The Journal of Child Psychology and Psychiatry

Journal of Child Psychology and Psychiatry 61:12 (2020), pp 1380–1387 doi:10.1111/jcpp.13227

Moderate-to-vigorous physical activity and processing speed: predicting adaptive change in ADHD levels and related impairments in preschoolers

Betsy Hoza,[1] Erin K. Shoulberg,[1] Connie L. Tompkins,[2] Caroline P. Martin,[1] Allison Krasner,[1] Marissa Dennis,[1] Lori E. Meyer,[3] and Hannah Cook[1]

[1]Department of Psychological Science, University of Vermont, Burlington, VT, USA; [2]Department of Rehabilitation and Movement Science, University of Vermont, Burlington, VT, USA; [3]Department of Education, University of Vermont, Burlington, VT, USA

Background: Preschool ADHD symptoms have predictive utility for later presence of ADHD diagnoses (Harvey, Youngwirth, Thakar, & Errazuriz, 2009, *Journal of Consulting and Clinical Psychology*, 77, 349; Lahey et al., 2004, *American Journal of Psychiatry*, 161(11), 2014), yet some level of inattention, hyperactivity, and impulsivity are present even in typically developing preschoolers. Physical activity (PA) is known to have a broad spectrum of positive effects on the brain in school-age typically developing children (Centers for Disease Control and Prevention, 2010, *The association between school based physical activity, including physical education, and academic performance*. Atlanta, GA: U.S. Department of Health and Human Services), including functions impaired by ADHD (Halperin, Berwid, & O'Neill, 2014, *Child and Adolescent Psychiatric Clinics of North America*, 23, 899), yet links between PA and ADHD levels and impairments have rarely been studied in either typically developing or at-risk preschool children. Importantly, impaired processing speed (PS), though not a symptom of ADHD, is a robust neuropsychological correlate (Willcutt & Bidwell, 2011, *Treating attention deficit hyperactivity disorder: Assessment and intervention in developmental context*. Kingston, NJ: Civic Research Institute) that may indicate additional risk for ADHD. Hence, we examined whether baseline PS moderates the association between preschoolers' PA, specifically moderate-to-vigorous PA (MVPA), and changes in ADHD levels and related behaviors. **Method:** Eighty-five preschoolers (49.4% female; $M_{\text{age}} = 4.14$, $SD_{\text{age}} = .64$) were drawn from a larger study of the effects of the *Kiddie Children and Teachers (CATs) on the Move* PA program on school readiness. The sample was largely Head Start eligible (68.2%) and ethnically diverse. Hierarchical regressions were utilized to examine links between MVPA, averaged over a school year, and changes in inattention (IA), hyperactivity/impulsivity (HI), oppositional behaviors, moodiness, and peer functioning, and whether these associations varied based on baseline PS. **Results:** Results indicated that for IA, HI, and peer functioning, higher amounts of MVPA were associated with greater adaptive change for those with lower (but not higher) levels of PS. **Conclusions:** Preschool MVPA may be a viable method of reducing ADHD levels and impairments for those with lower PS. **Keywords:** Attention-deficit/hyperactivity disorder (ADHD); physical activity (PA); moderate-to-vigorous physical activity (MVPA); processing speed (PS); prevention; early intervention; preschool.

Introduction

Attention-deficit/hyperactivity disorder (ADHD) is a complex neurobiological disorder, the exact etiology of which remains poorly understood. Adding to its perplexing nature, ADHD can manifest via multiple developmental pathways and its clinical presence does not uniformly dictate a specific outcome (Sonuga-Barke & Halperin, 2010). This heterogeneity in both origins and outcomes likely contributes to its current status as a disorder diagnosed and treated largely on the basis of its behavioral manifestations, despite the fact that its cause is thought to be, in large part, biological.

The core symptoms of ADHD include inattention, hyperactivity, and impulsivity, the latter two of which are typically combined in a single dimension for assessment purposes. Importantly, some levels of inattention, hyperactivity, and impulsivity are present even in typically developing populations, particularly in early childhood, making it clear that ADHD is a disorder defined by the severity of these behaviors rather than their presence (Sonuga-Barke & Halperin, 2010). In short, '…syndrome onset represents a transition of degree rather than of kind' (Sonuga-Barke & Halperin, 2010, p. 371). Yet, early ADHD or oppositional behaviors, evident during the preschool years, have been shown to predict later clinical diagnoses of ADHD and/or oppositional defiant disorder (ODD) in a subset of cases (Harvey et al., 2009; Lahey et al., 2004) indicating that they may be early markers of an emerging (or in some cases persisting) disorder. Importantly, not all individuals who display these early behaviors go on to develop ADHD. Harvey et al. (2009) suggest this presents a conundrum in that 'A wait-and-see approach misses an opportunity for early intervention for children whose early behavior problems represent a stable condition' (p. 353), whereas in contrast, a more proactive approach may target children whose problems are

Conflict of interest statement: No conflicts declared.

Published by John Wiley & Sons Ltd, 9600 Garsington Road, Oxford OX4 2DQ, UK and 350 Main St, Malden, MA 02148, USA

only temporarily elevated, perhaps even as a function of a developmental transition.

Given these conflicting considerations, Sonuga-Barke and Halperin (2010) have noted that there are numerous factors to consider when deciding when, how, and with whom to implement a preventative or early intervention. One consideration is whether children may be more amenable to environmental influences during certain periods of development. If so, it certainly makes sense to intervene at a time of potentially greater impact. Another consideration is the 'invasiveness' (p. 371) of an intervention, or any associated risks, which should be carefully assessed against potential costs and benefits. Higher risk interventions would require a more compelling justification than minimal or no-risk interventions. Finally, whether the intervention has the potential to alter one or more neurobiological processes associated with the disorder is worthy of consideration, although any such link may be hypothetical (i.e., unproven; Sonuga-Barke & Halperin, 2010). Since ADHD is a neurobiological disorder with multiple developmental pathways, there may be multiple opportunities for alteration of neurobiological processes. Hence, a preventative or early intervention with broad neurobiological impact might be more likely to 'hit' on a modifiable neurobiological process, even if no specific pathway to the disorder has yet been identified.

Why physical activity?

There are numerous reasons why physical activity (PA) may be beneficial in managing ADHD behaviors (Hoza, Martin, Pirog, & Shoulberg, 2016). For example, regular PA is thought to have a broad spectrum of positive effects on brain structure and function in typically developing populations. These effects of PA on the brain include increases in blood flow and oxygenation, promotion of neurogenesis, increased neurotransmitter levels and capillary growth, and increases in brain tissue volume, to name a few (Centers for Disease Control and Prevention, 2010). Importantly, these physiological effects would be expected to enhance cognitive functioning generally, promoting better attention, information processing, mood, and coping ability (Centers for Disease Control and Prevention, 2010). Since these areas of improvement associated with PA overlap substantially with areas of deficit in ADHD, it stands to reason that PA may improve (or even offset) symptoms of ADHD (Halperin et al., 2014).

Preliminary work from a handful of randomized trials examining this possibility in elementary school-aged children suggests that this may indeed be the case. Specifically, these studies collectively document improvement in ADHD or ADHD-risk samples as a function of PA in the domains of ADHD symptoms, behavior, neuropsychological functioning, affect, and peer functioning (see Hoza et al., 2016, for a review). Although much of this work is preliminary and in need of replication with larger samples and more stringent designs, the overarching conclusion is that PA may be promising in managing ADHD symptoms and associated impairments in elementary school-aged children (Hoza et al., 2016).

Although many types of physical movement constitute PA, in the current work, our focus was on moderate-to-vigorous PA (MVPA; e.g., PA activities such as jumping or running that result in increased heart and breathing rates; U.S. Department of Health & Human Services, 2018). Although the larger literature is lacking controlled studies specifically comparing different types and intensities of PA, prior studies document the preliminary usefulness of MVPA for managing ADHD symptoms and impairments in early elementary school children at risk for ADHD (Hoza et al., 2015; Smith et al., 2013). Hence, on the basis of this prior work, our focus was on MVPA specifically.

Why administer PA in early childhood?

As early childhood is a time in development marked by greater brain plasticity and PA can be implemented very early in life, it follows that early childhood may be an ideal time for PA interventions. PA can be implemented to whole populations of interest at minimal cost and without risk. In addition, at the population level, PA is associated with a host of developmental and health benefits beginning early in development. For example, one comprehensive review of the association between PA and health outcomes covering 96 studies in 36 countries (total $N = 72{,}291$; age range 1 month – 4.99 years) concluded that: 'Physical activity interventions were consistently (>60% of studies) associated with improved motor and cognitive development, and psychosocial and cardiometabolic health' (Carson et al., 2017, p. 33).

Hence, although exposure to PA early in life for particularly vulnerable populations such as those at risk for ADHD may be beneficial, such PA exposure may, at the same time, provide benefits even to those not at risk for ADHD, thus making whole population applications desirable. In the present study, we employ this approach to examine whether school-day MVPA, assessed across the school year in preschool classrooms where a PA intervention was being administered, is linked with change in behavioral outcomes. We expected that higher levels of MVPA would be associated with greater adaptive changes in behavioral adjustment.

Importance of potential moderating factors

In addition to studying the association of MVPA with ADHD-related behaviors and impairments, an understanding of factors that moderate the effect of PA on ADHD levels at any point on the continuum between typical and atypical development could result in meaningful information regarding prevention and treatment of this disorder. On average, there are certain neuropsychological deficits that are more common in those with versus without ADHD, such as response inhibition, working memory, and processing speed (Willcutt & Bidwell, 2011). Importantly, these difficulties are by no means a defining characteristic of ADHD as not all individuals with ADHD display these deficits (Willcutt & Bidwell, 2011) and they are present also in other types of disorders such as learning disabilities and autism spectrum disorders (Mayes & Calhoun, 2007; Willcutt & Bidwell, 2011). Nonetheless, neuropsychological functioning indicators, when particularly low or high, may serve as additional risk or protective factors for children with ADHD or ADHD-risk.

Cognitive processing speed (PS) is one of several such neuropsychological functions that, when deficient, may indicate ADHD-risk. Indeed, other neuropsychological functions (e.g., working memory, response inhibition) are additional likely candidates. However, given our necessity of focusing on only one measure (due to testing time constraints), we chose an initial focus on PS. PS is impaired in many children with ADHD, such that Willcutt and Bidwell (2011) have characterized it as 'among the most robust [neuropsychological] predictors of ADHD symptoms' (pp. 6–7). This led us to consider the role that PS may play in moderating the relation between MVPA and change in ADHD levels over time. It is possible that PA, in particular MVPA, may have a more beneficial effect on ADHD levels and associated impairments for those with greater PS impairments. In other words, low PS may be a risk factor for ADHD, and those who possess this risk may benefit most from a PA intervention. Therefore, we examined whether baseline PS would moderate the association between MVPA and behavioral outcomes. We expected that the link between MVPA and adaptive change in behavioral outcomes would be stronger for children with lower levels of baseline PS.

Methods

Participants and procedure

Preschool students ($N = 110$) considered high risk due to socioeconomic disadvantage (i.e., 68.2% Head Start eligible) were recruited from seven preschool classrooms in and around a small city. Classrooms were participating in a larger study examining the effects of the *Kiddie Children and Teachers (CATs) on the Move* PA program on school readiness. *Kiddie CATs on the Move* is a 30-min PA program designed to engage preschool students in MVPA through the use of adult-led age-appropriate structured aerobic physical activities interspersed with brief discussion and feedback periods (Meyer et al., 2017). Classrooms administered the PA program two, three, or four times per week for 19–22 weeks during a school year. These differences in program administration were due to school schedule differences.

Participants' PS was assessed at baseline, and teachers reported on students' levels of ADHD and oppositional behaviors, moodiness, and peer functioning at baseline and again at the end of the PA program year. School-day MVPA was assessed using accelerometry during five, two-week assessment periods spaced throughout the school year. Two assessments occurred when the program was not being administered (i.e., fall baseline, winter break from the PA program), and three assessments occurred when the program was being administered across the year (i.e., fall, winter, and spring). Hence, the emphasis was on total MVPA (not just program MVPA) across the school year.

As MVPA on program days is known to be significantly greater as compared to nonprogram or baseline days (Hoza et al., 2019) and considering Addy and colleagues' (Addy, Trilk, Dowda, Byun & Pate, 2014) suggestion that it is ideal to have seven valid accelerometer days to assess preschoolers' PA, participants were excluded from the current study if they did not have valid accelerometer data on at least seven program days and seven nonprogram or baseline days ($n = 23$). Two additional students were excluded from the study because they were unwilling or unable to complete the PS assessment ($n = 2$). There were no additional exclusionary criteria other than lack of parental consent for research participation. Participants were not screened for ADHD or other disorders. Thus, the sample for the current study included 85 preschoolers (49.4% female; $M_{\text{age}} = 4.14$, $SD_{\text{age}} = .64$). Participants' race/ethnicity was obtained from school records (52.9% Caucasian; 20% African American; 14.1% Asian; 11.8% other races/ethnicities, and 1.2% unspecified). Although PA data were aggregated across program, nonprogram, and baseline days, it is noteworthy that preschoolers participated in an average of 45.96 ($SD = 9.44$; Range = 24–65) *Kiddie CATs on the Move* sessions over the course of the school year.

Students were provided with a coloring book in return for their participation in the study, and teachers were paid $5 per student each time they completed ratings. The University of Vermont Institutional Review Board approved this study, and participants' parents/guardians provided written consent.

Measures

PA. ActiGraph accelerometers (ActiGraph models GT1M and GT3X+; Pensacola, FL) were used to collect PA data. PA data were considered valid on a given day if the child wore the accelerometer for at least 50% of the typical preschool day. When classrooms were open for a full day, data were valid when participants wore accelerometers for at least 210 min (50% of a 7-hr day), and when classrooms were open for a half day, data were valid when participants wore accelerometers for at least 105 min (50% of a 3.5-hr day). Across the five accelerometer assessments, participants had an average of 37.46 ($SD = 7.77$) days with valid accelerometer data. Established practices outlined by Pate et al. (2006) for assessing preschoolers' PA were used to initialize accelerometers and reduce accelerometer data into minutes spent in each PA intensity category (i.e., light, moderate, vigorous). For each participant, minutes spent within each PA intensity category and total wear time were aggregated across all days with valid accelerometer data. Percentage of time in MVPA was computed by summing the total minutes in moderate and vigorous PA and dividing this sum by total wear time. Accelerometers collected data in 15-s intervals, and the cutpoint for MVPA was 420 accelerometer counts per interval.

Cognitive processing speed. Processing speed was assessed using raw scores from the Rapid Picture Naming subtest from the Woodcock-Johnson IV Tests of Early

Cognitive Academic Development (Schrank et al., 2015). As raw PS scores were utilized, age was a covariate in all analyses to account for effects of development on scores.

Changes in ADHD and oppositional levels, mood, and peer functioning. The ADHD Rating Scale – IV Preschool Version (McGoey, DuPaul, Haley, & Shelton, 2007) was used to quantify levels of inattention (IA; nine items; Time 1 α = .94; Time 2 α = .94) and hyperactivity/impulsivity (HI; nine items; Time 1 α = .93; Time 2 α = .92). Items from the Pittsburgh Modified Conners Teacher Rating Scale (Pelham, 2002) were used to assess oppositional levels (four items; Time 1 α = .85; Time 2 α = .87), moodiness (3 items; Time 1 α = .84; Time 2 α = .82), peer behavior problems (six items; Time 1 α = .86; Time 2 α = .86; example item: 'Bossy: always telling other children what to do'), and peer reputation (three items; Time 1 α = .90; Time 2 α = .88; example item: 'Is disliked by other children') using the subscales reported by Hoza et al. (2015). All teacher-report items were rated on four-point Likert scales with higher scores indicating higher levels of behavior problems. Items were averaged within subscales. Change scores were calculated by subtracting Time 2 scores from Time 1 scores. Thus, more positive change scores indicate more adaptive change over the course of the school year. Descriptive statistics for outcome variables at Times 1 and 2 are presented in Table 1.

Missing data. For participants who entered the study after the program began (n = 4) or were unavailable for the baseline cognitive assessment (n = 1), missing data from a midpoint assessment were carried backward as baseline data. Similarly, two additional participants left school before program-end assessments were completed; thus, midpoint assessment data were carried forward as end-of-program data.

Data analysis strategy

Hierarchical regression analyses were utilized to examine whether the association between MVPA and change in outcomes varied as a function of PS. Variables were mean-centered at entry into the model. Models with significant interactions were examined at low (−1 *SD*) and high (+1 *SD*) levels of the moderator to facilitate the interpretation of interaction effects. All significant interactions were plotted using the template described by Dawson (2014).

Results

Descriptive statistics and intercorrelations among study variables are presented in Table 2. Higher levels of MVPA were linked with significantly more adaptive change in oppositional behaviors; this was the only significant bivariate association between MVPA and behavioral outcomes. PS was not significantly correlated with any change outcomes. For the most part, there were moderate-to-strong positive correlations among all outcomes, except change in moodiness was only associated with change in oppositional and peer behavior problems.

Age was positively associated with both MVPA and PS and negatively associated with change in HI levels; thus, older children were more likely to have higher levels of MVPA and PS, and younger children were more likely to demonstrate greater adaptive change in HI levels over the course of the school year. Sex (1 = male, 2 = female) was negatively associated with MVPA indicating that boys had significantly higher levels of MVPA as compared to girls. Accordingly, both age and sex were included as covariates in all models.

Results from hierarchical regression models are presented in Table 3. After controlling for covariates and PS, MVPA was a significant predictor of change in IA, oppositional behaviors, and peer reputation such that higher levels of MVPA were associated with greater adaptive change in these outcomes. The unique effect of PS did not significantly predict any change outcomes. The interaction of MVPA and PS was a significant predictor of change in IA levels, HI levels, peer behavior problems, and peer reputation. Follow-up simple slope analyses indicated that at lower levels of PS, higher levels of MVPA were linked with greater adaptive change in IA (b = 5.88, p = .002; Figure 1), HI (b = 4.15, p = .021; Figure 2), peer behavior (b = 4.22, p = .016; Figure 3), and peer reputation (b = 4.50, p = .001; Figure 4). At higher levels of PS, the associations between MVPA and change outcomes were not significant. The interaction of MVPA and PS did not predict significant change in oppositional behaviors or moodiness.

Table 1 Descriptive statistics for outcomes at Times 1 and 2

Variable	Mean (*SD*)	Range
Inattention (T1)	.61 (.71)	0–2.67
Inattention (T2)	.68 (.69)	0–2.67
Hyperactivity/Impulsivity (T1)	.56 (.70)	0–3.00
Hyperactivity/Impulsivity (T2)	.58 (.66)	0–2.67
Oppositional (T1)	.58 (.68)	0–2.50
Oppositional (T2)	.54 (.63)	0–3.00
Moodiness (T1)	.46 (.70)	0–3.00
Moodiness (T2)	.47 (.65)	0–2.33
Peer Behavior (T1)	.40 (.56)	0–2.50
Peer Behavior (T2)	.43 (.56)	0–2.50
Peer Reputation (T1)	.16 (.41)	0–2.00
Peer Reputation (T2)	.17 (.41)	0–2.00

T1 = Time 1; T2 = Time 2.

Discussion

Our two main hypotheses were as follows: (a) that higher levels of MVPA would be associated with greater adaptive change in behavioral adjustment and (b) that the link between MVPA and change in behavioral outcomes would be stronger for children with lower levels of baseline PS. By far, the most important finding emerging from this work was that for IA, HI, peer behavior problems, and peer reputation, the amount of MVPA across a school year was associated with greater adaptive change primarily for those who began the school year with lower levels of PS, thus supporting our second hypothesis. Although the main effect of MVPA (controlling for age, sex, and PS) was a significant predictor of change in 3 of 6 regression analyses (IA, oppositional behavior, peer reputation), the significant interaction between MVPA and PS in two of these instances

Table 2 Means, standard deviations, and intercorrelations among study variables

Variable	1	2	3	4	5	6	7	8	9	10	*M*	*SD*
1. Age	–										4.14	.64
2. Sex[a]	.03	–									1.49	.50
3. MVPA	.35***	−.33**	–								.15	.04
4. Processing Speed	.34***	.20	.04	–							43.72	20.23
5. Inattention change	−.10	.15	.10	.09	–						−.07	.47
6. Hyperactivity/Impulsivity change	−.34**	.04	−.03	−.07	.61***	–					−.02	.46
7. Oppositional change	−.13	−.07	.25*	−.08	.32**	.37***	–				.04	.52
8. Moodiness change	−.08	−.06	−.02	−.16	.16	.19	.48***	–			−.02	.54
9. Peer behavior change	−.12	.02	.06	−.14	.30**	.49***	.70***	.46***	–		−.03	.43
10. Peer reputation change	−.15	.01	.13	−.09	.37***	.42***	.35***	.17	.46***	–	.00	.34

MVPA, moderate-to-vigorous physical activity.
[a]1 = boys, 2 = girls.
*$p \le .05$; **$p \le .01$; ***$p \le .001$.

Table 3 Regression models predicting change in outcomes

Outcome	Step	Variable	*b*	*t*-Value	ΔR^2
Inattention change	1	Age	−.08	−.97	.03
		Sex[a]	.14	1.39	
	2	MVPA	2.63*	2.05*	.06
		PS	.00	.98	
	3	MVPA × PS	−.15*	−2.46*	.07*
Hyperactivity/impulsivity change	1	Age	−.24**	−3.28**	.12**
		Sex[a]	.05	.49	
	2	MVPA	1.51	1.23	.02
		PS	.00	.43	
	3	MVPA × PS	−.12*	−2.06*	.04*
Oppositional change	1	Age	−.11	−1.20	.02
		Sex[a]	−.07	−.63	
	2	MVPA	4.12**	2.95**	.10*
		PS	.00	−.14	
	3	MVPA × PS	−.02	−.30	.00
Mood change	1	Age	−.07	−.72	.01
		Sex	−.06	−.51	
	2	MVPA	−.13	−.08	.02
		PS	.00	−1.23	
	3	MVPA × PS	.02	.24	.00
Peer behavior change	1	Age	−.08	−1.12	.02
		Sex[a]	.02	.24	
	2	MVPA	1.40	1.17	.03
		PS	.00	−.98	
	3	MVPA × PS	−.13*	−2.27*	.06*
Peer reputation change	1	Age	−.08	−1.36	.02
		Sex[a]	.01	.15	
	2	MVPA	1.88*	2.00*	.05
		PS	.00	−.38	
	3	MVPA × PS	−.12**	−2.72**	.08**

*b*s are unstandardized coefficients at the predictor's entry into the model. MVPA = moderate-to-vigorous physical activity; PS, processing speed.
[a]1 = boys, 2 = girls.
*$p \le .05$; **$p \le .01$; ***$p \le .001$.

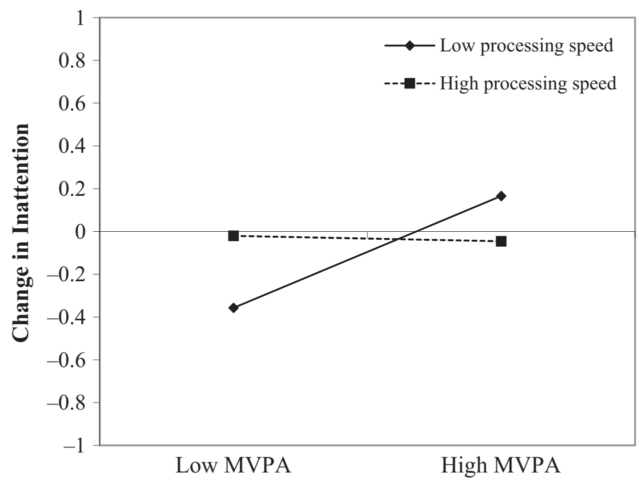

Figure 1 Interaction of moderate-to-vigorous physical activity and processing speed predicting change in inattention

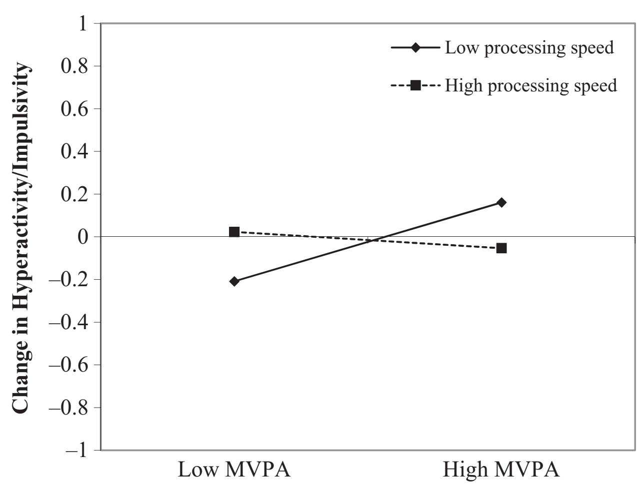

Figure 2 Interaction of moderate-to-vigorous physical activity and processing speed predicting change in hyperactivity/impulsivity

suggests that consideration of PS along with MVPA is necessary to fully understand the relation of MVPA to these outcomes.

The importance of considering specific neuropsychological deficits known to be common in children with or at risk for ADHD, such as low PS, in examining the effects of MVPA on behavioral change is clear from our results, although the explanation underlying this association is less evident. One possibility is that MVPA improves a specific vulnerability that is present in those with low PS, and perhaps with other specific neuropsychological

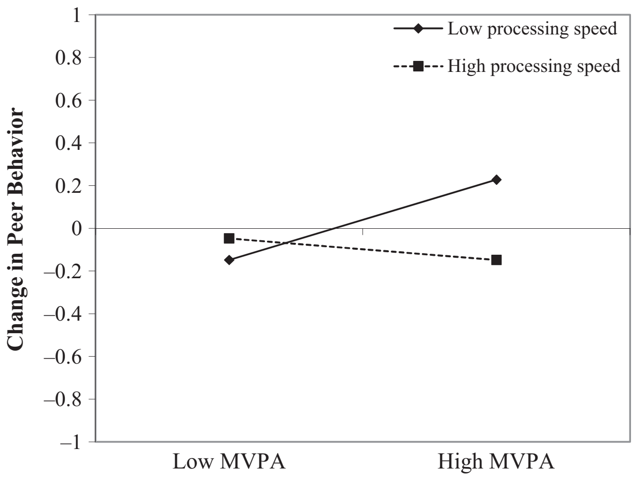

Figure 3 Interaction of moderate-to-vigorous physical activity and processing speed predicting change in peer behavior

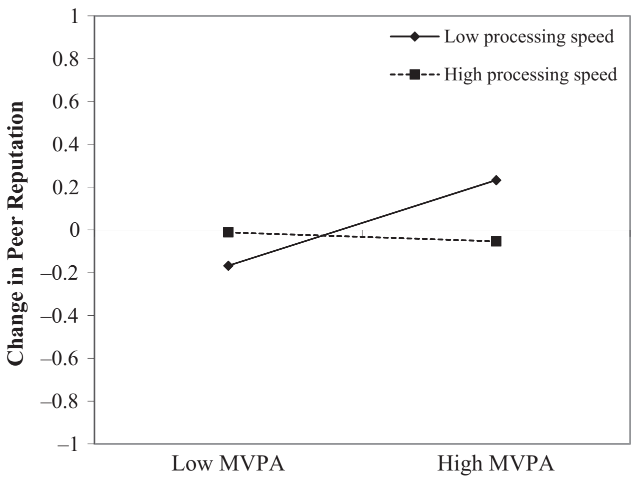

Figure 4 Interaction of moderate-to-vigorous physical activity and processing speed predicting change in peer reputation

deficits as well, although we could not assess this possibility as we did not assess other neuropsychological measures in our study. Another possibility is that chronic MVPA improves brain efficiency through its general effect on brain health via mechanisms such as increased blood flow and oxygenation, promotion of neurogenesis, increased neurotransmitter levels and capillary growth, and increases in brain tissue volume, all effects that are known to be brought about by PA (Centers for Disease Control and Prevention, 2010). If so, it is possible that the changes for children in the lower PS subgroup simply reflect the effects of better cognitive efficiency on behavioral and social functioning.

Importantly, age was positively correlated with both MVPA and PS, the two factors that interacted to predict change in behavioral outcomes. Because age was covaried, however, it is unlikely that the changes in behavioral outcomes obtained were simply due to general age-related brain maturation effects, even though it is conceivable that MVPA might promote general brain maturation. Prior studies have documented that there is, on average, roughly a 3-year delay in prefrontal cortical maturation in children with ADHD as compared to typically developing children (Shaw et al., 2007). Even with age controlled, it is possible that at least part of the obtained effect represents a 'catch-up' in cortical maturation among a subset of this at-risk sample whose brain maturation may have already been following a delayed trajectory. Such 'catch-up' effects would not necessarily track strongly with age, but might predict behavioral change. Studies examining this possibility directly using appropriate imaging techniques applied to clinically diagnosed samples with ADHD would be important to clarifying this possibility.

The only outcome directly related to MVPA, without a moderating effect of PS, was change in oppositional levels. The direction of this effect suggested that, on average, higher levels of preschool children's MVPA were associated with reductions in oppositional behaviors regardless of PS ability. This novel finding is of potentially great importance given the high comorbidity rates of ODD with ADHD (approximately 40%; MTA Cooperative Group, 1999). Specifically, it highlights the possibility that MVPA may be beneficial for preschoolers who are showing early oppositional behaviors. Of note, in prior work that considered the effect of a MVPA versus a sedentary classroom-based intervention on oppositional behaviors at the early elementary school level, teachers did not report reductions in oppositional behaviors over the course of a school year (Hoza et al., 2015), suggesting that oppositional behaviors may be more amenable to change with MVPA primarily in early childhood. Neither this prior study with elementary-age students nor the present one has been replicated, suggesting that definitive conclusions require additional independent studies.

Implications for preventive and early intervention

Although much remains to be studied regarding the relations among MVPA, PS, and behavioral adjustment at the preschool level, our results provide reason for optimism. We obtained a consistent pattern of findings demonstrating that MVPA was beneficial for reducing ADHD levels and related impairments in children with low PS, even in our high-risk community sample. Since there are no known detrimental effects of PA for healthy young children, and prior research has documented a variety of cognitive, developmental, psychosocial, and health benefits of PA in typically developing toddlers and preschool-aged children (Carson et al., 2017), there is no reason to delay the use of PA until behaviors become more severe or more closely approximate diagnostic levels. On the contrary, there is a chance that early use of PA might offset development of more severe symptoms (Halperin & Healey, 2011). Thus, our results do not support a 'wait-and-see' approach and instead suggest that even children whose ADHD and oppositional levels may be transient will likely derive some benefit from participating in MVPA.

Importantly, PA is a potentially low-cost method of addressing a range of behavioral (and health) risks, yet it is widely underutilized. Although many preschools incorporate free play and outdoor time into their schedules, recent work shows that only 62% of preschool children studied met the recommended guideline of 15 min/hr of PA on a daily basis (Tompkins et al., 2019). Thus, a structured and systematic approach, such as implementation of a PA program like *Kiddie CATs on the Move*, may be necessary to provide children with adequate levels of PA. Specifically, although many early learning standards and preschool curricula talk about opportunities for PA and outdoor play, our results suggest that a focus on MVPA in particular may be critical to producing beneficial effects at the preschool level.

Strengths and limitations

This study has a number of strengths and limitations. In the present study, changes in behavioral adjustment, mood, and peer functioning were assessed only from the perspectives of preschool teachers; no parent-report data were collected. Although focusing on teachers' perspectives of preschoolers' behavior represents a strength, it would also be helpful to know whether parents observed similar changes in the home environment. Understanding parents' perspectives on behavior is particularly important given that a prior study of MVPA on change in similar outcomes in a kindergarten through second-grade sample reported stronger effects in the home setting (Hoza et al., 2015). Considering informants from multiple settings would be an important addition for future research.

An additional limitation of our study is that its design is correlational and, hence, causal conclusions are not warranted. In other words, we cannot determine whether MVPA and PS are contributors or only correlates of the changes obtained. There is a need for future randomized controlled studies that explore the impact of varying levels of MVPA on symptoms and impairments related to ADHD across the continuum of PS ability levels in preschoolers. On the basis of prior randomized controlled trials with elementary-aged children suggesting that MVPA does impact ADHD symptoms and impairments (Hoza et al., 2015), we are hopeful that MVPA is a contributing factor. However, definitive conclusions require definitive evidence which is not currently available.

Conclusions

Our work shows that MVPA across a school year, coupled with a baseline measure of PS, predicts change in ADHD levels and related behaviors. For those lower in PS at the beginning of the school year, the relations between MVPA and changes in IA, HI, peer behavior, and peer reputation were positive and significant; the relation between MVPA and these outcomes was nonsignificant for those with higher levels of PS. Given the potential benefits of PA for overall health, its low cost, and possible benefits in reducing problematic behaviors, the addition of structured MVPA to preschool classrooms should be considered for all children, but especially for those at risk for ADHD.

Acknowledgements

This work was supported in part by monies provided through the State of Vermont Department of Health. Although this work product was funded in whole or in part with monies provided by or through the State of Vermont, the State does not necessarily endorse the researchers' findings and/or conclusions. The findings and/or conclusions may be inconsistent with the State's policies, programs, and objectives. This work was also supported in part by the Child and Adolescent Psychology Training and Research, Inc. The authors have declared that they have no competing or potential conflicts of interest.

Correspondence

Betsy Hoza, Department of Psychological Science, University of Vermont, 2 Colchester Ave., Burlington, VT 05405, USA; Email: bhoza@uvm.edu

Key points

- Some level of IA and HI is present at preschool age in many children, including typically developing children, yet these behaviors are difficult to manage and can be disruptive in the preschool setting.
- Structured MVPA may be a useful strategy for managing these problematic behaviors.
- PS appears to moderate the effects of MVPA on ADHD-related behaviors, with primary benefit occurring for children who are lower in PS.
- Policymakers and early childhood educators are encouraged to consider the possibility that structured MVPA may be a low-cost, easily accessible method for reducing ADHD levels and related behaviors in preschool classrooms.

References

Addy, C.L., Trilk, J.L., Dowda, M., Byun, W., & Pate, R.R. (2014). Assessing preschool children's physical activity: How many days of accelerometry measurement. *Pediatric Exercise Science*, *26*, 103–109.

Carson, V., Lee, E.-Y., Hewitt, L., Jennings, C., Hunter, S., Kuzik, N., … & Tremblay, M.S. (2017). Systematic review of the relationships between physical activity and health indicators in the early years (0–4 years). *BMC Public Health*, *17*(Suppl 5), 854.

Centers for Disease Control and Prevention. (2010). *The association between school based physical activity, including physical education, and academic performance.* Atlanta, GA: U.S. Department of Health and Human Services.

Dawson, J.F. (2014). Moderation in management research: What, why, when, and how. *Journal of Business and Psychology*, *29*, 1–19.

Halperin, J.M., Berwid, O.G., & O'Neill, S. (2014). Healthy body, healthy mind?: The effectiveness of physical activity to treat ADHD in children. *Child and Adolescent Psychiatric Clinics of North America*, *23*, 899–936.

Halperin, J.M., & Healey, D.M. (2011). The influences of environmental enrichment, cognitive enhancement, and physical exercise on brain development: Can we alter the developmental trajectory of ADHD? *Neuroscience and Biobehavioral Reviews*, *35*, 621–634.

Harvey, E.A., Youngwirth, S.D., Thakar, D.A., & Errazuriz, P.A. (2009). Predicting attention-deficit/hyperactivity disorder and oppositional defiant disorder from preschool diagnostic assessments. *Journal of Consulting and Clinical Psychology*, *77*, 349–354.

Hoza, B., Martin, C.P., Pirog, A., & Shoulberg, E.K. (2016). Using physical activity to manage ADHD symptoms: The state of the evidence. *Current Psychiatry Reports*, *18*, 113.

Hoza, B., Shoulberg, E.K., Tompkins, C.L., Meyer, L.E., Meyer, C.P., Krasner, A., … & Cook, H. (2019). Preschool physical activity guideline compliance and school readiness: A program evaluation. Manuscript under review.

Hoza, B., Smith, A.L., Shoulberg, E.K., Linnea, K.S., Dorsch, T.E., Blazo, J.A., … & McCabe, G.P. (2015). A randomized trial examining the effects of aerobic physical activity on attention-deficit/hyperactivity disorder symptoms in young children. *Journal of Abnormal Child Psychology*, *43*, 655–667.

Lahey, B.B., Pelham, W.E., Loney, J., Kipp, H., Ehrhardt, A., Lee, S.S., … & Massetti, G. (2004). Three-year predictive validity of DSM-IV attention deficit hyperactivity disorder in children diagnosed at 4–6 years of age. *American Journal of Psychiatry*, *161*(11), 2014–2020.

Mayes, S.D., & Calhoun, S.L. (2007). Learning, attention, writing, and processing speed in typical children and children with ADHD, autism, anxiety, depression, and oppositional-defiant disorder. *Child Neuropsychology*, *13*, 469–493.

McGoey, K.E., DuPaul, G.J., Haley, E., & Shelton, T.L. (2007). Parent and teacher ratings of attention-deficit/hyperactivity disorder in preschool: The ADHD Rating Scale-IV Preschool Version. *Journal of Psychopathology and Behavioral Assessment*, *29*, 269–276.

Meyer, L.E., Martin, C.P., Pirog, A., Krasner, A., Dennis, M., Hoza, B., … & Shoulberg, E.K. (2017). *Kiddie children and teachers on the move* (2nd edn). University of Vermont. Unpublished manuscript.

MTA Cooperative Group. (1999). A 14-month randomized clinical trial of treatment strategies for Attention-Deficit/Hyperactivity Disorder. *Archives of General Psychiatry*, *56*, 1073–1086.

Pate, R.R., Almeida, M.J., McIver, K.L., Pfeiffer, K.A., & Dowda, M. (2006). Validation and calibration of an accelerometer in preschool children. *Obesity*, *14*, 2000–2006.

Pelham, W.E. (2002). *Attention deficit hyperactivity disorder: Diagnosis, assessment, nature, etiology, and treatment.* University at Buffalo. Unpublished manuscript.

Schrank, F.A., McGrew, K.S., & Mather, N. (2015). *Woodcock-Johnson IV tests of early cognitive and academic development.* Rolling Meadows, IL: Riverside.

Shaw, P., Eckstrand, K., Sharp, W., Blumenthal, J., Lerch, J.P., Greenstein, D., … & Rapoport, J.L. (2007). Attention-deficit/hyperactivity disorder is characterized by a delay in cortical maturation. *Proceedings of the National Academy of Sciences of the United States of America*, *104*, 19649–19654.

Smith, A.L., Hoza, B., Linnea, K., McQuade, J.D., Tomb, M., Vaughn, A.J., … & Hook, H. (2013). Pilot physical activity intervention reduces severity of ADHD symptoms in young children. *Journal of Attention Disorders*, *17*, 70–82.

Sonuga-Barke, E.J.S., & Halperin, J.M. (2010). Developmental phenotypes and causal pathways in attention deficit/hyperactivity disorder: Potential targets for early intervention? *Journal of Child Psychology and Psychiatry*, *51*, 368–389.

Tompkins, C.L., Shoulberg, E.K., Meyer, L.E., Martin, C.P., Dennis, M., Krasner, A.S., & Hoza, B. (2019). Distinct methods for assessing compliance with a physical activity guideline for children in preschools. *Journal of Physical Activity & Health*, *16*(10), 902–907.

U.S. Department of Health and Human Services. (2018). *Physical activity guidelines for Americans* (2nd edn). Washington, DC: U.S. Department of Health and Human Services.

Willcutt, E.G., & Bidwell, L.C. (2011). Neuropsychology of attention deficit hyperactivity disorder: Implications for assessment and treatment. In S.W. Evans & B. Hoza (Eds.), *Treating attention deficit hyperactivity disorder: Assessment and intervention in developmental context* (pp. 6-1–6-24). Kingston, NJ: Civic Research Institute.

Accepted for publication: 3 February 2020