The Relationship Between Physical Activity and Executive Function Performance in Children With Attention-Deficit Hyperactivity Disorder

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Abstract:

Children with attention-deficit hyperactivity disorder (AD/HD) consistently perform worse on executive function (EF) tasks relative to those without AD/HD. Physical activity has a small effect on cognition in children and may be particularly beneficial for children with AD/HD by impacting fundamental EF deficiencies that characterize this disorder. The purpose of this study was to explore the extent to which physical activity is associated with EF in children with AD/HD. Eighteen boys (M age = 10.61, SD = 1.50) with AD/HD were recruited to complete four EF tasks. Physical activity was measured with an accelerometer that provided daily minutes of moderate-to-vigorous intensity physical activity; this measure was a significant predictor of performance on the Tower of London planning task, adjusted $R2 = .28$, $F(1, 16) = 7.61$, $p < .05$, and was positively associated with other EF measures. These results suggest that higher physical activity is associated with better EF performance in AD/HD children.

Keywords: exercise | pediatrics | psychology | cognition

Article:

Whereas there is some evidence for the cognitive benefits of exercise for children, there is limited research examining these benefits specifically in children diagnosed with psychiatric disorders. Attention-deficit hyperactivity disorder (AD/HD) is one of the most common psychiatric disorders among children and is characterized by developmentally inappropriate levels of inattention, impulsivity, and hyperactivity. One of the most prominent theories of the pathophysiology of AD/HD emphasizes deficits in behavioral inhibition resulting in impairments in executive functions (Barkley, 1997). Executive functions (EF) are defined as the cognitive functions that serve to maintain an appropriate problem-solving set to attain a future goal (Welsh & Pennington, 1988) and encompass cognitive domains that are highly relevant for daily life activities, appropriate behavior, and academic and social function. Children with AD/HD consistently perform more poorly on a range of EF tasks relative to control participants

(Pennington & Ozonoff, 1996; Shallice et al., 2002; Wilcutt, Doyle, Nigg, Faraone, & Pennington, 2005).

Despite these documented deficits in EF and the implications these have for cognitive and behavioral functioning, there are no published studies that have explored physical activity (PA) as an adjunctive behavioral treatment that could benefit children with AD/HD. Although the relationship between PA and EF in AD/HD populations has not been specifically explored, there are a number of studies providing evidence that PA benefits EF in older adults (e.g., Colcombe & Kramer, 2003) and there is more limited evidence that PA benefits the cognitive performance of children (see Tomporowski, Davis, Miller, & Naglieri, 2008 for a review). When reviewed meta-analytically, results from 44 studies (Sibley & Etnier, 2003) demonstrate a significant positive effect of PA on cognition in children (ES = 0.32, SD = 0.27) with larger effects seen in children of elementary (ES = 0.40, SD = 0.26) and middle school age (ES = 0.48, SD = 0.27). Similarly, in an earlier meta-analysis by Etnier et al. (1997), a small effect size ($g = 0.36$) was found for chronic PA and cognition in children ages 6–13 years.

It has been proposed that PA benefits EF by modifying brain structure and function, particularly in the frontal regions of the brain. This is of particular relevance to AD/HD populations considering that AD/HD models posit that a core deficit in frontal lobe function underlies its various cognitive and behavioral manifestations (Castellanos & Tannock, 2002; Durston, 2003). Animal studies document various cerebral changes as a result of PA that may lead to enhanced executive functioning including increased cerebral blood flow, angiogenesis and neurogenesis, and increased release of brain-derived neurotrophic factor. Research with humans suggests that the same physiological mechanisms may explain the relationship between PA and enhanced executive functioning (Churchill et al., 2002).

In summary, it is plausible that PA may benefit children with AD/HD by positively impacting EF. Anecdotally, parents and teachers often report that AD/HD symptoms improve following engagement in PA. Recent claims in the media and popular press also advocate for AD/HD patients to participate in regular exercise to help manage symptoms. However, no published studies have scientifically tested the relationship between PA behavior and cognitive function in school-age children with AD/HD. While stimulant medications have proven efficacious in treating the core symptoms of AD/HD in the short-term, there is little known about the long-term effects of medication and there is wide individual variation in therapeutic effectiveness, optimal dosage level, and side effects. Thus, behavioral interventions (such as PA) which might augment the traditional forms of therapy for AD/HD are needed (Barkley, 2006). The purpose of this study was to collect data relative to the relationship between PA and EF in children with AD/HD. It was hypothesized that higher PA would be associated with better performance on EF tasks.

Methods

Twenty children diagnosed with AD/HD were recruited through advertisements placed at local AD/HD clinics, medical providers, specialty AD/HD schools, and various relevant support agencies. To be included in the study, participants had to be diagnosed with AD/HD by a medical professional and currently taking medication to treat AD/HD symptoms. Although it is certainly likely that PA might be more beneficial to AD/HD children who are not currently medicated, the vast majority of AD/HD children are medicated and, therefore, we sought to explore relationships between variables in a sample already receiving this form of treatment. As a result of the higher prevalence rate of AD/HD in boys relative to girls and because behavioral and cognitive symptoms vary significantly as a function of gender, only boys were included in this study. The study was approved by the University's Institutional Review Board.

Data were collected from September through December. Participants were instructed not to engage in structured PA within 3 hr of the testing period to reduce the potential impact of acute PA on cognitive function. They were also instructed to take their medication as usual. Following the informed consent process, parents completed a demographic questionnaire while the child completed four EF tasks. The tasks were administered in randomized order by the same researcher. All tasks were administered at a developmentally appropriate level and instructions for each task were provided to the participant as suggested by each test manual. Each task had practice trials for the child to ensure that instructions were understood. The completion of all four tasks took approximately 45 min.

Following the completion of these tasks, the child was given an accelerometer to wear to assess his PA during waking hours for a consecutive 7-day period. During the 7-day period the participant was asked to complete a daily PA log. Parents were called daily to ensure their compliance with the directions. After 7 days, the researcher collected the accelerometer and the PA log from the participant. Parents were paid $50 upon completion of the study.

PA Measures

New Lifestyles NL-1000 Accelerometer. The Yamax accelerometer is made in Japan and previous models of this brand have been extensively validated (Schneider, Crouter, & Bassett, 2004; Vincent, Pangrazi, Raustorp, Tomson, & Cuddihy, 2003). The NL-1000 records moderate-to-vigorous physical activity (MVPA) time accumulation and includes an internal clock and 7-day memory function. The accelerometers were sealed so that they could not be accidentally reset and to reduce potential reactivity (Vincent & Pangrazi, 2002). Children were instructed to put in the accelerometer when they woke in the morning and to take it off at bedtime. They could only remove it for bathing, swimming, and sleeping. A detailed list of instructions, including diagrams of how to wear the accelerometer correctly based on the manufacturers' instructions, were given to each participant. Upon collection of the accelerometers, MVPA time accumulation was recorded.

Daily PA Log. Because accelerometers are not able to assess all types of activities (e.g., skateboarding, swimming), a daily activity log was also used so that participants could record these types of activities. Participants also recorded if the accelerometer was left off for any period of time and what activities were done during the time the accelerometer was off. Physical activities identified by the children were found in the Compendium of Energy Expenditures for Youth (Ridley, Ainsworth, & Olds, 2008). For physical activities with a MET value > 3.0 (indicative of moderate PA), the number of minutes the child was engaged in the activity was added to that day's activity minutes. For any activities in which it may have been questionable that the activity was engaged in at a moderate intensity for the entire duration of time listed (e.g., rode bike for 60 min, skateboarding for 30 min), 50% of the time recorded was added to that day's total minutes and then included in the MVPA calculations for each participant. This occurred on seven occasions and this 50% value was used to ensure that time spent in PA would not be artificially inflated.

EF Measures

Inhibition. Conners's Continuous Performance Test (CPT-II Version 5.1 for Windows; Conners, 2004) is a computerized 14-min visual performance task in which the participant must respond repeatedly to nontarget figures (capital letters) and then inhibit responding when the infrequently presented target figure appears (the letter X). The CPT II produces a number of outcome variables, but for the purposes of this study, only results for omissions and commissions were used. Omissions represent the number of targets the participant fails to respond to (not hitting the space bar when a letter that is not an X is presented). Commissions refer to the number of times a participant responds to the nontarget stimulus (letter X) as it appears on the screen. Both omission and commission scores were converted to age and gender appropriate T-scores with higher T-scores indicative of worse performance. Participants sat in front of the computer throughout the task. In accordance with the manual instructions, the examiner left the room following completion of the practice trial.

Planning. The Tower of London 2nd edition (Culbertson & Zillmer, 2005) requires the child to copy a modeled pattern of three colored beads (red, blue, green) in as few moves as possible. For this study, three main percentile scores were used: Total Move Score (TMS), Total Correct Score (TCS), and Total Execution Time (TET). The TMS is the sum of all moves taken to solve the problems that exceeded the minimum required move score. The TCS score indicates how many of the 10 problems were solved in the minimum number of moves. The TET score indicates how long the participant took to solve the problems. Percentile scores are adjusted for age and higher percentile scores represent better performance and more efficient planning abilities.

Working Memory. The Digit Span (DS) subtest of the WISC-IV (Wechsler, 2003) is a widely used, standardized memory task that is sensitive to deficits in attention and executive functioning. The DS Forward task involves listening to a sequence of numbers from two to eight digits long (e.g., 6-8-2) and repeating the sequence aloud in order. The DS Backward task follows the same procedure however the participant must repeat the number sequences in reverse order (e.g., 2-8-6). Scores on the DS reflect the number of digits in the longest sequence a participant successfully repeats before two consecutive failed trials. A total scaled score including both DS Forward and Backward was used for the analysis with higher scores indicative of better performance. The raw scores were adjusted for age and gender using standardized z scores (Wechsler, 2003).

Processing Speed. The Children's Color Trails Tests 1 and 2 (CCTT 1 & 2; Llorente, Williams, Satz, & D'Elia, 2003) closely resemble the Children's Trail Making Test A & B (TMT A & B; Reitan & Herring, 1985) and provide measures that have a minimal reliance on language skills. Test 1 requires the connection of one set of encircled numbers (1–15) in ascending order by drawing a line from one circle to the next as quickly as possible. Even numbers are printed in a yellow background while odd numbers are printed in a pink background. Test 2 consists of two sets of encircled numbers (1–15), with one set printed in a pink background and another set printed in a yellow background. The child must draw a line connecting the numbers in ascending order, alternating between pink and yellow circles while disregarding the numbers with inappropriate color sequencing (e.g., connecting a pink 1 to a yellow 2 to a pink 3 to a yellow 4 and so on). Outcome variables used in this study were Test 1 and 2 time-to-completion scores (T-scores) with higher T-scores indicating better performance.

Treatment of Accelerometer Data

Accelerometer values for each participant were examined to assess the incidence of missing data. All participants provided at least 2 days of accelerometer data (11 recorded 7 days, 4 provided 6 days, 3 provided 5 days, and 2 recorded 2 days). Data were reduced to include only those cases with at least 5 days of accelerometer data because although evidence suggests that accelerometer/pedometer data are of sufficient reliability when collected for at least 3–4 days in children ages 7–15 years (Rowe, Mahar, Raedeke, & Lore, 2004; Strycker, Duncan, Chaumeton, Duncan, & Toobert, 2007; Tudor-Locke, Williams, Reis, & Pluto, 2004); 4–5 days appears to be the necessary time to obtain a more adequate measure of PA patterns in children Grades 1–6 (alpha coefficient of 0.80; Trost, Pate, Freedson, Sallis, & Taylor, 2000). Data were further reduced by removing any data for single days in which less than 1,000 steps were recorded. This cut point has been used in previous research to identify PA outliers in younger age groups (Tudor-Locke, Giles-Corti, Knuiman, & McCormack, 2008). Three days of data that had less than 1,000 steps were removed. Based on these inclusion criteria, 18 participants were included in the final sample. All reported accelerometer values reflect PA on at least 4 weekdays and at least 1 weekend day (17 of the 18 participants recorded activity for both weekend days). This is important because previous research shows increased reliability (e.g., Rowe et al., 2004; Tudor-Locke et al., 2004; Ward, Evenson, Vaughn, Rodgers, & Troiano, 2005) and reduced bias (Duncan, Schofield, & Duncan, 2006) when pedometers/accelerometers are used on both weekdays and weekends. Total MVPA minutes for included days were computed and average MVPA/day was calculated (Strycker et al., 2007; Tudor-Locke et al., 2008).

Statistical Analyses

All statistical analyses were conducted using SPSS 16.0 (SPSS Incorporated, Chicago, IL). Descriptive analyses were performed on the MVPA and EF measures. Separate regression analyses were used with MVPA as a predictor of each EF outcome. Because this study is the first to be conducted in this area, it was considered exploratory so adjustments to alpha were not made ($\alpha = .05$ for all analyses) and effect sizes are provided to guide subsequent research.

Results

The final sample consisted of 18 boys ranging in ages from 8 to 12 years with a mean age of 10.61 years ($SD = 1.50$). Descriptive information for the sample is summarized in Table 1. Descriptive information for the PA and EF measures are presented in Table 2.

Table 1 Descriptive Information for Demographics of the AD/HD Sample

	Total Sample (N = 18)		
	M	***SD***	**Range**
Age	10.61	1.50	8–12
Height (in)	56.75	4.27	50–66
Weight (lbs)	87.82	19.77	55.7–125.2
BMI	19.07	4.27	13.13–26.41
Ethnicity	Frequency	%	
Caucasian	13	72.2%	
African American	5	27.8%	
Grade			3–8
3	2	11.1%	
4	2	11.1%	
5	4	22.2%	
6	5	27.8%	
7	4	22.2%	
8	1	5.6%	
Combined Family Income (n = 17)			
<$25,000	1	5.9%	
$25,000–$49,999	2	11.8%	
$50,000–$74,999	2	11.8%	
$75,000–$99,999	4	23.5%	
>$100,000	9	47.1%	

AD/HD Characteristics

Based on parent report, all participants were previously diagnosed with AD/HD by a medical professional when they were 8 years old or younger and were diagnosed as follows: predominately hyperactive-impulsive (n = 5), predominately inattentive (n = 2), combined type (n = 8), not reported (n = 3). When possible, parents provided documentation from their health care professional regarding AD/HD diagnosis (n = 11). All participants were currently using stimulant medications, either methylphenidate or amphetamine, for treatment of AD/HD and had been taking these medications for a period of 6 months or longer. Two participants reported using melatonin as a sleep aid, and three others reported using omega 3 supplements in the treatment of AD/HD in addition to their stimulant medication. Three children used medication on weekdays only, and 15 used medication daily. On the testing day all children had taken their medication as prescribed. According to parent self- reports, 45% of the children were diagnosed with at least one comorbid disorder; 55% reported no comorbidities.

Table 2 Correlation Matrix and Descriptive Data for Physical Activity and the Executive Function Variables

	Measure	1	2	3	4	5	6	7	8	9
1	MVPA	—								
2	Digit Span	.37	—							
3	TOL TMS	.57*	.26	—						
4	TOL TCS	.18	–.32	.63**	—					
5	TOL TET	.53*	.39	.89**	.35	—				
6	CCTT 1	.36	.07	.34	–.19	.51*	—			
7	CCTT 2	.45	.67**	.39	–.22	.55*	.47*	—		
8	Omissions[a]	–.11	–.42	–.17	.23	–.42	–.18	–.47	—	
9	Commissions[a]	.25	–.11	–.25	–.32	–.32	.19	.01	.32	—
	M	38.47	11.06[c]	34.28	35.78	36.94	38.83	40.78	50.06[b]	49.19[b]
	SD	17.56	4.24	31.19	31.74	33.36	12.87	10.57	9.10	11.10

Note. CCTT = Children's Color Trails Test; MVPA = minutes of moderate-to-vigorous intensity activity; TOL = Tower of London; TMS = Total Move Score; TCS = Total Correct Score; TET = Execution Time.

[a]Lower score equals better performance and a negative relationship is expected to be observed. [b]T-score. [c]Adjusted for age.

*$p < .05$, **$p < .01$.

The Relationship Between MVPA and EF

Regression analyses revealed that MVPA was a significant predictor of performance on the Tower of London TMS (adjusted R2 = .28, F(1, 16) = 7.61, p < .05) and Tower of London TET (adjusted R2 =.23, F(1,16) = 6.11, p < .05). Higher PA was associated with lower TMS and faster execution times, which are indicative of better performance. In addition, although nonsignificant, correlations for five of the other six EF outcome measures with MVPA were in the hypothesized direction, with higher MVPA predictive of better EF performance (rs = .20–.45, see Table 2).

Discussion

Physical activity was found to be a significant predictor of planning as assessed with the Tower of London TMS and TET. This is an important finding since planning has been identified as one of the more consistent EF impairments in children with AD/HD (Asato, Sweeney, & Luna, 2006; Welsh, Satterlee-Cartmell, & Stine, 1999; Wilcutt et al., 2005). In their meta-analysis comparing AD/HD and non-AD/HD children on EF, Wilcutt et al. (2005) reported effect sizes of d = 0.51–0.69 for Tower tasks. Pennington and Ozonoff (1996) found the greatest effects (d = 1.08) for planning measures in their comparison of children with and without AD/HD. The correlations for the Tower of London TMS and TET in this study yielded comparable effect sizes of d = 1.4 and d = 1.2, respectively (see Cohen, 1988). This suggests, then, that the difference in EF performance that is related to PA is of the same magnitude as the difference seen between AD/HD and non-AD/HD children. Performance on the Tower of London reflects the ability to plan and choose appropriate responses while inhibiting task irrelevant responses. These processes are critical features of efficient problem solving and the association of PA with these is particularly relevant and meaningful for children with AD/HD. Further, although this study was not designed to assess a causal relationship, PA has been shown to be causally linked to planning in a sample consisting of children with (n = 5) and without AD/HD (n = 89). Using an experimental design, Davis et al. (2007) reported that children in the exercise group performed better than those in a nonexercise control group on a planning measure assessed after the intervention.

While analyses revealed that MVPA was only significantly associated with Tower of London TMS and TET, relationships for five of the other six EF variables with MVPA were in the hypothesized direction, indicating that higher PA may be associated with better EF performance more generally. The fact that the majority of findings were in the hypothesized direction suggests that the results are likely to be statistically reliable with a larger sample size and make it less likely that the current findings are due to chance. Notably, the small to moderate correlations observed in this study are consistent with the small effect sizes previously reported when examining the impact of PA on EF (Etnier et al., 1997; Tomporowski et al., 2008). Alternatively, the stronger results for planning performance relative to performance on other EF tasks may reflect the importance of considering that EF is made up of subcomponents that might be differentially affected by exercise (Etnier & Chang, 2009). This may then suggest that EF tasks need to continue to be examined separately, rather than broadly (as with composite scores) to further our understanding of their relationship with and sensitivity to PA.

Before discussing the implications of these findings, it is important to consider the limitations of this study. The findings of this study are based on a small sample size (n = 18), which most likely affected the power to detect significant relationships in this group of AD/HD children. A sample size (based on the average r obtained for the EF measures) of n = 46 would be needed to achieve adequate statistical power (power = 0.80, alpha = .05) and test the reliability of the results. We were also not able to ascertain the severity of AD/HD in the current sample, thus we do not know if the magnitude of AD/HD symptoms was typical or extreme. In addition, measuring PA comes with many inherent limitations, as there is no gold standard for its assessment. The NL-1000 and daily PA log were considered appropriate for providing an indication of an overall level of PA in children ages 8–12 years. This method provided objective measures of PA with the logs providing an opportunity to include additional information relative to the quantification of PA. Lastly, the use of a correlational design precludes us from identifying a causal relationship between PA and EF performance. However, this study provides a foundation and rationale for future investigation to test for causal relationships.

Implications and Future Research

The fact that the results of this study showed that PA is a significant predictor of Tower of London performance despite children being on medication is promising and provides support for further investigation of the effects of PA on EF. Currently, most children who are diagnosed with AD/HD use medication to treat the symptoms of the disorder. However, medication may be ineffective for 25–40% of children (Swanson et al., 1993) or produce deleterious side effects that interfere with numerous life domains. Further, based on anecdotal reports, some parents choose not to medicate their children for various personal reasons. If PA can be established as a helpful adjunctive treatment for children taking medication for AD/HD, this may allow those children to perform better cognitively or to reduce their medication dosage in conjunction with an increase in regular PA.

Future research with a larger sample of medicated AD/HD children is needed to ascertain the reliability of the current findings. Because this study demonstrated a predictive relationship between PA and measures of planning, more research would clarify the influence of PA on AD/HD in general and EF in this population of children specifically. For example, investigating various modalities of exercise, along with frequency, duration, and intensity would further elucidate the PA–EF relationship and inform potential PA intervention strategies. In addition, it would be useful to compare AD/HD children to a matched sample of non-AD/HD children to see if the relationships hold on EF tasks. Future research should also examine the relationship between PA and cognitive performance for children who are not on medication for AD/HD as PA might provide an alternative way to manage the cognitive symptoms of their disorder. To our knowledge, this is the first study to look at the relationships between objective measures of PA and EF performance specifically in children diagnosed with AD/HD. The findings of this study have clear relevance to AD/HD treatment approaches and suggest that PA may have positive implications for EF performance in children diagnosed with and taking medications for AD/HD.

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