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A Randomized Trial Examining the Effects of Aerobic Physical Activity on Attention-Deficit/Hyperactivity Disorder Symptoms in Young Children

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Abstract

The goal of this study was to compare the effects of before school physical activity (PA) and sedentary classroom-based (SC) interventions on the symptoms, behavior, moodiness and peer functioning of young children (M_{age} = 6.83) at risk for attention-deficit/hyperactivity disorder (ADHD-risk; n = 94) and typically developing children (TD; n = 108). Children were randomly assigned to either PA or SC and participated in the assigned intervention 31 minutes per day, each school day, over the course of 12 weeks. Parent and teacher ratings of ADHD symptoms (inattention, hyperactivity/impulsivity), oppositional behavior, moodiness, behavior toward peers, and reputation with peers, were used as dependent variables. Primary analyses indicate that the PA intervention was more effective than the SC intervention at reducing inattention and moodiness in the home context. Less conservative follow-up analyses within ADHD status and intervention

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groups suggest that a PA intervention may reduce impairment associated with ADHD-risk in both home and school domains; interpretive caution is warranted, however, given the liberal approach to these analyses. Unexpectedly, these findings also indicate the potential utility of a before school SC intervention as a tool for managing ADHD symptoms. Inclusion of a no treatment control group in future studies will enable further understanding of PA as an alternative management strategy for ADHD symptoms.

Keywords

Physical activity; ADHD; behavior; peer; mood; young children; aerobic

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Attention-Deficit/Hyperactivity Disorder (ADHD) is a chronic neurodevelopmental disorder. It is characterized by symptoms of inattention and hyperactivity/impulsivity and is linked to impairment in multiple domains (i.e., home, school, peer functioning; American Psychiatric Association, 2013). Few evidence-based options are available to families for treating childhood ADHD other than psychotropic medications (primarily stimulants) and labor-intensive behavioral interventions. Stimulant medications are not without risk, however, and are simply unacceptable to some families (Halperin & Healey, 2011), particularly for use with young children (Wigal et al., 2006). Similarly, behavioral interventions are viewed as overly burdensome by some parents and teachers, and are costly to implement in terms of training and effort for ongoing management (Benner-Davis & Heaton, 2007). Further, neither of these interventions completely normalizes the gamut of attentional, behavioral, and social deficits that characterize ADHD (Hoza et al., 2005; Swanson et al., 2001). Even when implemented effectively, these evidenced-based interventions have limited maintenance of effects (Jensen et al., 2007), with symptoms typically returning in the months following treatment.

An accumulating body of data suggests that ADHD is a chronic disorder that persists into adolescence and adulthood in a majority of cases (Barkley, Fischer, Smallish & Fletcher, 2002; Biederman, Petty, Clarke, Lomedico, & Faraone, 2011; Hechtman, 1991; Hinshaw et al., 2012). This life-long conceptualization of the disorder necessitates a shift in focus from acute to chronic management in a manner similar to chronic medical disorders such as diabetes or arthritis. Lifestyle changes with the potential to successfully manage ADHD over the long term, beginning at an early age and continuing across the life span, may be critically important to positive outcomes for individuals with the disorder. In addition, early intervention strategies targeting at-risk individuals with subthreshold levels of symptoms may serve as a useful tool to delay or prevent onset of full-blown disorder in those at risk for ADHD. In sum, there is a need for novel, alternative strategies that families, schools, and individuals can use to manage the disorder over a long period of time.

The idea that physical activity (PA) could be utilized to manage the broad spectrum of symptoms and impairments that characterize ADHD is both innovative and exciting. Physical activity is "any bodily movement produced by skeletal muscles that results in energy expenditure" (Caspersen, Powell, & Christenson, 1985, p. 126); it encompasses various forms such as deliberate exercise, sport, play, and active transport. Aerobic PA in the moderate-to-vigorous range of intensity (i.e., intensive enough to make one breathe hard and requiring at least the effort necessary for brisk walking) is often spontaneously displayed by young children in an array of naturally occurring play activities (e.g., tagging or chasing games) and has various potential health benefits for children (see Marshall & Welk, 2008; Stensel, Gorely, & Biddle, 2008). Thus, creating a structured intervention that capitalizes on inherently engaging and enjoyable activities to reduce dysfunction and promote health is an appealing possibility.

The exact mechanism by which PA might ameliorate symptoms of ADHD is not definitively known. Prominent hypotheses developed through animal work and research with other populations who experience cognitive challenges (e.g., the elderly) focus on structural and functional brain changes. Specifically, PA may benefit cognitive function through improved oxygenation and blood flow in the brain, promotion of cerebral capillary growth, increase in neurotransmitter levels (e.g., serotonin, norepinephrine), production of neurotrophins (e.g., BDNF) that promote neural plasticity, and increases in brain tissue volume (for reviews, see Centers for Disease Control & Prevention, 2010; Halperin & Healey, 2011; Hillman, Erickson, & Kramer, 2008; Ploughman, 2008). Regardless of the specific mechanism, PA appears to foster brain health in ways that could offer benefits to those experiencing ADHD symptoms.

A handful of well-designed studies have examined the effects of PA on cognitive functioning in typically-developing (TD) preadolescent youth (see Berwid & Halperin, 2012; Verburgh, Königs, Scherder, & Oosterlaan, 2013, for reviews). The variability in the type of PA (acute vs. chronic) examined, age of participants studied, and restricted set of measures considered substantially constrains the ability to draw broad conclusions. Nonetheless, this small body of research supports the tentative conclusion that PA benefits cognitive function in TD children (Berwid & Halperin, 2012). It also raises the possibility that those with existing deficits in cognitive function (such as children with ADHD) may have the most to gain from a PA intervention (Diamond & Lee, 2011).

Because various functional capacities are closely intertwined, reports linking aerobic PA to improved cognitive functioning suggest that PA may be utilized to improve functional capacities in an array of domains affected by cognitive capabilities (e.g., social, emotional, behavioral). For example, it has long been argued that cognitive outcomes are closely intertwined with behavioral issues (Bass, 1985). Along these lines, early yet admittedly minimally controlled dissertation studies suggest that regular aerobic activity (e.g., running) may improve classroom disruptive behaviors such as hyperactivity (Elsom, 1981, as cited in Bass, 1985) or talking out of turn (Evans, 1981, as cited in Bass, 1985). Similarly, uncontrolled case descriptions suggest that regular aerobic activity may benefit peer relationships and allow children treated with medication for their behavioral difficulties to function effectively with lower amounts of psychotropic medication (Shipman, 1984). Importantly, TD children who are classified as physically active and/or meet age-appropriate fitness standards also are at lower risk of developing depressive symptoms than their less active/fit counterparts (Tomson, Pangrazi, Friedman, & Hutchison, 2003). Hence, improvements brought about by PA could potentially encompass a wide variety of domains influenced by cognitive capacity such as behavioral, social, and emotional functioning, all areas that are problematic for children with ADHD.

The limited existing studies of acute or chronic PA on cognitive or behavioral functioning of youth diagnosed with, or at risk for, ADHD suggest positive effects (e.g., Pontifex, Saliba, Raine, Picchietti, & Hillman, 2013; Smith et al., 2013; Verret, Guay, Berthiaume, Gardiner, & Béliveau, 2012). Pontifex and colleagues (2013) reported that an acute 20-minute PA session at moderate intensity on a motor-driven treadmill improved neurocognitive function, inhibitory control, and reading and math performance in 8 to 10 year old children with ADHD (n = 20) as well as healthy controls (n = 20). Two other studies using a slightly longer (30-minute) single session of PA reported similarly positive effects on the Conners' Continuous Performance Test II (Medina et al., 2010), and Stroop Color-Word and Wisconsin Card Sort Non-perseverative Errors and Categories Completed (Chang, Liu, Yu & Lee, 2012). A pilot study (Smith et al., 2013) examining a school-based before school physical activity program for young children (Grades K-3; n = 14) at risk for ADHD (exhibiting four or more symptoms of hyperactivity/impulsivity) showed positive effects of chronic PA. Teacher-reported improvements in inattention/overactivity and oppositional defiant behavior yielded moderate effect size values (Cohen's *d*s of .70 and .41, respectively). Similarly-sized improvements were found for an ecological measure of inhibitory control (Red Light/Green Light; *d*=.60) and daily observed frequencies of interrupting (*d* =.78; Smith et al., 2013). In another small sample study (Verret et al., 2012) comparing children diagnosed with ADHD who either did (n = 10) or did not (n = 11) participate in a thrice weekly 45-minute PA program at midday (i.e., lunchtime), beneficial effects of PA were reported. Specifically, motor performance, parent- and teacher-rated behavior, and neuropsychological tests of information processing and auditory sustained attention showed improvements (Verret et al., 2012). Collectively, these small sample preliminary studies provide evidence that PA may be a viable strategy for improving symptoms, behavior, achievement, inhibitory control, and neurocognitive function in youth with elevated ADHD symptoms. Yet, there are a number of shortcomings to these existing studies that limit their impact. The Smith et al. sample was quite small (n = 14 who completed treatment) and no control group was used. Although including a control group, the Verret et al. (2012) study did not randomly assign participants to PA and control groups. Relatedly, in this same study, there was disproportionate use of medication across the intervention and control groups (Verret et al., 2012).

With this backdrop, the main goal of the present study was to conduct a randomized trial assessing the usefulness of a before school moderate-to-vigorous PA intervention for reducing symptoms, behavioral problems, emotion dysregulation (i.e., moodiness), and peer difficulties in young children (Kindergarten, 1st, and 2nd grades) displaying high levels of ADHD symptoms, as well as TD children, compared to a sedentary classroom-based intervention. We selected children of this age because they are old enough to have significant ADHD symptoms and to be exposed to a teacher and formal elementary school setting, yet young enough to be medication naïve (Cox, Motheral, Henderson, & Mager, 2003) and at a developmental stage of relatively high brain plasticity (Li, Brehmer, Shing, Werkle-Bergner, & Lindenberger, 2006). We chose to target a medication naïve group of children to avoid potential confounds of medication in interpreting effects.

Our goal for the current study was to improve upon the limitations of the few existing studies of PA applied to children with elevated ADHD symptoms in the following ways. First, we employed a relatively large sample that provided adequate power to test within-subject intervention response across a range of measures. Second, we used random assignment of participants to chronic physically active versus sedentary conditions. Third, we utilized a wide range of outcome measures covering key domains of assessment and utilizing multiple informants. Fourth, aligned with a developmental psychopathology perspective (Cicchetti, 1993), we recruited a sample of children with and without elevated symptoms of ADHD to better understand how the hypothesized associations may vary as a function of level of risk for ADHD. Importantly, in young children, even those without documented risk for ADHD, the presence of symptoms associated with ADHD are more prevalent than with older children (DuPaul, Power, McGoey, Ikeda, & Anastopoulos, 1998), increasing the potential for a broader impact beyond the ADHD-risk group. Finally, given the persisting nature of ADHD and the need for effective long-term management strategies, we applied a chronic, 5-day per week, 12-week PA intervention to assess its potential as an ongoing management strategy for ADHD symptoms.

We examined the preliminary hypothesis that a program emphasizing chronic moderate-to-vigorous PA would reduce hyperactivity/impulsivity and inattention, and enhance behavioral, emotional, and social functioning in children more than a sedentary classroom-based program. We expected to see these effects both for children high on ADHD symptoms as well as TD children, although the effect sizes were expected to be larger for children initially high on ADHD symptoms who had greater deficits, and hence, greater room for improvement.

Method

Participants

The intervention sample consisted of 202 (54% male) early elementary school students in Kindergarten, 1st, and 2nd grades and ranging in age from 4.44 to 8.90 years (M_{age} = 6.83, SD_{age} = 0.96). Participants were racially and ethnically diverse (68.3% Caucasian, 14.4% mixed race, 7.9% African American, 2.0% Asian, and 7.4% other races). Seventy-four percent of participants had at least one parent with some post-secondary education. Children were recruited from participating schools located at study sites in two small U.S. cities.

Preliminary screening—Eligibility was determined using a two-step screening process. At Step 1, parents provided informed consent for screening, and then parents and teachers completed ratings on the ADHD-IV Rating Scale (DuPaul, 1991) on potential participants (N = 428). The ADHD-IV Rating Scale is an age- and gender-normed scale consisting of the DSM-IV symptoms of ADHD rated on a 0 (*never or rarely*) to 3 (*very often*) scale. Participants at or above the 90th percentile based on normative cutoffs for parent or teacher ratings of hyperactive/impulsive (HI) or total symptoms on this scale were eligible for secondary screening as potential participants at-risk for ADHD (ADHD-risk). Potential TD participants were eligible for secondary screening if they were below the 90th percentile on parent and teacher reports of HI, inattention (IA), and total problems on the ADHD-IV Rating Scale.

Secondary screening to establish eligibility—At Step 2, parents completed additional study measures about their children ($N = 338$) at an in-person screening; a subset of these measures were used to establish final eligibility. In addition, parents affirmed informed consent at the in-person screening pertaining specifically to the intervention portion of the study. Participants were ultimately identified as at-risk for ADHD based on several criteria. First, at least five HI symptoms were endorsed by parent report on the ADHD module of the National Institute of Mental Health Diagnostic Interview Schedule for Children, Version IV (DISC-IV; Shaffer, Fisher, Lucas, Dulcan, & Schwab-Stone, 2000). The DISC-IV is an interviewer-administered computerized structured diagnostic interview to assess child psychiatric diagnoses; only the ADHD module was administered. For children who met the 90^{th} percentile cutoff at initial screening, but failed to meet the five HI symptoms on the DISC-IV, up to two additional unique symptoms by teacher report from the ADHD-IV Rating Scale could be utilized to reach the required five HI symptoms for inclusion in the ADHD-risk group. This strategy was similar to one used to obtain a symptom count of six in the Multimodal Treatment Study of Children with ADHD (Hinshaw et al., 1997). A second requirement for inclusion in the ADHD-risk group was impairment in two or more domains as reported by parent and/or teacher on the Impairment Rating Scale (Fabiano et al., 2006) or by parent report on the DISC-IV impairment questions. Inclusion criteria for TD participants required four or fewer endorsed HI and IA symptoms on the DISC-IV; further, to avoid recruiting a “supernormal” sample, TD children were not excluded on the basis of impairment in one or more domains.

Additional eligibility requirements for both ADHD-risk and TD participants included the following: a non-verbal, verbal, or total IQ score that was not less than 1.5 SD below the mean (i.e., standard score ≥ 78) on the Kaufman Brief Intelligence Test, Second Edition (KBIT-2; Kaufman, & Kaufman, 2004); no current diagnosis of a pervasive developmental disorder, intellectual disability, or a seizure disorder; no medical conditions contraindicating PA; not taking medications for attention or behavior issues; residing with the current caretaker for at least six months; and having at least one English-speaking caretaker with telephone access.

Procedures

All intervention participants ($N_{\text{ADHD-risk}} = 94$; $N_{\text{TD}} = 108$) were randomly assigned to one of two before-school interventions: PA ($N_{\text{ADHD-risk}} = 49$; $N_{\text{TD}} = 55$) or art in a sedentary classroom setting (SC; $N_{\text{ADHD-risk}} = 45$; $N_{\text{TD}} = 53$). Importantly, to minimize parent and teacher expectations regarding the interventions, parents and teachers were informed that participants would be randomly assigned to either a supervised before-school art or physical activity program to examine how these programs influenced behavior and attention in young children. No expectations that one intervention might outperform the other were communicated to parents, teachers, or program staff. As part of the randomization process, participant grade, sex, and ADHD-risk status were examined within each cohort at each school to keep these factors as balanced as possible across intervention groups. Specifically, if an overrepresentation resulted on any of these factors in either intervention condition, a subgroup was re-randomized to achieve balance. Body mass index (BMI) was also examined post-randomization to ensure that average BMI was approximately equivalent across intervention groups; if not, a limited number of adjustments were made to achieve pre-treatment equity (e.g., highest BMI participant in one group was switched with lowest BMI participant in the other group). Descriptive statistics for factors used in the randomization process are presented in Table 1 by intervention group. Chi-square and ANOVA analyses indicated no intervention group differences based on factors considered during randomization.

Both intervention programs were administered daily over 12 weeks when school was in session. Intervention programs were administered during winter and spring months to ensure that participants were acclimated to the school context before the intervention began. The PA intervention involved continuous activity at a rate that required children to breathe hard, a benchmark used in the PA literature to describe energy expenditure in the moderate-to-vigorous range (see Marshall & Welk, 2008). PA was structured within age-appropriate activities and games that maintained participants' interest. The SC program was designed to keep participants sedentary, but engaged in classroom-based art projects for the duration of the before-school program. Each daily intervention program was 31 minutes in duration. The program day was organized in the following manner: (1) a 2-minute large group activity; (2) three, 9-minute small group stations (in the PA program, the last minute of each station was used for transitioning to the next station); and (3) another 2-minute large-group activity. Each program followed a structured manual with suggested activities spelled out for each day of the program. For example, in PA, a typical day might consist of a game of "tag" for the initial large group activity, followed by "Sharks and Minnows," "Spiders and Flies," and an obstacle course for the three small group stations, finishing with "Follow the Leader" for the final large group activity. Similarly, in SC, the initial large group activity might be an art show, followed by construction of a pop-up frog broken into three small group stations such as (1) trace and cut out the frog (2) decorate the frog (3) assemble the frog, finishing with a large group clean-up activity. The manuals were developed specifically for this study; more information regarding the programs and manuals may be obtained from the first or second authors. ADHD-risk and TD participants were not separated for the interventions.

In both the PA and SC settings, research staff members were trained to use praise and effective instructions freely. Emphasis was placed on having all children attend to the instructor before instructions were given ("Stand on the line, eyes on me" in PA; "hands in your lap, eyes on me" in SC). Participants received a sticker for each of the three activity segments during which they were actively involved. Participants whose participation lapsed at a PA or SC station for more than a cumulative two minutes did not receive a sticker for that station; thus, number of stickers accumulated throughout the program was a proxy for the dose of intervention received. Importantly, participation in the PA or SC activity (regardless of appropriateness of child behavior) was the criterion for receiving a sticker. Each participant who earned a specified number of stickers by the end of each week received either a small (value approximately $0.25; earned if participant received at least 75%, but less than 100% of stickers) or large (value approximately $1.00; earned if participant received 100% of stickers) prize. No other behavior management strategies were used.

Numerous strategies were utilized to increase the likelihood that procedures were consistent across study sites. Specifically, program supervisors from both sites participated in joint site comprehensive training sessions prior to the start of the intervention. In addition, supervisors monitored program fidelity throughout the interventions and participated in weekly calls between the sites to review study protocols.

Measures

Participation rates—Intervention participation rates were calculated by dividing the number of participation stickers received during the course of the intervention by the number of possible stickers that could be earned across the intervention.

Manipulation check—To examine if participants in the PA condition increased their fitness level more than participants in the SC condition, the Progressive Aerobic Cardiovascular Endurance Run (PACER; Leger, Mercier, Gadoury, & Lambert, 1988) was used to measure aerobic capacity pre- and post-intervention. Participants completed a series of continuous 15-meter shuttle run segments that become progressively more difficult because of the decreasing time allowed to complete a segment. If a participant did not complete the run in the designated time frame, the segment was considered a miss. The count of the 15-meter segments that each participant completed in the designated time frame before the second (consecutive or nonconsecutive) miss was the measure of aerobic capacity.

Medication use—Although participants were medication naïve at study entry, participants were permitted to seek and start medication during the intervention. At mid- and post-intervention, parents were asked if participants began medication to treat symptoms of ADHD during the intervention. This information was examined in supplemental analyses.

Symptom severity—Parent and teacher reports of ADHD and oppositional symptom severity were collected at both pre-intervention (Time 1; T_1) and post-intervention (Time 2; T_2). ADHD symptom severity was assessed using the home and school versions of the ADHD-IV Rating Scale (DuPaul, 1991), previously described in the preliminary screening section, and yielding measures of HI symptom severity (nine items; parent report: $T_1\alpha = .93$; $T_2\alpha = .92$; teacher report: $T_1\alpha = .96$; $T_2\alpha = .95$) and IA symptom severity (nine items; parent report: $T_1\alpha = .94$; $T_2\alpha = .92$; teacher report: $T_1\alpha = .96$; $T_2\alpha = .95$). Oppositional symptom severity was measured using a revised version of the Oppositional/Defiant subscale of the Pittsburgh Modified Conners Parent and Teacher Rating Scale (PMC; Pelham, 2002). One item from the original five-item subscale was removed for the current study (i.e., "temper outburst – behavior explosive and unpredictable") to prevent singularity (i.e., redundant items on distinct assessments) with a moodiness subscale derived from the PMC (described below). Reliability estimates for this version of the subscale were acceptable (parent report: $T_1\alpha = .83$; $T_2\alpha = .76$; teacher report: $T_1\alpha = .89$; $T_2\alpha = .81$). For all PMC subscales, respondents used a four-point scale (0 = *not at all*, 3 = *very much*) to rate participants. Thus, higher values on the PMC indicate more extreme problems.

Moodiness—Three items from Pelham's (2002) PMC (i.e., "temper outburst – behavior explosive and unpredictable"; "cries often and easily"; and "mood changes quickly and drastically”) were used to assess participant moodiness in the current study. Chronbach's alphas (parent report: $T_1\alpha$ = .80; $T_2\alpha$ = .82; teacher report: $T_1\alpha$ = .84; $T_2\alpha$ = .86) suggest good internal consistency of scores.

Peer functioning—Items from Pelham's (2002) PMC also were used to develop two peer subscales for the current study. The first subscale included six items assessing problematic peer behavior (i.e., “disturbs other children”; “fights, hits, punches, etc.”; “frequently interrupts other children's activities”; “bossy: always telling other children what to do”; “teases or calls other children names”; and “refuses to participate in group activities”) and was internally consistent (parent report: $T_1\alpha$ = .83; $T_2\alpha$ = .78; teacher report: $T_1\alpha$ = .82; $T_2\alpha$ = .82). In light of findings indicating that positive behavior in the peer context does not necessarily correspond with improved peer reputations for children with ADHD (Mrug, Hoza, Pelham, Gnagy, & Greiner, 2007), a separate three-item peer reputation subscale was developed from Pelham's (2002) PMC (i.e., “is disliked by other children”; “is actively rejected by other children”; and “is simply ignored by other children”; parent report: $T_1\alpha$ = .82; $T_2\alpha$ = .89; teacher report: $T_1\alpha$ = .82; $T_2\alpha$ = .91). Higher values on the respective subscales correspond with poorer peer functioning.

Data Analysis

A series of 2 (within-subject factor: time) × 2 (between subjects factor: ADHD-risk vs. TD status) × 2 (between subjects factor: PA vs. SC intervention group) mixed model ANOVAs was conducted to examine if symptom severity, moodiness, or peer functioning changed (1) over the course of the intervention (main effect of time); (2) over the course of the intervention as a function of ADHD-risk status (interaction of time and status); (3) over the course of the intervention as a function of intervention group (interaction of time and intervention group); and (4) over the course of the intervention as a function of both status and intervention group (three-way interaction of time, status, and intervention group). Given the lack of previous work comparing the efficacy of a PA intervention with other interventions, or with a randomized control group, we were unable to estimate expected between-subjects effects prior to beginning the study (i.e., whether adaptive change over the course of the intervention was stronger for the PA condition as compared to the sedentary condition). Thus, initial power analyses were based on within-subjects effects and, consistent with this approach, planned follow-up dependent-samples *t*-tests were used to examine pre-post intervention change within groupings based on status and intervention group. Effect sizes (i.e., Cohen's *d*) were calculated by dividing the pre-post change over the course of the intervention by the pooled standard deviation of the pre-test scores for the focal status group (i.e., ADHD-risk or TD). Thus, for example, effect sizes for the ADHD-risk group in the PA intervention were calculated by dividing the pre-post change for that specific group by the pooled standard deviation of the pre-test score for the entire ADHD-risk status group.

No data were missing for parent reports at pre-intervention and data from one participant were missing on the PMC measure for teacher reports at pre-intervention. Data missing on post-intervention measures ranged from 4% – 9% across ratings and reporters. Thus, intent-to-treat procedures were used in analyses to address missing data at Time 2. Specifically, for missing data at post-intervention, pre-intervention scores from the same item were used for the post-intervention value.

Results

Preliminary Analyses

Correlations among assessments—Correlational analyses were conducted to examine the within-rater intercorrelations among assessments and confirm that the constructs assessed were distinct. No within-rater correlations reached a level that indicated extreme multicollinearity (i.e., .90 or greater; Tabachnick & Fidell, 2013; see Table 2). The correlation between parent T_1 ratings on the HI and IA subscales of the ADHD-IV Rating Scale was substantial ($r = .87$; $p < .001$). However, given evidence that the parent version of the ADHD-IV Rating Scale is comprised of distinct HI and IA factors that correspond to DSM-IV symptom criteria for ADHD (DuPaul et al., 1998), these subscales were considered separately in analyses.

Examination of group differences at pre-testing—Means and standard deviations calculated within intervention group and status are presented in Table 3 for all study variables. To verify that randomization procedures were effective at distributing participants equally across intervention groups based on ADHD and oppositional symptom severity, moodiness, and peer functioning, a series of independent samples *t*-tests examined if mean-level ratings of participants' pre-intervention symptom severity, moodiness, and peer functioning varied based on intervention group assignment within each status group. Across all study measures, there were no mean-level pre-intervention differences based on intervention group for either the ADHD-risk or TD group. Additional *t*-tests confirmed that both parents and teachers reported that ADHD-risk participants had higher levels of pre-intervention symptom severity, moodiness, and peer problems than TD participants on all study variables in both the PA and SC intervention groups (all ps $\leq .01$).

Participation rates—The overall mean participation rate for the intervention was 86%. Participation in the intervention differed significantly based on intervention group (PA = 83%; SC = 88%; p =.04). Moreover, an examination of participation rates by status within intervention group revealed that ADHD-risk participants in the PA group (participation rate = 76%) had significantly lower rates of participation ($p = .003$) as compared with their TD counterparts (participation rate = 89%). In the SC condition, participation rates for ADHD-risk participants (participation rate = 86%) and TD participants (participation rate = 90%) did not differ significantly.

Manipulation check—A 2 (time) × 2 (intervention group) mixed model ANOVA examined if change in aerobic capacity varied over the course of the intervention by intervention group. A significant Time × Intervention Group interaction, $F(1, 186) = 5.31$, $p = .02$, confirmed that increase in aerobic capacity over the course of the intervention was greater in the PA group ($M_{increase} = 2.12$) than the SC group ($M_{increase} = 0.74$).

Pre-Post Analyses

Change in symptom severity—Overall, parents reported that children's ADHD and oppositional symptom severity decreased over the course of the intervention, HI symptoms: $F(1, 198) = 69.21$, $p < .001$, $\eta^2_{partial} = .26$; IA symptoms: $F(1, 198) = 64.31$, $p < .001$, $\eta^2_{partial} = .25$; oppositional symptoms: $F(1, 198) = 25.91$, $p < .001$, $\eta^2_{partial} = .12$. These main effects of time were qualified by significant Time × Status interactions such that symptom severity in the ADHD-risk group decreased more as compared with the TD group for all measures of symptom severity, HI symptoms: $F(1, 198) = 9.93$, $p = .002$, $\eta^2_{partial} = .05$; IA symptoms: $F(1, 198) = 11.59$, $p = .001$, $\eta^2_{partial} = .06$; oppositional symptoms: $F(1, 198) = 9.75$, $p = .002$, $\eta^2_{partial} = .05$. In addition, a significant Time × Intervention interaction for IA symptoms indicated that reductions in IA symptom severity were greater for participants in the PA condition as compared with the SC condition, $F(1, 198) = 6.53$, $p = .01$, $\eta^2_{partial} = .03$. No three-way interactions between time, status, and intervention were significant.

Teachers also reported overall reductions in ADHD symptom severity, HI symptoms: $F(1, 198) = 61.80$, $p < .001$, $\eta^2_{partial} = .24$; IA symptoms: $F(1, 198) = 21.87$, $p < .001$, $\eta^2_{partial} = .10$. These main effects of time were qualified by significant Time × Status interactions indicating that reduction in ADHD symptom severity was greater for participants in the ADHD-risk group than the TD group, HI symptoms: $F(1, 198) = 24.29$, $p < .001$, $\eta^2_{partial} = .11$; IA symptoms: $F(1, 198) = 13.51$, $p < .001$, $\eta^2_{partial} = .06$. However, these findings did not vary as a function of intervention. Moreover, teachers did not report change in oppositional symptom severity.

Results from planned follow-up analyses examining pre-post intervention change in symptom severity within status and intervention groups are presented in Table 4. For participants at-risk for ADHD in the PA and SC conditions, significant adaptive change was observed on all parent reports of ADHD and oppositional symptom severity. Moreover, teachers reported reductions in ADHD symptom severity for ADHD-risk participants in both the PA and SC groups. However, teachers did not report change in oppositional symptom severity for either ADHD-risk group. For PA participants in the TD group, parents reported significant decreases in ADHD, but not oppositional, symptom severity. Moreover, for SC participants in the TD group, parents only reported significant HI symptom severity reductions. In the school context, teachers did not report change in ADHD symptom severity for TD participants in the PA group; however, they did report significant decreases in HI and IA symptom severity for TD participants in the SC group. Teachers did not report change in oppositional symptom severity for either TD group.

Change in moodiness—Parents reported overall adaptive pre-post change in moodiness, $F(1, 198) = 9.79$, $p = .002$, $\eta^2_{partial} = .05$. This main effect of time was qualified by significant Time × Status, $F(1, 198) = 11.54$, $p = .001$, $\eta^2_{partial} = .06$; and Time × Intervention, $F(1, 198) = 4.70$, $p = .03$, $\eta^2_{partial} = .02$, interactions. Specifically, improvements in moodiness were greater for participants in the ADHD-risk group than the TD group and greater for participants in the PA group than the SC group. The Time × Intervention × Status interaction was not significant. Follow-up analyses examining change in moodiness over the course of the intervention within intervention group and status revealed that parents reported adaptive change in moodiness for TD and ADHD-risk participants in the PA group, but not the SC group (see Table 4). Teachers did not report change in moodiness over the course of the intervention.

Change in peer functioning—Parents reported overall reductions in problematic peer functioning, behavior with peers: $F(1, 198) = 30.78$, $p < .001$, $\eta^2_{partial} = .14$; peer reputation: $F(1, 198) = 7.12$, $p = .008$, $\eta^2_{partial} = .04$. These main effects of time were qualified by significant Time × Status interactions indicating that reductions in problematic peer functioning were larger for participants in the ADHD-risk group than the TD group, behavior with peers: $F(1, 198) = 8.05$, $p = .005$, $\eta^2_{partial} = .04$; peer reputation: $F(1, 198) = 5.50$, $p = .02$, $\eta^2_{partial} = .03$. However, reductions in problematic peer functioning did not vary as a function of intervention group. Teachers reported an overall decrease in problematic peer behavior, $F(1,197) = 15.66$, $p < .001$, $\eta^2_{partial} = .07$; however, this main effect of time did not vary based on ADHD-risk status or intervention group. Moreover, teachers did not report change in peer reputation over the course of the intervention.

Results from follow-up analyses conducted within status and intervention group (see Table 4) indicated that parents reported significant reductions in problematic peer behaviors for ADHD-risk participants in the PA and SC groups. However, for ADHD-risk participants, parents only reported improvement in peer reputation for PA participants. In addition, for the ADHD-risk group, teachers only reported significant improvement in peer functioning for participants in the PA group on the peer behavior measure. For TD participants, parents and teachers reported significant reductions in problematic peer behaviors for participants in the PA condition, but not the SC condition. Neither parents nor teachers reported significant change in peer reputation for TD participants.

Medication Use

Parents reported that four participants started medication at some point during the intervention. All of these participants were in the ADHD-risk group (PA intervention = 3; SC intervention = 1). The pattern of significant effects for pre-post intervention change was not altered when the four participants who began medication during the program were removed from analyses.

Discussion

The main goal of the present study was to assess the usefulness of a chronic before school moderate-to-vigorous PA intervention, relative to a SC intervention, for reducing ADHD and oppositional symptoms, moodiness, and peer difficulties in young children (Kindergarten, 1st, and 2nd graders). To our knowledge, this is the first large sample randomized trial to address this question for an ADHD-risk sample. Our first hypothesis was that chronic aerobic PA would reduce dysfunction for both children in the ADHD-risk and TD groups more than a sedentary classroom-based program. Our second hypothesis was that the benefit of PA vs. SC would be more apparent for the ADHD-risk group than TD children. Below we discuss our results separately for outcomes related to symptoms, moodiness, and peer functioning.

Symptoms

In regards to ADHD and oppositional symptoms, our results provided partial support for our first hypothesis. Specifically, we found greater reductions in parent-reported IA symptoms on a DSM-IV symptom-based rating scale for children in the PA intervention, relative to those in the SC program, regardless of status group (i.e., ADHD-risk or TD). Differential improvement on ADHD symptoms by intervention group, however, was not reported by teachers. Interestingly, as shown in Table 4, despite the lack of a significant Time × Intervention interaction for teacher reports of ADHD symptoms, effect sizes for improvements in ADHD symptoms reported by teachers were similar to those reported by parents for ADHD-risk children receiving the PA intervention (Cohen's *d* effect sizes were .69 for parents and .54 for teachers on HI, and .65 for parents and .61 for teachers on IA). Hence, the non-significant Time × Intervention interaction by teacher report appears to be attributable to the negligible effect of intervention observed by teachers specifically for TD children receiving the PA intervention (Cohen's *d* of .10 for HI and .08 for IA). Planned pre-post comparisons assessing change within status and intervention groups confirmed that both parents and teachers reported significant pre-post ADHD symptom change for ADHD-risk children receiving the PA intervention; however, only parents observed significant pre-post symptom change for TD children in the PA condition. Similarly, parents, but not teachers, reported significant change in oppositional symptoms for ADHD-risk children receiving the PA intervention.

Why parents, but not teachers, observed ADHD symptom improvement with PA for the TD children is not immediately apparent, especially since the PA program occurred more proximally in time to when teachers observed children than parents. One possibility is that TD children are better able to control any HI and IA behaviors in the school setting given their better developed (or less impaired) cognitive control, but let down their guard in the more comfortable home setting. Alternatively, teachers who must spread their attention across many children may end up focusing the most on those who demand attention, in other words, those who are high maintenance. Teachers, therefore, may be less likely to notice changes in generally well-behaving children. These explanations are admittedly speculative and future work is required before any definitive conclusions may be drawn.

Our second hypothesis—greater predicted benefit of PA over SC for ADHD-risk versus TD children—was not supported for the symptom outcomes. Interestingly, however, when collapsed across PA and SC interventions, there were significant Time × Status interactions according to both parent and teacher raters for HI and IA symptoms, and for oppositional symptoms by parent report, indicating greater improvement for ADHD-risk than TD children. One could argue that the ADHD-risk children simply had greater room to improve given their higher levels of ADHD symptoms relative to TD children before the interventions began, and that, conversely, improvements for TD children may have been limited by floor effects. Given the moderate-to-large effect sizes for improvements in ADHD symptoms by parent report for TD children receiving the PA intervention, this explanation is unlikely to be the full story. Yet, it is important for the reader to remember that even though effect sizes for the TD children were comparable to those for the ADHD-risk group, absolute change in ADHD symptoms was substantially greater for ADHD-risk children;

hence the change for the ADHD-risk group is likely to be of greater clinical significance. Finally, without a no-treatment control group of either ADHD-risk or TD children, we are not able to rule out effects of development or regression to the mean as explanations for our findings; hence we highly recommend that future studies include a no-treatment control or waitlist control condition.

It was surprising that planned comparisons showed the SC intervention to result in ADHD symptom reductions for the ADHD-risk group slightly lower in magnitude than PA but still significant by parent report, and comparable to PA by teacher report. In reflecting on potential explanations for this pattern, we reviewed our SC procedures relative to the PA procedures. Both settings used effective instructions and praise as their primary tools for managing behavior and an incentive for participation. However, due to the nature of the activities -- moderate-to-vigorous aerobic activity in the PA condition vs. completing table tasks (i.e., art projects) in SC -- these same strategies implemented in the SC context may have had the effect of training classroom attention and on-task behavior in our participants. Indeed, the completion of the art project required that the child was focused, attentive to instructions and feedback from the teacher, and on task. It may be that our SC intervention exposed our young participants to additional opportunities to learn and practice attentive and on-task behavior in an actual classroom setting that closely approximated their regular school classroom and activities.

This explanation is post hoc and should be considered with caution. Nonetheless, it is conceptually appealing and consistent with behavioral training literature suggesting that strategies employed to promote desired behaviors (such as attention and on-task behavior) are particularly effective when trained in a setting similar to the target setting (Martin & Pear, 2011). This interpretation also corresponds with recommendations for teacher-facilitated classroom behavioral intervention techniques (e.g., effective instructions, clarity regarding classroom rules, use of praise) to address deficits associated with ADHD (DuPaul,Weyandt, & Janusis, 2011). Accordingly, future work should include such an intervention condition alongside both a PA and no treatment control condition to disentangle these effects.

Moodiness

In support of our first hypothesis, parents reported significant improvements in moodiness for children in the PA condition only, regardless of ADHD-risk or TD status. Further, examination of effect sizes for our planned comparisons revealed a pattern of results consistent with our second hypothesis—that is, larger improvements in moodiness for the ADHD-risk group receiving PA than for the TD children in PA—although this effect did not reach statistical significance, suggesting the need for interpretive caution. Overall, these results suggest that PA benefits mood in children generally, a finding consistent with prior work (Tomson et al., 2003). Similar effects on moodiness by teacher report were not apparent. Given that teachers are generally not believed to be the best informants of children's internalizing symptoms (Loeber, Green, & Lahey, 1990), this was not surprising.

Peer Functioning

According to our planned comparisons, both ADHD-risk and TD children improved on peer behavior as a function of the PA intervention. This effect was evident by both teacher and parent report. Parents, but not teachers, also reported improvement in peer behavior for the ADHD-risk children receiving SC. Examination of effect sizes for these planned comparisons revealed a pattern of peer behavioral improvements larger in magnitude for the ADHD-risk group receiving PA than for the TD participants in PA, though these differences were not significant; hence our second hypothesis was not supported for peer behavior. Importantly, planned comparisons revealed that the only pre-post significant change in peer reputation was observed by parent report for ADHD-risk children in the PA condition. Given the difficulty noted in the literature of altering a negative reputation with peers once such a reputation has been established (Hoza, 2007; Mrug et al., 2007), there is cause for cautious optimism based on this result.

Strengths and Limitations

Strengths of this study include random assignment to intervention conditions, a comparison group that controlled for additional peer interactions and adult attention received, use of multiple raters and multiple outcome domains, and a relatively diverse sample (approximately 32% non-White). Nonetheless, although our sample size yielded enough power to detect differential effects of intervention group on change in attention and moodiness in the home context, it is possible that our sample size lacked sufficient power to detect other potential, albeit smaller, between-subjects effects. Because this is a new and potentially important area of intervention research for youth with ADHD, a Type II error may be more costly than a Type I error. Therefore, we chose to report planned follow-up analyses examining pre-post change in study outcomes separately within status and intervention groups. This is most consistent with our a priori power analysis and allows readers to draw their own conclusions. Further, findings from these follow-up analyses may provide valuable information for the development of future interventions aimed toward understanding the efficacy of PA as a tool to address problematic symptoms, moodiness, and peer behavior associated with ADHD.

Despite these strengths, a primary limitation of our work is that we were not able to tease apart potential maturation or regression to the mean effects from intervention effects. Initially, the SC condition was intended to fulfill this purpose, serving as a sedentary control group. However, given the unforeseen positive effects resulting from the SC condition, we are not able to detect whether these improvements in the SC group resulted from maturation, regression to the mean, general expectation effects, or an inadvertent classroom-based attention training. Thus, additional research will need to address this question. Future work would also benefit from the inclusion of follow-up assessments to determine the duration of effects associated with a PA intervention. Moreover, a systematic examination of how varying amounts of PA impact improvement could yield valuable information regarding dose-response effects.

What is clear, however, is that PA appears to be an intervention that does no harm. Only positive change, on average, was observed from its implementation. Therefore, as we await the results of future studies, schools should feel comfortable to integrate PA into the school day. It is unlikely to have any negative effects and may produce positive effects comparable to those seen in the present study. Importantly, although we focused this study on children with risk for ADHD and TD children, this intervention paradigm could easily be extended to other populations of children at risk for behavior problems, moodiness, and peer difficulties.

Summary

This study provides cautiously optimistic support for the possibility that chronic PA is an effective strategy for improving some deficits associated with ADHD in young children. In addition, the moderate-sized positive effects of PA in the follow-up analyses for ADHD-risk children by parent report on all measures, and by teacher report on a subset of measures, provide an important foundation for future work examining the efficacy of PA as a treatment for ADHD. Importantly, TD children receiving the PA intervention were rated by their parents as also showing improvement on a majority of outcomes, although improvement by teacher report was minimal for the TD group (only one of six measures). Further, the comparable improvements seen for ADHD-risk children in the SC intervention by teacher report, and to a lesser extent by parent report, suggest that ecologically-based classroom training in attending to and following teacher instructions, and appropriately participating in classroom activities, may itself be an efficacious intervention strategy for improving classroom behavior in young children during the early elementary school years. Finally, the lack of a no treatment control group prevents us from ruling out maturation or regression to the mean effects, and hence, inclusion of such a group is highly recommended in future studies.

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Table 1

Descriptive Statistics for Factors Considered During Randomization

	PA Group (*N* = 104)	SC Group (*N* = 98)
Status (%)		
ADHD-risk	47.1	45.9
TD	52.9	54.1
Sex (%)		
Boys	55.8	51.0
Girls	44.2	49.0
Grade (%)		
Kindergarten	26.9	28.6
1st Grade	37.5	40.8
2nd Grade	35.6	30.6
BMI [*M* (*SD*)]		
Boys	17.09 (2.01)	17.21 (2.62)
Girls	17.28 (2.63)	17.64 (3.84)

Table 2

Correlations among Symptom Severity, Moodiness, and Peer Functioning Variables

	1	2	3	4	5	6	7	8	9	10	11	12
1. HI Symptoms (Pre)	--	.77	.55	.45	.66	.39	.81	.63	.51	.39	.57	.39
2. IA Symptoms (Pre)	.87	--	.38	.34	.47	.32	.61	.76	.39	.28	.42	.32
3. Opp. Symptoms (Pre)	.56	.54	--	.73	.76	.56	.52	.35	.65	.41	.58	.37
4. Moodiness (Pre)	.54	.55	.72	--	.57	.51	.43	.29	.48	.57	.39	.34
5. Peer Behavior (Pre)	.63	.60	.74	.70	--	.72	.69	.49	.62	.35	.71	.53
6. Peer Reputation (Pre)	.37	.33	.39	.43	.64	--	.37	.33	.39	.20	.45	.59
7. HI Symptoms (Post)	.81	.76	.48	.50	.58	.37	--	.78	.60	.44	.71	.49
8. IA Symptoms (Post)	.71	.83	.47	.49	.51	.25	.86	--	.47	.33	.55	.42
9. Opp. Symptoms (Post)	.40	.41	.69	.55	.55	.30	.53	.50	--	.61	.82	.61
10. Moodiness (Post)	.33	.34	.46	.65	.43	.26	.44	.45	.68	--	.55	.40
11. Peer Behavior (Post)	.54	.49	.53	.53	.68	.46	.69	.60	.61	.55	--	.73
12. Peer Reputation (Post)	.25	.21	.24	.25	.35	.55	.41	.33	.38	.39	.62	--

Notes. Correlations for teacher reports are above the diagonal and correlations for parent reports are below the diagonal. All reported correlations are significant; values equal to or greater than .25 are significant at $p < .001$; values less than .25 are significant at $p < .01$. HI = hyperactivity/impulsivity; IA = inattention; Opp = oppositional.

Table 3

Means and Standard Deviations for Study Variables within Status and Intervention Group

	At-risk for ADHD PA Group (N = 49)				At-risk for ADHD SC Group (N = 45)				Typically Developing PA Group (N = 55)				Typically Developing SC Group (N = 53)[a]			
	Pre		Post		Pre		Post		Pre		Post		Pre		Post	
Measure	***M***	***SD***	***M***	***SD***	***M***	***SD***	***M***	***SD***	***M***	***SD***	***M***	***SD***	***M***	***SD***	***M***	***SD***
Parent Reports																
HI Symptoms	1.98	.57	1.54	.64	1.83	.69	1.47	.67	.55	.35	.31	.24	.56	.39	.45	.34
IA Symptoms	1.79	.63	1.38	.67	1.71	.62	1.42	.71	.54	.35	.30	.32	.47	.34	.43	.40
Opp. Symptoms	1.51	.70	1.27	.68	1.47	.80	1.07	.57	.68	.46	.59	.47	.72	.56	.66	.65
Moodiness	1.24	.87	.90	.76	1.03	.86	.83	.74	.46	.43	.36	.35	.40	.50	.52	.72
Peer Behavior	1.06	.56	.76	.56	.88	.58	.69	.52	.27	.26	.19	.20	.32	.38	.23	.24
Peer Reputation	.44	.62	.28	.51	.36	.45	.25	.45	.09	.20	.05	.17	.03	.12	.06	.21
Teacher Reports																
HI Symptoms	1.69	.87	1.23	.97	1.75	.83	1.24	.87	.46	.54	.40	.57	.46	.59	.29	.37
IA Symptoms	1.73	.86	1.23	.88	1.80	.74	1.30	.82	.60	.67	.56	.65	.49	.56	.34	.43
Opp. Symptoms	.77	.79	.63	.67	.64	.78	.57	.71	.19	.42	.19	.38	.19	.42	.18	.34
Moodiness	.45	.65	.40	.65	.39	.73	.27	.48	.13	.42	.13	.37	.09	.26	.09	.24
Peer Behavior	.82	.68	.62	.60	.71	.51	.58	.57	.25	.38	.17	.33	.23	.39	.18	.30
Peer Reputation	.45	.59	.35	.49	.37	.57	.36	.59	.11	.31	.06	.24	.12	.35	.12	.35

Notes. PA = physical activity; SC = sedentary classroom-based; HI = hyperactivity/impulsivity; IA = inattention; Opp. = oppositional.

[a]Data for one participant at pre-testing were missing on teacher PMC subscales; thus, *n*s for typically developing SC participants on oppositional symptoms, moodiness, peer behavior and peer reputation subscales are 52.

Table 4

Effect Sizes for Pre- to Post-Intervention Change within Status and Intervention Group

Measure	At-risk for ADHD PA Group	At-risk for ADHD SC Group	Typically Developing PA Group	Typically Developing SC Group
Parent Reports				
HI Symptoms	**.69**	**.57**	**.65**	**.31**
IA Symptoms	**.65**	**.46**	**.68**	.13
Opp. Symptoms	**.31**	**.53**	.19	.11
Moodiness	**.40**	.23	**.21**	−.26
Peer Behavior	**.54**	**.34**	**.24**	.26
Peer Reputation	**.30**	.19	.26	−.15
Teacher Reports				
HI Symptoms	**.54**	**.60**	.10	**.29**
IA Symptoms	**.61**	**.62**	.08	**.24**
Opp. Symptoms	.18	.09	.01	.03
Moodiness	.07	.17	.02	.00
Peer Behavior	**.32**	.22	**.21**	.15
Peer Reputation	.16	.01	.15	.01

Notes. Effect sizes representing significant ($p < .05$) adaptive pre-post intervention change are in boldface. Effect sizes (i.e., Cohen's d) were calculated by dividing the pre-post change over the course of the intervention by the pooled standard deviation of the pre-test scores for the focal status group (i.e., ADHD-risk or TD). PA = physical activity; SC = sedentary classroom-based; HI = hyperactivity/impulsivity; IA = inattention; Opp. = oppositional.