related symptoms. However, objective and valid studies of the effects of NFB training on children with CP are lacking. Hence, this study focused on the effects of NFB training on brain waves and cognition of children with CP.

SUBJECTS AND METHODS

This study included 30 children with CP and was performed at I Hospital in Korea in 2011. The subject selection criteria were as follows: no NFB-related treatment in the previous 2 years; no internal, or neurological surgery in the previous 2 months; and no specific medical problems, including psychological problems. Parents of all the children included in this study were given a complete explanation of the study and were asked to voluntarily sign the participation consent forms before the experiments. Subjects were randomly allocated to one of two groups (the NFB training group and the control [CON] group) using a table of random sampling numbers. A pretest was performed after obtaining information on physical and medical conditions. Subjects in the 2 groups were provided traditional rehabilitation therapy in 30-minute sessions, semi-weekly for 6 weeks. For the single-blind analysis, each group was segregated from the other. One group received treatment in the morning, and the other group received treatment in the afternoon; subjects in both groups were forbidden to talk about the treatment. After 6 weeks of intervention, a posttest was performed, and the results were analyzed. One child each in the NFB and CON groups withdrew from the experiment. Thus, the final numbers of children who participated in the post-test were 14 in the NFB group and 14 in the CON group. The demographic characteristics of each group are shown in Table 1.

The NeuroComp System (Neurocybernetics Company, Missouri, America) was used for NFB. The NFB training method used a beta-SMR training mode with the subjects' eyes open. The rewards for the feedback were auditory and visual rewards. The reward brain wave was set at either the SMR wave (12–15 Hz) or mid-beta wave (15–18 Hz) frequency depending on the location of the cerebral cortex.

The subjects' brain waves were measured by QEEG-8 (Laxtha Inc., Daejeon, Korea) and quantitatively analyzed by Complexity 2.0 (Laxtha), a brain wave analysis system. For the brain wave analysis, forms of measured brain waves

were first examined to check whether there was any influx of an extra wave; then, brain wave data of 180 seconds were selected (discarding the data of the first and last 10 seconds) by observing the forms of the brain waves with the NFB system. Because delta waves (between 0.5 and 4 Hz) are easily contaminated by noise such as blinks (2–4 Hz) or head movements (0.5–1 Hz) due to an unstable posture, only brain waves between 4 and 50 Hz were extracted and used in the analysis. The fast Fourier transform, a method for transforming raw data into frequencies, was used.

Spectral edge frequency (SEF) is a measure used to investigate the activity of the cerebral cortex, and it indicates the degree of work load and the depth of anesthesia. SEF quantitates and expresses the area ratio against the whole frequency range in Hz, indicating how much the ratio is skewed toward high frequency, and the power spectrum distribution of brain waves¹⁴. SEF has several definitions such as SEF 25%, SEF 50% (median frequency), SEF 90%, and SEF 95%, and these are used differently according to the purpose of a study. In this study, SEF 50% and SEF 95% were analyzed. Because the coherence index of the frontal lobe reflects short-term memory ability, it may be used as a feedback index for memory improvement for patients with an abnormally low index. The SEF index reflecting brain wave awakening is abnormally low in patients with a low brain arousal level, such as those who have chronic fatigue syndrome; moreover, SEF training is performed for normalization of its skew¹⁵.

In this study, the Loewenstein Occupational Therapy Cognitive Assessment (LOTCA) was used as a tool for evaluating cognition. This method was standardized by Katz et al. and has 5 components: orientation (O), visual perception (VP), visuomotor organization (VO), thinking operation (TO), and attention and concentration (AC)¹⁶. The reliability among testers was $r = 0.82$ – 0.97 for the 26 subtests, and the reliability of the testing tool was $r = 0.89$, which is satisfactory¹⁶. SPSS ver. 12.0 was used to calculate averages and standard deviations.

Descriptive statistics were adopted to analyze the general characteristics of the subjects. The SEF value and cognition difference within a group before and after the treatment were tested using the paired t-test, whereas the difference between groups was tested using the independent t-test. For all data, statistical significance was accepted at values of $p < 0.05$.

RESULTS

The SEF values and cognition changes before and after

Table 2. Comparison of SEF 50%, 95% and LOTCA (Mean \pm SD)

Item	subtest	NFB		CON	
		Pre	Post	Pre	Post
EEG (Hz)	SEF 50%*	10.33 \pm 3.03	15.37 \pm 4.35*	9.73 \pm 2.88	11.59 \pm 4.40
	SEF 95%	36.61 \pm 4.69	39.10 \pm 3.64	33.70 \pm 7.44	34.84 \pm 6.11
LOTCA (score)	O*	6.00 \pm 1.46	6.71 \pm 1.26*	6.78 \pm 1.76	6.92 \pm 1.54
	VP*	19.64 \pm 4.39	20.14 \pm 4.48*	19.71 \pm 4.61	19.78 \pm 4.54
	VO*	19.57 \pm 5.47	20.92 \pm 5.32*	19.21 \pm 5.91	19.35 \pm 5.87
	TO*	15.42 \pm 4.25	15.92 \pm 4.06*	14.64 \pm 4.84	14.78 \pm 4.80
	AC	2.71 \pm 0.99	3.21 \pm 0.57*	3.07 \pm 0.82	3.21 \pm 0.69
	Total*	63.35 \pm 14.86	66.92 \pm 14.43*	63.42 \pm 15.75	63.92 \pm 15.68*

Note. * $p < 0.05$, NFB: Neurofeedback training group, CON: control group, O: Orientation, VP: Visual perception, VO: Visuomotor organization, TO: Thinking operation, AC: Attention and Concentration

NFB are shown in Table 2. The NFB and CON groups did not show a significant difference between before and after the intervention in SEF 95%. However, both groups showed a significant difference between before and after the intervention in SEF 50% ($p < 0.05$). For differences in cognition between before and after NFB training, the NFB group showed a significant difference in all LOTCA subtests ($p < 0.05$) while the CON group showed a significant difference only in the LOTCA total score ($p < 0.05$), not in the subtests scores. A comparison of the pre-post-intervention differences between the 2 groups indicated that the LOTCA total score and subtests O, VP, VO, and TO were significantly different ($p < 0.05$), but the AC subtest was not.

DISCUSSION

This study aimed to verify the effect of NFB training on the SEF index and cognition improvement of children with CP by measuring and analyzing the brain waves of the subjects.

The development of NFB is keeping pace with the technical development of quantitative EEG, computer devices and programs, and individual medical protocols⁵. SEF 50% refers to the frequency below which 50% of the total power of a given frequency is located. The SEF 50% value under anesthesia or in the state of sleep is below 5 Hz; values above 6 Hz represent consciousness¹⁷. A comparison of the pre-post-intervention differences in the 2 groups, indicated that both groups showed significant differences in SEF 50% (NFB 5.03 ± 5.35 , CON 1.85 ± 3.43 ; $p < 0.05$). This means that the change in the consciousness level was greater in the NFB group than in the CON group, and the cognitive load was increased.

SEF 95% refers to the frequency below which 95% of the total power of a given frequency is located. This expresses the degree of cognitive load felt while performing tasks. SEF 95% may represent the mental stress level and is often used, as in this study, as an evaluation index of the consciousness level while performing tasks that require concentration. Higher SEF 95% values indicate increased upper level beta or gamma waves in the power spectrum distribution. Moreover, it is believed that there is an increase in the

consciousness or cognitive load level¹⁸.

In this study, the comparison of the SEF 95% results obtained before and after the intervention indicates that the NFB group showed a greater difference than the CON group, but this difference was not statistically significant. This means that there was little difference between the 2 groups with respect to the mental stress level when performing tasks.

Treatments for enhancing cognitive function are of great interest because performing activities of daily living is very difficult for children with deficiencies in cognitive function. Several treatment approaches can be used. A simple and inexpensive method that uses picture cards and family photos can improve memory and, the use of virtual reality can improve the learning capacity of patients with memory loss enabling them to perform real-life tasks. Another method is the NFB approach, which is currently being tested in children with various diagnoses, with EEG biofeedback⁴. Strehl et al. (2006) provided NFB training for 23 ADHD children 5 times a week in a total of 30 one-hour sessions. A significant difference in intelligence quotient (IQ) was observed, and hyperactivity in these children decreased¹⁹. Surmeli et al. (2010) provided NFB training for 23 children with moderate MR and Down syndrome, and they observed significant improvements in activities and cognitive function but no change in IQ²⁰. Linder et al. (1996) provided NFB training for 6 months and reported finding significant differences in IQ, hyperactivity, and attention. Continuous and steady NFB training is helpful for patients with cognitive problems²¹.

With respect to cognition before and after our NFB training, the NFB group showed a significant difference ($p < 0.05$) in all LOTCA subtest scores while the CON group showed a significant difference only in the total score. A comparison of the within group differences indicated that the LOTCA total and O, VP, VO, and TO subtest scores were significantly different ($p < 0.05$) but the AC subtest score was not. In this study, the treatment period was 6 weeks and a longer duration of NFB training might have resulted in more significant improvement in cognitive function of the subjects.

Previous studies of NFB training have mostly focused on

ADHD and epilepsy. Studies of NFB training for children with CP are rare, and no intervention has been conducted as a treatment concurrent with rehabilitation. However, children with CP are regularly provided with traditional physical therapy in rehabilitation schools or hospitals, which makes the specific effect of NFB difficult to identify. In our study, we compared 2 CP groups undergoing rehabilitation treatment and verified the effect of NFB training. The limitations of this study were that the results are not generalizable to all children with CP because of the small number of subjects. Moreover, uncontrolled movements of the CP subjects during the measurement of brain waves might have affected the results. Detailed and diverse investigations should be performed considering the number and characteristics of the subjects and the NFB training period.

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