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# Effects of combination exercises on electroencephalography and frontal lobe executive function measures in children with ADHD: A pilot study.

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## Abstract

**The purpose of the present study was to investigate the effects of exercise on neuropsychological variables of executive function and physiological variables with electroencephalography in children with attention-deficit hyperactivity disorder. The participants included 12 boys in grades 1-4 who were randomly assigned to the combined exercise group (n=6) or control group (n=6). A 60 m exercise program (10-m warm-up, 40 m main exercise, and 10 m cool down) was performed three times a week for a total of 12 weeks. For the electroencephalography, a learning curve was utilized, and the electrodes were firmly attached to the children's scalps. Golden's paediatric stroop color and word test was used to measure executive function in the frontal lobe. After 12 weeks, the F3 and F4 TASK results and color-word scores were significantly increased in the exercise group compared with the control group. The 12 week combination exercise program (jump rope and ball exercises) had positive effects on the electroencephalography and frontal lobe executive function measures of children with attention-deficit hyperactivity disorder.**

**Keywords:** Attention-deficit hyperactivity disorder, Electroencephalography, Executive function.

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## Introduction

Children with Attention-Deficit Hyperactivity Disorder (ADHD) tend to exhibit inattention, impulsivity, and hyperactivity because of diminished self-control. In addition, they tend to have low self-esteem and self-confidence and may experience difficulty developing interpersonal and social relationships [1]. Children with hyperactivity may have difficulty attending to tasks as they exhibit behavior control problems, which may include incessant talking [2]. Therefore, early intervention programs that help these children maintain healthy connections and successfully mingle in society are desperately needed [3].

Various neurophysiological studies that have used functional magnetic resonance imaging, single-photon emission computed tomography, positron emission tomography, and Electroencephalography (EEG) have shown that frontal lobe dysfunction, particularly, prefrontal lobe dysfunction, may be responsible for ADHD [4-6]. Ongoing research studies in the field of neuropsychology have investigated the behavioral deficits of patients with frontal lobe dysfunction. Attention, language, spatial and sequential ordering, memory [7], and management/executive function have been investigated in these studies [8]. Several different neuropsychological tools have been developed and used to measure and test activity in various parts of the brain [8].

Recent studies have shown that exercise is an effective intervention for patients with ADHD. In a study by Armstrong and Drabman, children with ADHD reported improved confidence and self-efficacy after exercise therapy [9]. Choi highlighted the importance of exercise and physical activity in the treatment of ADHD and described the attention-improving power of aerobic exercises [10]. Thus, researchers are increasingly interested in finding exercises that effectively accommodate the psychological and physiological characteristics of children with ADHD. Nevertheless, research on the effectiveness of various types of physical activity, including combination exercises, as an alternative intervention for ADHD is still sparse.

Therefore, this study investigated the effects of exercise on the neuropsychological variables of executive function and physiological variables with electroencephalography in children with ADHD. The combination exercise in the current study was developed by incorporating a jump rope and balls, which are easily accessible and perennially preferred by children.

## Subjects and Methods

Upon obtaining approval from the Institutional Review Board for the study, potential participants were recruited from the Kwandong University Hospital's paediatric psychiatry department, which is located in Gangneung city. A thorough information session regarding the purpose and procedures of the current study was conducted, and a written informed consent that was drafted in accordance with the policies of the Institutional Review Board was then obtained from each volunteering parent whose child was diagnosed with ADHD. The children were diagnosed with a series of testing and scale assessments that were conducted by a medical doctor. The parents were asked to submit a detailed record of the types and amounts of foods that were consumed by the children during the previous day. The food reports were then analysed with a computer-aided nutritional analysis program (CAN-pro 3.0) in order to extract the children's dietary habits and nutritional profiles. Subsequently, children with similar dietary habits and nutritional profiles were selected for the study (Table 1).

The final participants included 18 boys in grades 1-4. The block randomization method was used to distribute the participants between the combination exercise group and no-exercise (control) group. After the elimination of six children who dropped out of the study for personal reasons, 12 children (six in the exercise group and six in the control group) completed the 12-week program. The specific selection criteria were the following: 1) Male elementary-school-aged children (grade levels, 1-4) who understood the study purpose and provided consent; 2) Children who obtained the approval of the tending physicians and parents for participation in the exercise program; 3) Children who met the diagnostic criteria for ADHD in the Diagnostic and Statistical Manual of Mental Disorders, version IV; 4) Children with Korean Educational Development Institute-Wechsler Intelligence Scale for Children scores of 80 and above; 5) Children with Conners parent questionnaire scores of 16 and above; 6) Children with no current or previous history of medication or other therapies for ADHD and who were free of other psychological disorders; and 7) Children who had not participated in regular exercise for the previous 6 months.

***Table 1.*** *Physical characteristics of subjects.*

| Group | N | Age (years) | Height (cm) | Weight (kg) | Fat (%) |
|---|---|---|---|---|---|
| CEG | 6 | 8.83 ± 0.98 | 131.23 ± 6.20 | 28.33 ± 4.68 | 13.73 ± 3.40 |
| NEG | 6 | 8.83 ± 0.98 | 133.12 ± 7.91 | 27.32 ± 5.31 | 13.70 ± 3.87 |

Values are M ± SD. CEG: Combined Exercise Group; NEG: Non Exercise Group. Between-group differences were not significant (unpaired Student's t-tests).

The program consisted of 60 min of exercise (10 m warm-up, 40 m main exercise, and 10 m cool down), and it was performed three times a week for 12 weeks. The intensity of the main exercise was gradually increased until the participants were within 45-75% of their heart rate reserve and 11-16% of their rating perceived exertion. Each participant wore a heart rate monitor (Sport Tester, Polar Electro, Kempele, Finland). The exercise program is described in Table 2.

***Table 2.*** *Combined exercise program.*

| Order | Contents | | Period | Intensity | Time |
|---|---|---|---|---|---|
| **Warm-up** | **Stretching** | | **1-12 weeks** | | **10 min** |
| | Ball (15 min) | Rope-jumping (25 min) | | | |
| | sitting balance | non rope-jumping | 1-4 weeks | 45 ~ 55% HRR or 11~12 RPE | |
| | airplane arms | rope-walking | | | |
| | touch down | rope-jumping | | | |
| | right and left raise | double bounce step | | | |
| | back, shoulder stretch | bounce step | | | |
| Main exercise | knee raise | jogging step | 5-8 weeks | 55~65% HRR or 13~14 RPE | 40 min |
| | heel taps | boxer step | | | |
| | toe taps | scissors | | | |
| | leg extension | side swing | | | |
| | prone bounces | curling step | | | |
| | back extension | | 9-12 weeks | 65~75% HRR or 15~16 RPE | |

| | | | |
|---|---|---|---|
| | forward | side step | | |
| | backward | couple rope-jumping | | |
| | side by side | group rope-jumping | | |
| | limbering | group rope-jumping | | |
| Cool-down | Stretching | | 1-12 weeks | 10 min |

In order to measure body composition, weight (kg), height (cm), body fat (%), muscle weight (kg), and paediatric body-mass index (kg/$m^2$) were measured. All of the participants were instructed to avoid engaging in excessive physical activity for 24 h before the measurements and fast for 4 h before the measurements. The measurements were performed with the bioelectrical impedance analysis method with the participants wearing light clothing.

For the EEG, a learning curve (Computerized Biofeedback System, ProComp Infiniti, Thought Technology Ltd., Montreal, Quebec, CAN) was utilized. The electrodes were firmly attached to the children's scalps, and the children were instructed to minimize movement. The placement of the electrodes was determined by the position of Cz. The electrodes were then attached to the ears to measure the voltage change between them. The frontal-lobe β waves, which have been reported to be associated with ADHD, were measured [11]. In addition, measures of the relaxed-state Eyes-Closed (EC) and Eyes Open (EO) of the left (F3) and right (F4) lobes and TASK were performed.

In order to measure the executive function of the frontal lobe, Golden's paediatric Stroop Color and Word Test was used. The Stroop Color and Word Test is a neuropsychology tool that measures self-control and the ability to suppress reactions. It consists of a color and word test and interference test, and it is typically used to assess various functions of the frontal lobe, including perception and tracking, processing speed, sequential processing, selective visual attention, and continuous visual attention. The participants were presented with a board that contained color words printed in colors not corresponding to the color words (e.g., the color word red printed in blue). Next, they were instructed to name the colors of the words as fast as possible while avoiding errors. Their reaction time was measured by the test administrator.

The results were analysed with SPSS 18.0 statistics software (IBM Corporation, Armonk, NY, USA). The mean and standard deviation were computed for all of the parameters. In order to verify the normality of the data distribution, a Kolmogorov-Smirnov test was performed. In order to test the homogeneity of the major participant variables before the exercises, a t-test (independent t-test) was performed. To examine the pre- and post-exercise differences within the groups, paired t-tests were performed. Independent t-tests were conducted to examine the post-exercise differences between the groups. The level of significance was set at $p<0.05$.

## Results

The results of the analyses of the EEG changes both within and between the groups are shown in Table 3. The EEG measures in the exercise group increased from (mean $\bar{x}$ ± standard deviation) 18.22 ± 0.63 to 19.01 ± 1.41 Hz after the 12 week session. In the no-exercise group, the EEG measures decreased from 19.94 ± 2.50 to 18.90 ± 0.60 Hz during the same period, and the change was insignificant. The F3 EO measure in the exercise group increased from 19.91 ± 1.93 to 21.58 ± 2.60 Hz after the 12 week session, while it increased from 20.63 ± 2.86 to 21.21 ± 1.41 Hz in the no-exercise group. However, the changes were statistically insignificant. The F3 TASK measures in the exercise group increased significantly from 20.47 ± 2.36 to 25.44 ± 4.46 Hz ($p<0.05$) after the 12 week session, while it increased from 19.77 ± 2.13 to 20.06 ± 2.30 Hz, which was insignificant, in the no-exercise group.

The F4 EC measure in the exercise group increased from 18.69 ± 0.50 to 18.93 ± 0.66 Hz after the 12 week session, while it decreased from 20.43 ± 2.00 to 19.63 ± 2.18 Hz in the no-exercise group. However, the changes were statistically insignificant. In the exercise group, the F4 EO measure increased significantly from 20.67 ± 1.73 to 22.30 ± 1.97 Hz ($p<0.05$) after the 12 week session, while it decreased non-significantly from 22.45 ± 0.99 to 22.38 ± 2.74 Hz in the no-exercise group. The F4 TASK measure in the exercise group increased significantly from 20.93 ± 1.52 to 22.19 ± 1.14 Hz ($p<0.05$) after the 12 week session. In the no-exercise group, the F4 TASK measure increased significantly from 21.10 ± 1.37 to 23.03 ± 2.80 ($p<0.05$).

A statistically significant difference was found in the F3 TASK measures between the two groups ($p<0.05$). However, no significant differences were found in the F3 EC, F3 EO, F4 EC, F4 EO, and F4 TASK measures between the two groups after the 12 week session.

***Table 3.*** *Changes in electroencephalography (β-wave) at baseline and after 12 weeks.*

| | | | Pre | Post |
|---|---|---|---|---|
| F3 | EC (Hz) | CEG | 18.22 ± 0.63 | 19.01 ± 1.41 |
| | | NEG | 19.94 ± 2.50 | 18.90 ± 0.60 |
| | EO (Hz) | CEG | 19.91 ± 1.93 | 21.58 ± 2.60 |
| | | NEG | 20.63 ± 2.86 | 21.21 ± 1.41 |
| | TASK (Hz) | CEG | 20.47 ± 2.36 | 25.44 ± 4.46*# |

| | | | | |
|---|---|---|---|---|
| | | NEG | 19.77 ± 2.13 | 20.06 ± 2.30 |
| F4 | EC (Hz) | CEG | 18.69 ± 0.50 | 18.93 ± 0.66 |
| | | NEG | 20.43 ± 2.00 | 19.63 ± 2.18 |
| | EO (Hz) | CEG | 20.67 ± 1.73 | 22.30 ± 1.97* |
| | | NEG | 22.45 ± 0.99 | 22.38 ± 2.74 |
| | TASK | CEG | 20.93 ± 1.52 | 22.19 ± 1.14* |
| | | NEG | 21.10 ± 1.37 | 23.03 ± 2.80* |

Values are M ± SD. CEG: Combined Exercise Group; NEG: Non Exercise Group. Significantly different from the baseline value in the same group (Paired t-test; *p<0.05, **p<0.01). Significantly different from the between group (unpaired t-test, #p<0.05).

The analyses of the changes in the executive function of the frontal lobe, both within and between the groups, are shown in Table 4. The Color-Word Scores of the exercise group increased significantly from 43.50 ± 6.98 to 54.17 ± 5.38 s after the 12 week session (p<0.01). The scores of the no-exercise group also increased significantly from 41.00 ± 5.97 to 50.50 ± 3.15 s (p<0.05). The Interference Score of the exercise group increased from 46.17 ± 10.32 to 48.00 ± 5.44 s after the 12 week session. The score decreased from 55.33 ± 14.60 to 43.33 ± 12.24 s in the no-exercise group. However, the changes were not statistically significant in either group. No statistically significant differences were found between the groups for the Color-Word Score or Interference Score, which were used to measure the executive function of the frontal lobe.

***Table 4.*** *Changes in stroop at baseline and after 12 weeks.*

| | | Pre | Post |
|---|---|---|---|
| Color-Word (sec) | CEG | 43.50 ± 6.98 | 54.17 ± 5.38** |
| | NEG | 41.00 ± 5.97 | 50.50 ± 3.15* |
| Interference Score (sec) | CEG | 46.17 ± 10.32 | 48.00 ± 5.44 |
| | NEG | 55.33 ± 14.60 | 43.33 ± 12.24 |

Values are M ± SD. CEG: Combined Exercise Group, NEG: Non Exercise Group. Significantly different from the baseline value in the same group (Paired t-test; *p<0.05, **p<.01). Significantly different from the between group (unpaired t-test, #p<0.05).

## Discussion

EEG recordings can be categorized into α, β, θ, and δ waves. The α and β waves are associated with attention. The α waves straddle between sleep and activity. In addition, they are the brain waves present during relaxation, and they are strongly associated with anxiety and stressful situations. The β-waves are associated with a heightened state of alertness and active thinking, such as states of conscious effort, attention, and focused attention [12]. Alba examined β-wave EEG biofeedback in order to study children's perception and learning [12]. Hillard verified the effectiveness of an attention-strengthening program through β-waves. Becker investigated sedation and relaxation in hyperactive children through α-waves. Thus, EEG has been used in various brain-activity studies. Because diminished β-waves are associated with attention deficits, EEG biofeedback with β-waves has started to garner attention [11,13].

In the present study, the exercise group showed a significant increase in β waves in the F3 TASK, F4 TASK, and F4 EO conditions. The control group showed a significant increase in β waves in the F4 TASK condition. After 12 weeks, a significant difference was found in the F3-TASK β waves between the groups. Huh reported that attention improved significantly in 17 3rd and 5th graders who participated in a 12 week Taekwondo and Kendo program (60 min per day, 3 times per week, for 12 weeks) [14]. Lee reported that therapeutic climbing activities while wearing a weighted vest had positive effects on the brain waves and attention span of a child with ADHD [15]. These results are consistent with the present findings. In the present study, TASK increased in both the left and right brains of the children who participated in the exercise program. This could have been due to the jump rope and ball exercises, which encouraged unilateral use of the body, promoted growth of the corpus callosum, and integrated the development of the brain hemispheres. In addition, repeatedly practicing stretching, balancing, and jumping over the rope, which requires focus, could have contributed to the improved brain activity.

The TASK of the control group also increased significantly, but not as much as in the exercise group. This could have been due to medication. The participating children were on methylphenidate, which is a stimulant of the central nervous system and which has a chemical structure that is similar to catecholamine, which activates neurotransmitters. Considering that methylphenidate is known to increase brain arousal, activity level, and central nervous system sensitivity [16], it could have helped the brain activation. The above findings suggest that the effectiveness of medication that can alleviate the symptoms of ADHD to a certain degree can be increased if combined with exercise.

Low color-word scores and interference scores on the Stroop test are characteristic of children with ADHD [17]. Barkley reported that children with ADHD exhibit serious behavioral problems that are a result of damage to the frontal lobe, which also negatively affects their learning [18]. The color-word scores in this study improved significantly in both groups, but no difference was observed between the groups. In the beginning of the study, both groups had T scores that were just above 40 points, which is regarded as marginal. However, the groups exhibited T scores that were above 50 points after the 12 week period, which indicated a significant improvement. The children in the current study were recruited immediately after they were diagnosed with ADHD. All of them were put on a methylphenidate regimen. Therefore, the ADHD symptoms might have been alleviated to a degree in the control group as well, which was evidenced by the increased color-word score.

However, the greater improvement in the exercise group supports the results of a study by the MTA Cooperative Group that reported that, in addition to medication, behavioral and psychological interventions are required to achieve more significant improvements [19]. Our findings also indicated that the executive function of the frontal lobe, which is related to self-regulation, was improved by exercise. Given that the EEG and executive function measures improved significantly in the exercise group, the various movements in the combination and regular exercises could have had positive psychological and physiological impacts on the children with ADHD. Combination exercise could be an effective intervention that increases the executive function of the frontal lobe, which subsequently improves the reaction time and self-regulation in children with ADHD. Therefore, combination exercises are expected to help achieve positive results in terms of the behavior and academic performances of children with ADHD [20].

Nonetheless, rather than merely regarding the various behavioral and cognitive symptoms of ADHD as structural and functional deficiencies of frontal lobe-basal ganglia development, a broader view will be beneficial in future studies examining the correlations between various neural networks responsible for higher cognitive functions.

In conclusion, the 12 week combination exercise program (jump rope and ball exercises) used in the current study had positive effects on the EEG and frontal lobe executive function measures in children with ADHD. Based on these findings, we suggest that combination exercise is an effective intervention for improving the symptoms of ADHD in children.

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