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A Preliminary Examination of Aerobic Exercise Effects on Resting EEG in Children With ADHD

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Abstract

Objective: This study attempted to determine whether the effects of physical exercise were reflected in the resting electroencephalographic (EEG) pattern of ADHD children. **Method:** Thirty-two ADHD children were assigned to either an exercise group or a control group. The exercise group participated in a water aerobics program for 8 weeks, whereas no intervention was administered to the control group. Resting EEGs were recorded under open-eyes condition before and after the intervention. Data from eligible participants, 15 from the exercise group (11 boys and 4 girls, 7.93 ± 1.02 years) and 14 from the control group (14 boys, 8.27 ± 1.04 years), were further analyzed. **Results:** While controlling for the baseline resting EEG, separate ANCOVAs indicated that the exercise group showed smaller theta/alpha ratios over the frontal and central brain sites after the intervention compared with the control group. **Conclusion:** This finding suggests that aerobic exercise may enhance the cognitive functions of children with ADHD, as reflected in resting EEG. *(J. of Att. Dis. XXXX; XX(X) XX-XX)*

Keywords

cognitive benefits, inhibition, physical exercise, fitness, EEG ratios

ADHD is a pervasive developmental disorder that is characterized by inappropriate levels of inattention, impulsivity, and hyperactivity. The disorder-related syndromes can also have severe consequences in individual, social, and familial aspects due to the serious financial, psychological, and academic impact on children with ADHD and their families (Biederman, 2005). Although stimulant medication is an easy intervention to improve functioning in children with ADHD, parents may prefer not to implement medication as a treatment because of documented side-effects such as sleep disturbances, reduced appetite, mood disorders, and reduced growth rate (Stockl, Hughes, Jarrar, Secnik, & Perwien, 2003; Swanson et al., 2006). It is crucial to seek an economical and low-risk treatment for ADHD symptoms.

The underlying neurobiological mechanisms of ADHD are considered complex (Curatolo, Paloscia, D'Agati, Moavero, & Pasini, 2009), but electroencephalographic (EEG) studies have revealed that increased slow-wave activity (e.g., the theta band) and decreased fast-wave activity (e.g., the alpha and beta bands), as well as elevated resting theta/alpha and theta/beta power ratios were commonly observed in ADHD children (Lansbergen, Arns, van Dongen-Boomsma, Spronk, & Buitelaar, 2011; Snyder & Hall, 2006). These abnormal EEG characteristics are proposed to be associated with compromised inhibitory ability and cortical hypoarousal (Kinsbourne, 1973; Schutter, Leitner, Kenemans, & van Honk, 2006), which may result from abnormal frontostriatal network (Emond, Joyal, & Poissant, 2009), delayed brain maturation (Shaw et al., 2006), and dysfunctional neurotransmitter systems (Pliszka, 2005). Although some studies have criticized the validity of these resting EEG parameters as diagnostic markers for ADHD symptoms (Ogrim, Kropotov, & Hestad, 2012), meta-analytic reviews have reported medium to large effect sizes for utilizing these resting EEGs to differentiate ADHD individuals from normal counterparts (Arns, Conners, & Kraemer, 2013).

Given that deficits in neurotransmitter systems and neural networking could be mechanisms underlying ADHD pathology and abnormal resting EEGs could be the

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manifestation of ADHD symptoms, it is expected that physical activity would ameliorate deviant brain oscillations via positive changes in cognitive and neural functioning. Previous studies have shown the promising effect of aerobic exercise on cognitive functions through increasing the circulation of neurochemicals, brain-derived neurotrophic factor, and growth factors (Voss, Nagamatsu, Liu-Ambrose, & Kramer, 2011), as well as changes in patterns of functional activation (Colcombe et al., 2004). Also, chronic aerobic exercise may serve to enhance intelligence, cognition, and academic achievement in normal children (Tomporowski, Davis, Miller, & Naglieri, 2008). Similar findings were found in children with ADHD. Several studies have reported that physical activity amount (Gapin & Etnier, 2010) and chronic physical exercise interventions (Smith et al., 2013; Verret, Guay, Berthiaume, Gardiner, & Béliveau, 2012) may positively affect the behavioral symptoms, cognitive performance, and executive function of children with ADHD. Furthermore, researchers have suggested that physical exercise shows promise as an effective treatment for improving long-term cognitive and functional outcomes of ADHD individuals (Archer & Kostrzewa, 2012; Halperin & Healey, 2011). A recent study has indicated that physical fitness, particularly power fitness, was associated with better attentional self-control as reflected by the resting EEG theta/alpha ratio in children with ADHD (Huang, Huang, Hung, Shih, & Hung, in press). Based on these findings, physical exercise can provide beneficial effects on behavioral and cognitive functions of individuals with ADHD.

Although these findings provide convergent evidence for the positive effect of physical activity on cognitive function of individuals with ADHD, little research has been conducted to explore the association between physical activity and resting EEG. Given that EEG recording is a sensitive measure of baseline brain states and resting EEG patterns are indicators distinguishing ADHD individuals from healthy participants, observed changes in resting EEG after physical activity intervention can further determine the effect of physical activity on cognitive function of ADHD. This study applied water aerobics exercise as an intervention to participants because it enhances physical fitness through providing full-body resistance with minimal joint stress (Piotrowska-Całka, 2010). The purpose of the present study was to examine the effect of water aerobics exercise on resting EEGs in children with ADHD.

Method

Participants

Thirty-two children from two elementary schools, aged 5 to 10 years, were referred by school health centers to participate in this study. Recruitment criteria were as follows: (a) diagnosis of ADHD by their own pediatricians according to the *Diagnostic and Statistical Manual of Mental Disorders* (4th ed.; *DSM-IV*; American Psychiatric Association [APA], 1994) criteria, (b) right-hand dominant, and (c) the absence of neurological disorders, autism spectrum, and serious affective disorders. All children were assigned to either the exercise group (n = 16) or the control group (n = 16) according to their school districts. To identify the severity of ADHD symptoms for each group, parent and teacher ratings on the Disruptive Behavior Disorders (DBD) Rating Scale (Pelham, Gnagy, Greenslade, & Milich, 1992) were utilized. The DBD Rating Scale is a checklist to evaluate the *DSM-IV* symptoms of ADHD, oppositional defiant disorder, and conduct disorder; however, only ADHD symptoms were used for the purposes of this study. The average number of inattentive and hyperactive/impulsivity symptoms for the exercise group was 6.2 (SD = 1.3) and 5.7 (SD = 1.5), respectively. For the control group, the mean number of inattentive and hyperactive/impulsivity symptoms was 6.4 (SD = 1.2) and 5.8 (SD = 1.4). Written informed consent was provided by the parents and the children following a full explanation of the study in accordance with the Institutional Review Board of the university. For the final analysis, one participant from the exercise group and two participants from the control group who were absent more than four sessions during the aquatic exercise programs or whose EEG data were contaminated by noise were excluded (Table 1).

Table 1. Mean (*SD*) Demographic Data According to Group.

	Exercise (n = 15)	Control (n = 14)
Gender (boy:girl)	11:4	14:0
Age (years)	7.93 (1.02)	8.27 (1.04)
BMI (kg/m^2)	17.54 (3.00)	16.72 (2.09)
ADHD type		
ADHD-I	4	3
ADHD-HI	2	1
ADHD-C	9	10
Treatment		
Medication	7	6
Behavior	3	1
None	5	7

Note. BMI = body mass index; ADHD-I = predominantly inattentive subtype; ADHD-HI = predominantly hyperactive-impulsive subtype; ADHD-C = combined hyperactive-impulsive and inattentive subtype.

Water Aerobics Intervention

The exercise group participated in a water aerobics class twice a week for 8 weeks at a swimming pool. Each class was led by the same instructor and lasted 90 min. Each water aerobics session consisted of four stages: (a) a 5-min stretching and warm-up; (b) a 40-min aerobic exercise at

50% to 60% of maximum heart rate; (c) a 40-min perceptual-motor water exercise, including coordination, balance, and power to reinforce different aspects of motor skills; and (d) a 5-min cool-down period. During the aerobic exercise, heart rate was monitored by a monitoring device to ensure that the prescribed intensity was maintained. The records showed a significant increase in heart rate during the period of aerobic exercise (125.4 ± 10.3 bpm [beats/min]), compared with the resting period (78.1 ± 5.1 bpm), $t(14) = 32.22$, $p < .01$. In contrast, the control group was instructed to refrain from vigorous physical activity and participation in any regular exercise programs.

Electrophysiological Recording

The continuous EEG data were recorded from nine electrode sites (frontal: F3, F4, Fz; central: C3, C4, Cz; parietal: P3, P4, Pz) using a NeuroScan Quik-Cap in accordance with the standards of the International 10-20 system. The ground electrode was placed on the middle forehead, and all electrodes were referenced to linked ears. Vertical electrooculogram (VEOG) was collected from electrodes attached above and below the left eye and the horizontal electrooculogram (HEOG) from the outer canthus of each eye. Electrode impedance was kept below 10 kΩ. EEG and EOG were amplified with a bandwidth of DC-to-100 Hz. The sampling rate was 500 Hz. In addition, a 60-Hz notch filter was utilized during the data acquisition. Prior to data processing, EEG data were filtered using a band-pass cutoff of 1 to 30 Hz (12 dB/octave) and EOG corrected by an algorithm (Semlitsch, Anderer, Schuster, & Presslich, 1986). The continuous EEG data were segmented into 2-s epochs. After a baseline correction and visual inspection for artifact, the cleaned EEG data were Fast Fourier transformed and subsequently ln-transformed. Mean power estimates were calculated using fixed frequency bands (4-7.5 Hz for theta, 8-13 Hz for alpha, 13.5-25 Hz for beta). Electrodes from the same areas were combined to derive the average power values. Furthermore, the ratio coefficients of theta/alpha and theta/beta at each cortical site were computed.

Procedure

For participants of the exercise group, resting EEG was collected before and after the 8-week water aerobic program. Similarly, resting EEG of the control group was recorded before and after the same time interval. Participants were instructed to refrain from medications and caffeine intake at least 24 hr prior to the EEG collections. Participants seated quietly in a comfortable chair with eyes open and fixated upon a cross on the wall, while EEG was collected in a sound-attenuated testing room. EEG data were collected for six sessions, 30 s per session. The procedures of the first and second resting EEG collections were parallel.

Statistical Analysis

Several independent-samples *t* tests and chi-square tests were used to compare the demographic variables between the exercise and the control groups where appropriate. Furthermore, the ANCOVA was applied to compare the difference in each posttest EEG parameters between the groups by using the pretest EEG as the covariate. Multiple comparisons with Bonferroni–Holm adjustments were used to control for experiment-associated inflation of Type 1 error for small sample sizes. The criterion of statistical significance was set as .05 prior to the adjustment.

Results

Demographic Analyses

Independent *t* tests confirmed that there were no differences in age, $t(27) = -0.89$, $p = .38$, and body mass index, $t(27) = 0.84$, $p = .41$, between the groups. Similarly, the chi-square tests revealed no group differences with respect to ADHD type ($p = .78$) and treatment ($p = .50$), except for gender distribution ($p = .04$).

Posttest EEGs

As shown in Table 2, the ANCOVA revealed that the exercise group exhibited smaller theta/alpha ratios in the frontal site, $M_{\text{exercise adj.}} = 1.17$, $M_{\text{control adj.}} = 1.34$; $F(1, 26) = 9.47$, $p = .005$, $\eta^2 = .27$;, and in the central site, $M_{\text{exercise adj.}} = 0.98$, $M_{\text{control adj.}} = 1.09$; $F(1, 26) = 4.44$, $p = .045$, $\eta^2 = .15$, compared with the control group. No significant group differences were observed for other comparisons, $F(1, 26) = 0.07\text{-}1.04$, $p = .318\text{-}.799$.

Discussion

The exercise group revealed smaller theta/alpha ratios in both the frontal and central brain areas as compared with the control group, indicating the possibility for aerobic exercise to alleviate cognitive deficiencies commonly observed in children with ADHD. A larger theta/alpha ratio has been interpreted from two perspectives: Low power in fast oscillations is associated with reduced executive functioning and self-control underlying the hypoarousal model of ADHD (Rowe et al., 2005), whereas high power in slow oscillations is related to a maturational delay reflected in diminished inhibition of subcortical drives and impulses (Schutter et al., 2006). Previous research has reported that physical activity intervention is beneficial to the cognitive function of ADHD children, particularly with respect to executive tasks requiring inhibitory control (Smith et al., 2013). Several studies have indicated that children with ADHD exhibit higher response accuracy and better stimulus-related processing according to readings taken after a

Table 2. Mean (*SD*) Resting EEG Power and Ratios Between the Exercise and Control ADHD Groups.

	Exercise				Control			
Measure	Pretest		Posttest		Pretest		Posttest	
Frontal								
Theta power (Ln μV)	2.12	(0.37)	2.04	(0.32)	2.41	(0.42)	2.38	(0.46)
Theta/alpha ratio	1.37	(0.21)	1.23	(0.18)	1.24	(0.27)	1.23	(0.18)
Theta/beta ratio	−11.17	(47.15)	−2.39	(23.64)	5.82	(25.43)	−1.52	(11.51)
Central								
Theta power (Ln μV)	2.18	(0.36)	2.17	(0.33)	2.45	(0.49)	2.36	(0.50)
Theta/alpha ratio	1.20	(0.21)	1.04	(0.15)	1.04	(0.17)	1.02	(0.22)
Theta/beta ratio	−0.04	(23.43)	0.86	(13.74)	4.28	(15.46)	−0.66	(7.63)
Parietal								
Theta power (Ln μV)	2.16	(0.38)	2.22	(0.36)	2.47	(0.65)	2.36	(0.57)
Theta/alpha ratio	1.39	(0.13)	1.33	(0.12)	1.26	(0.14)	1.27	(0.13)
Theta/beta ratio	−3.15	(18.50)	8.62	(52.88)	−3.15	(18.50)	20.60	(77.11)

Note. EEG = electroencephalographic.

single bout of exercise as compared with those taken after seated readings (Pontifex, Saliba, Raine, Picchietti, & Hillman, 2013), and boys with ADHD showed increased spontaneous blink rate and decreased motor impersistence after vigorous exercise (Tantillo, Kesick, Hynd, & Dishman, 2002). From a study using spontaneously hypertensive rats, commonly used as an animal model for ADHD, chronic exercise was facilitative in inhibiting the developmental rise of blood pressure in terms of increasing glutamic acid decarboxylase mRNA in the caudal hypothalamus (Little, Kramer, Beatty, & Waldrop, 2001). These findings suggest that the benefits of physical exercise on inhibitory function may generate from efficient allocation of attentional resources and enhanced expression of neurochemical substances.

Furthermore, the smaller resting theta/alpha ratio observed in the exercise group could be mostly driven by increased alpha power because no significant group difference was found in theta power, while the exercise group demonstrated larger alpha power in the frontal, $M_{\text{exercise adj.}} = 1.95$, $M_{\text{control adj.}} = 1.71$; $F(1, 26) = 5.56$, $p = .026$, $\eta^2 = .18$, and central sites, $M_{\text{exercise adj.}} = 2.36$, $M_{\text{control adj.}} = 2.12$; $F(1, 26) = 5.06$, $p = .033$, $\eta^2 = .16$, compared with the control group. Lower resting alpha observed in ADHD individuals has been proposed to relate to problems in attentional self-control (Woltering, Jung, Liu, & Tannock, 2012). These individuals may over-activate their neural circuit for processing external stimuli during a relaxing state, which may be associated with a lack of inhibition over sensory input (Rowe et al., 2005). Importantly, physical activity is found to improve executive function via improving the allocation of attentional resources during information processing. For example, ADHD children with greater motor ability exhibited better allocation of attentional resources and faster cognitive processing speed when performing an inhibitory task, compared with those with lower motor ability (Hung et al., 2013). Verret et al. (2012) indicated that ADHD children who participated in a 10-week physical activity program demonstrated faster speeds of visual research and better sustained auditory attention than their control counterparts. Moreover, Huang et al. (in press) observed a smaller resting theta/alpha ratio from ADHD children with better power fitness, suggesting that physical fitness may be associated with normalizing their arousal and inhibitory systems. By using the sample of healthy children, increased inhibitory responses were observed from behavioral performance and neuroelectrical indices after an 8-week coordinative exercise program (Chang, Tsai, Chen, & Hung, 2013).

In conclusion, our finding can add to the knowledge on the association between aerobic exercise and cognitive ability of children with ADHD as reflected in baseline cortical activity. Such evidence emphasizes the importance of utilizing aerobic exercise as a potential intervention to ameliorate the cognitive deficits in ADHD children. However, the nature of a quasi-experimental design, a relatively small sample size, and an unbalanced gender proportion are some limitations of the present study and therefore replications are needed. Furthermore, although the possibility is low, we could not completely rule out the possibility that the observed effect was a result of less attention paid to the control group. Future researchers are also recommended to explore the relationship between the reduction in theta/alpha ratio and ADHD symptoms to advance understanding of aerobic exercise effects on the cognitive function of ADHD children. Nevertheless, the findings of improved resting EEG in the exercise group after controlling for differences in preintervention EEG lend some support to the present study.

Declaration of Conflicting Interests

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