Exercise Improves Behavioral, Neurocognitive, and Scholastic Performance in Children with Attention-Deficit/Hyperactivity Disorder

Matthew B. Pontifex, PhD[1], Brian J. Saliba, BS[1], Lauren B. Raine, BS[1], Daniel L. Picchietti, MD[1,2], and Charles H. Hillman, PhD[1]

Objective To examine the effect of a single bout of moderate-intensity aerobic exercise on preadolescent children with attention-deficit/hyperactivity disorder (ADHD) using objective measures of attention, brain neurophysiology, and academic performance.

Study design Using a within-participants design, task performance and event-related brain potentials were assessed while participants performed an attentional-control task following a bout of exercise or seated reading during 2 separate, counterbalanced sessions.

Results Following a single 20-minute bout of exercise, both children with ADHD and healthy match control children exhibited greater response accuracy and stimulus-related processing, with the children with ADHD also exhibiting selective enhancements in regulatory processes, compared with after a similar duration of seated reading. In addition, greater performance in the areas of reading and arithmetic were observed following exercise in both groups.

Conclusion These findings indicate that single bouts of moderately intense aerobic exercise may have positive implications for aspects of neurocognitive function and inhibitory control in children with ADHD. *(J Pediatr 2013;162:543-51)*.

Attention-deficit/hyperactivity disorder (ADHD) affects more than 2.5 million school-aged children in the US.[1-3] ADHD is characterized by developmentally inappropriate levels of inattention, overactivity, distractibility, and impulsiveness, which manifest during childhood.[1,4,5] Research suggests that failures in inhibitory control, as well as the neural processes subserving inhibitory control, may represent the core cognitive deficit underlying the manifestation of ADHD.[6] Specifically, a growing body of research has suggested that ADHD-related deficits in inhibitory control are associated with failures in the cascade of processes underlying the stimulus–response relationship, including reductions in the allocation of attentional resources, delays in the speed at which stimuli are processed, and failures to appropriately implement action monitoring processes as assessed using neuroelectric measures.[7-16] Although pharmacologic treatments have largely proven effective in managing ADHD symptoms,[17] potential adverse effects, high costs, and incomplete responses argue for other treatments for children with ADHD.[18,19]

Reports from parents, teachers, and scholars have suggested that one such treatment option may be single bouts of short-duration, moderate-intensity aerobic exercise.[20-22] Despite some recent findings by Medina et al[23] suggesting that single bouts of exercise may facilitate reaction time (RT)-based measures of attentional vigilance, there is a paucity of empirically sound evidence in children with ADHD to support such claims. The vast majority of support for these assertions is drawn from previous research in healthy children, suggesting that participation in a single bout of structured physical activities lasting at least 20 minutes is beneficial for various cognitive functions, including aspects of concentration,[24-26] brief tests of reading and mathematics achievement,[27,28] and inhibitory control.[28] The effects of single bouts of exercise also appear to mirror the neurocognitive deficits associated with ADHD, such that a single bout of moderate-intensity aerobic exercise serves to increase the allocation of attentional resources, and facilitates stimulus classification and processing speed, with a disproportionately larger effect for task conditions with the greatest inhibitory control demands.[29-32] Accordingly, given the striking similarity between the aspects of cognition that are influenced by acute exercise and those that exhibit ADHD-related deficits, the purpose of this study was to examine the effect of a single bout of aerobic exercise on the modulation of inhibitory control deficits in children with ADHD using objective measures of behavioral inhibition, neurocognitive function, and scholastic performance. It was hypothesized that children with ADHD would experience similar benefits from acute exercise as those experienced by children without ADHD,[28] with greater response execution, attentional allocation, and scholastic achievement being observed after a bout of moderate-intensity exercise.

ADHD	Attention-deficit/hyperactivity disorder
ERN	Error-related negativity
ERP	Event-related brain potential
RT	Reaction time
WRAT3	Wide Range Achievement Test, 3rd edition

From the [1]Department of Kinesiology and Community Health, University of Illinois at Urbana-Champaign; and [2]Department of Pediatrics, Carle Foundation Hospital, Urbana, IL

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Methods

The ADHD group comprised 20 children (6 females) aged 8-10 years recruited from the east-central Illinois area based on suspected or diagnosed ADHD free of any comorbid conditions (Table I). The term "suspected ADHD" refers to children whose parents, school staff, or primary care provider expressed suspicion of ADHD but for whom no diagnostic assessment had been sought from a developmental specialist.[33] Clinical status was verified through the ADHD supplement of the Kiddie Schedule for Affective Disorders and Schizophrenia, Present and Lifetime Version semistructured diagnostic interview using *Diagnostic and Statistical Manual of Mental Disorders,* Fourth Edition, Text Revision criteria for any subtype of ADHD, including evidence for impairment in 2 or more settings and onset of symptoms before age 7 years.[1] Children with ADHD were screened to ensure that they currently exhibited ongoing ADHD symptoms using the ADHD Rating Scale IV.[34] Healthy match control children were yoked by sex, age, pubertal status, and socioeconomic status, with no significant differences observed between the groups [t (38) $\leq$ 1.6; $P \geq .12$ for all]. All participants had normal or corrected-to-normal vision and were free of any central nervous system active drug therapy for at least 1 month before testing. All participants were screened for comorbid conditions, including autism spectrum disorders, using the Social Communication Questionnaire,[35] and for anxiety, conduct, somatic, and affective disorders (including depressive and bipolar disorders) using the *Diagnostic and Statistical Manual*–oriented scores of the Child Behavioral Checklist.[36] All participants provided written assent, and their legal guardians provided written informed consent in accordance with the Institutional Review Boards of the University of Illinois at Urbana-Champaign and Carle Foundation Hospital.

Inhibitory Control Task

Participants completed a modified version of the Eriksen flanker task[9,37] to assess inhibitory aspects of cognitive control. This paradigm is conceptually simplistic in that it requires the discrimination of a centrally presented target stimulus amid lateral flanking stimuli. In this task, participants were required to make a left-hand thumb press on a Neuroscan STIM system switch response pad (Compumedics, Charlotte, North Carolina) when the target stimulus pointed left and a right-hand thumb press when the target stimulus pointed right. Thus, participants were instructed to respond as accurately as possible to the direction of a centrally presented target fish amid either congruous (target facing the same direction) or incongruous (target facing the opposite direction) flanking goldfish. The task also manipulated stimulus–response compatibility to vary cognitive control requirements by instructing participants first to complete a compatible condition (described above), and then complete an incompatible condition in which they were instructed to respond in the direction opposite that of the centrally presented target arrow (ie, when the target fish pointed left, the correct response was to the right, and vice versa[38]). For each compatibility condition, 2 blocks of 100 trials were presented with equiprobable congruency and directionality. The stimuli were 3-cm-tall yellow fish, which were presented focally for 200 ms on a blue background, with a fixed interstimulus interval of 1700 ms. This task allows for the assessment of a number of variables, including median RT (to better represent the central response tendency of children with ADHD[39-41]) and response accuracy. Furthermore, the trial-by-trial nature of the task allows for assessment of median RT for correct trials immediately following an error (n + 1, termed posterror median RT), which provides a behavioral indicator of the increased recruitment and implementation of top-down control,[42,43] as well as for correct trials following a match correct trial (a subset of correct trials matched to specific error trials based on RT).[44]

Table I. Participant demographic and clinical characteristics (±1 SE)

Measure	ADHD subtype			Healthy match control	*P* value*
	ADHD-C	ADHD-I	ADHD-H		
Number	6 (2 females)	11 (3 females)	3 (1 female)	20 (6 females)	
Age, years	9.3 ± 0.3	9.5 ± 0.3	9.6 ± 0.9	9.8 ± 0.1	.13
Tanner stage	1.5 ± 0.1	1.5 ± 0.2	1.0 ± 0.0	1.4 ± 0.1	.86
Kaufman Brief Intelligence Test composite (IQ)	111.7 ± 4.6	110.2 ± 4.0	121.3 ± 2.7	118.7 ± 2.9	.12
Socioeconomic status	2.5 ± 0.3	2.0 ± 0.3	3.0 ± 0.0	2.3 ± 0.2	.99
Body mass index, kg/m^2	16.7 ± 0.6	18.5 ± 0.9	14.1 ± 0.3	20.0 ± 1.2	.06
K-SADS-PL inattentive symptoms	7.3 ± 0.3†	7.0 ± 0.3†	3.7 ± 1.3	-	-
K-SADS-PL impulsive/hyperactive symptoms	6.5 ± 0.2†	3.3 ± 0.4	8.0 ± 1.0†	-	-
ADHD-IV Composite percentile	98.2 ± 1.3†	98.2 ± 0.7†	90.0 ± 5.5†	31.3 ± 4.2	<.001
ADHD-IV Inattentive percentile	92.7 ± 4.1†	92.0 ± 2.2†	62.3 ± 12.3	36.8 ± 5.6	<.001
ADHD-IV Impulsive/Hyperactive percentile	94.5 ± 2.1†	80.5 ± 6.1	91.3 ± 0.9†	37.5 ± 5.1	<.001
DBRS Distractible subscale *t* score	66.2 ± 6.5†	64.7 ± 3.5†	49.3 ± 2.9	44.8 ± 1.2	<.001
DBRS Impulsive-Hyperactive subscale *t* score	65.5 ± 4.5†	59.8 ± 3.2	56.0 ± 6.4	44.9 ± 1.3	<.001
DBRS ODD subscale *t* score	57.0 ± 3.5	51.0 ± 3.3	47.7 ± 4.3	43.7 ± 1.0	.001
Autism spectrum disorder score	7.0 ± 1.1	4.6 ± 1.0	7.3 ± 0.9	3.5 ± 0.8	.04

DBRS, Disruptive Behavior Rating Scale; *K-SADS-PL*, Kiddie Schedule for Affective Disorders and Schizophrenia-Present and Lifetime Version; *ODD*, oppositional defiance disorder.
ADHD subtype was based on K-SADS-PL diagnostic interview classification.
*Analysis was conducted between the participants with ADHD and the healthy match control group.
†Denotes clinically significant values for each severity scale. Percentiles ≥90 on the ADHD-IV rating scale indicate high likelihood for the presence of ADHD. *t* scores <60 on the DBRS are considered normal behavioral ratings. Children with ADHD scoring high on the ODD subscale of the DBRS were retained, given the high comorbidity between ADHD and ODD.[83] An autism spectrum disorder score <15 indicates the absence of autism spectrum disorders.