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Different neurocognitive functions regulating physical aggression and hyperactivity in early childhood

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Abstract

Background—There are strong parallels between early childhood and adolescent behavior problems. However, we do not know if behavioral symptoms associate with neurocognitive processes in very young children as they do in older children.

Methods—We studied a population-based birth cohort of children (N = 1,950) whose developmental trajectories of physical aggression and hyperactivity were assessed between the ages of 17 and 41 months. We measured the following neurocognitive abilities at 41 months of age: Receptive vocabulary, visuospatial organization, and short-term memory.

Results—After controlling for other neurocognitive abilities, frequent physical aggression was related specifically to receptive vocabulary deficits ($p < .0001$) while frequent hyperactivity was related specifically to deficits of visuospatial organization ($p < .0001$). The pattern of associations was robust despite controls for socioeconomic and perinatal status.

Conclusions—The different neurocognitive correlates of physical aggression and hyperactivity problems observed during adolescence are apparent in early childhood. Whereas physical aggression problems are associated with language deficits, hyperactivity problems are related to non-verbal deficits.

Keywords

Longitudinal studies; neuropsychology; development; aggression; hyperactivity; attention deficit-hyperactivity disorder; conduct disorder; executive function; pre-school children

Although there are strong parallels between early and later childhood psychiatric disorders (Egger & Angold, 2006), it is not clear whether disruptive behaviors in infants, toddlers, and preschoolers are associated with neurocognitive processes in the same way as in older children and adults. An important obstacle in the neurocognitive study of externalizing problems in older children has been the tendency to focus on one disorder or syndrome at a

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time (e.g., for conduct disorder see Morgan & Lilienfeld, 2000, or for ADHD see Nigg, Willcutt, Doyle, & Sonuga-Barke, 2005), instead of examining multiple disorders simultaneously. Further, when two disorders have been considered simultaneously, researchers have typically examined one while controlling for the other (Déry, Toupin, Pauzé, Mercier, & Fortin, 1999; Giancola, Mezzich, & Tarter, 1998; Séguin, Boulerice, Harden, Tremblay, & Pihl, 1999). These studies provide neurocognitive information about one behavior problem while controlling for a second one, but they do not provide neurocognitive information on the second controlling for the first. By considering behavior problems simultaneously we found that histories of physical aggression and hyperactivity from kindergarten to adolescence each accounted for unique variance in neurocognitive function in early adulthood (Séguin, Nagin, Assaad, & Tremblay, 2004).

In contrast to these studies of older children, the main obstacle in neurocognitive studies of physical aggression and hyperactivity during early childhood has been the use of global behavior scales (Séguin & Zelazo, 2005). Like the labels ‘antisocial’ or ‘externalizing’ that are applied to older children, the labels ‘disruptive’ and ‘hard-to-manage’ when applied to very young children may encompass a broad range of problem behaviors with different developmental patterns and etiologies. There may be complementary obstacles as well. In a recent review of clinic and community studies, Séguin and Zelazo (2005) noted considerable variation across studies that would preclude firm conclusions about early neurocognitive problems associated with externalizing, disruptive, or hard-to-manage behavior problems. Whereas some studies found clear relations between behavior problems and neurocognitive function (see Mariani & Barkley, 1997, for example), others suggested a more complex association, including suppression effects, once hyperactivity was taken into account (McGee, Partridge, Williams, & Silva, 1991, for example). Study designs are often incomplete, with some prospective studies of behavior problems considering early neurocognition but failing to account for early behavior problems (Stattin & Klackenberg-Larsson, 1993). Séguin and Zelazo (2005) proposed that the lack of more definitive conclusions may come from a) the fact that disruptive behavior is normative in the preschool years, b) the early history of those behaviors has rarely been ascertained, and c) behavior problems are often not clearly specified.

Although high levels of disruptive behavior problems are normative during the preschool years, their frequency typically declines after this age (Bongers, Koot, van der Ende, & Verhulst, 2003). This decline is well documented for physical aggression (Bongers et al., 2003; National Institute of Child Health and Human Development Early Child Care Research Network, 2004) and hyperactivity (Bongers et al., 2003). Beyond average declines, the study of age-related changes in behavior problems reveals patterns of both continuity and discontinuity (Aguilar, Sroufe, Egeland, & Carlson, 2000; Barker et al., 2007; Bongers, Koot, van der Ende, & Verhulst, 2004; Broidy et al., 2003; Côté, Vaillancourt, LeBlanc, Nagin, & Tremblay, 2006; Moffitt, Caspi, Harrington, & Milne, 2002; Nagin & Tremblay, 1999; National Institute of Child Health and Human Development Early Child Care Research Network, 2004; Raine, Yaralian, Reynolds, Venables, & Mednick, 2002; Tremblay et al., 2004). High stable levels of aggression or hyperactivity from the preschool years may indicate developmental mental health problems, and very young children who show these patterns share many of the same risk factors as violent delinquents or adolescents with ADHD (Huijbregts, Séguin, Zoccolillo, Boivin, & Tremblay, 2007; Nagin & Tremblay, 2001; Tremblay et al., 2004). Most importantly, several studies have also recently shown that trajectories of different early disruptive behavior problems may be correlated but are not identical (Bongers et al., 2004; Huijbregts et al., 2007), which challenges the notion of using global behavior scales at such young ages.

Besides careful measurement of behavior problems, it is also important to target key neurocognitive abilities. For example, several studies propose that an early combination of poor behavior regulation and cognitive problems, particularly language abilities, may be an important harbinger of chronicity (Heller, Baker, Henker, & Hinshaw, 1996; McGee et al., 1991; Wåhlstedt, Thorell, & Bohlin, 2008), although some studies do not support that hypothesis (Aguilar et al., 2000; Coy, Speltz, DeKlyen, & Jones, 2001). The decline in disruptive behavior begins shortly before school entry and coincides with marked improvements in children's ability to use language to regulate their behavior (Jacques & Zelazo, 2005; Zelazo, Müller, Frye, & Marcovitch, 2003), a link that can be observed in kindergartners (van Daal, Verhoeven, & van Balkom, 2007), and that is already apparent, though very modest, at 19 months of age (Dionne, Tremblay, Boivin, Laplante, & Pérusse, 2003). These improvements are also seen, for example, in children's executive function (e.g., Jacques, Zelazo, Kirkham, & Semcesen, 1999). The pattern of increasing linguistic control of behavior and decreasing externalizing problems in childhood may reflect the fact that, during early childhood, children typically acquire the linguistically mediated executive skills needed to regulate problem behaviors (Séguin & Zelazo, 2005; Zelazo et al., 2003). Therefore, in those relatively rare cases where children's levels of physical aggression or hyperactivity remain high beyond the preschool years, the development of linguistic ability may be poor. The Cognitive Complexity and Control (CCC) theory–revised proposes that children regulate their behavior by formulating rules in potentially silent self-directed speech such as 'I must not hit others', or 'I must sit quietly in class' (Zelazo et al., 2003). The ability to formulate and use these rules undergoes systematic changes during the course of the preschool years, changes that are related to general indices of language skill, such as receptive vocabulary (Jacques & Zelazo, 2005). However, other abilities are also thought to play a role in disruptive behavior problems. For example, one study of disruptive preschoolers found that not only verbal but also visuospatial abilities were impaired (Cole, Usher, & Cargo, 1993). Early visuospatial abilities are thought to be related to nonverbal aspects of social behavior and affect regulation. It is through that association that visuospatial abilities would, in turn, relate to behavior problems (Raine et al., 2002). It was proposed that poor early spatial abilities may constitute a stronger risk factor for persistent antisocial behavior problems than verbal abilities (Raine et al., 2002). However, Cole et al.'s (1993) study used a global behavior index and did not test for specificity of cognitive ability. Raine et al.'s (2002) study used a global index of disruptive behavior controlling for hyperactivity, but specific variance associated with hyperactivity was not examined.

The first aim of the present study was to examine whether we can detect a relation between an estimate of language function and histories of physical aggression and hyperactivity as early as 41 months of age, and whether such a relation is additive or synergistic. Second, to assess the specificity of this relation, we also examined children's performance on two non-linguistic measures of neurocognitive function: Visuospatial organization and short-term memory. Vocabulary and visuospatial organization tests are often combined as a short form of assessment of general intellectual function (Wechsler, 1989); that is, they are used as estimates of linguistic and non-verbal intellectual function, respectively. Finally, short-term memory is also involved in verbal intellectual function (Zelazo, Jacques, Burack, & Frye, 2002) and constitutes a basic ability necessary for executive function (Pennington & Ozonoff, 1996) and the regulation of hyperactivity in young adults (Séguin et al., 2004).

Methods

Participants

Children were enrolled in the Québec Longitudinal Study of Child Development (QLSCD; Jetté & Des Groseilliers, 2000), an epidemiological sample which represented approximately 96.6% of the population of infants born between October 1997 and July 1998

in the province of Québec (Canada). An initial sample of 2,817 infants (representing about 3.6 % of the births during this period) was selected via Québec's Master Birth Registry and contacted. At enrollment (at approximately 5 months of chronological age), these children were singletons of 59 to 64 weeks of gestational age. Stratification plan, exclusion criteria, and accounts for initial attrition of this epidemiological study are extensively documented elsewhere (Jetté & Des Groseilliers, 2000). Key exclusion criteria and sample demographics are presented in the Appendix.

Maternal ratings of behavior at ages 17, 29, and 41 months were used in the current study, and neurocognitive testing was performed at 41 months (M = 40.6 months, SD = .58, N = 1,950). The study was approved by the Internal Review Board of the Institut de la Statistique du Québec. Informed consent was obtained in writing from the primary caregiver, usually the mother, after complete description of the study and at each assessment. All data were collected during home visits.

Measures

Physical aggression items were 1) hits, bites, kicks; 2) fights; and 3) bullies others. Hyperactivity items were: 1) can't sit still, is restless (or hyperactive), 2) fidgets, 3) is impulsive, acts without thinking, 4) has difficulty waiting for turn in games, and 5) cannot settle down to do anything for more than a few moments. Mothers rated frequency as never, sometimes, or often. At 17 months, 29 months, and 41 months, internal consistencies for physical aggression were .80, .82, and .72, respectively; for hyperactivity they were .75, .75, and .71, respectively (Huijbregts et al., 2007). The intraclass correlation among mother and father ratings computed from another similar study using the same instrument at 41 months (N = 355) was .61 for physical aggression (Tremblay et al., 2004), and .66 for hyperactivity. These scales, drawn from the Preschool Behavior Questionnaire (Tremblay, Vitaro, Gagnon, Piché, & Royer, 1992) are well validated (Baillargeon et al., 2007) and, for example, are sensitive to environmental, perinatal and familial risk and protective factors (Côté et al., 2007; Huijbregts et al., 2007), and to early sleep patterns (Touchette et al., 2007). Inattention scores at age 41 months, concurrent to neurocognitive testing, were used to test the assumption that neurocognitive test scores reflect children's performance when they give their full attention to the task. Inattention items were 1) unable to concentrate; 2) inattentive. Internal consistency at 41 months for these two items was acceptable but relatively low at .60.

Trajectories of both physical aggression and hyperactivity were computed for all children using a group-based methodology (PROC TRAJ for the SAS statistical software package) that identifies distinctive clusters of individuals who tend to follow similar patterns of behavior over time (Jones & Nagin, 2007). Although they have been reported elsewhere (Huijbregts et al., 2007), we briefly summarize them in the Appendix.

Neurocognitive tests administered during home visits to 41-month-old children were the Peabody Picture Vocabulary Test-Revised (PPVT-R; an index of receptive language for which scores were standardized within Francophone (Dunn, Theriault-Whalen, & Dunn, 1993) and Anglophone versions (Dunn & Dunn, 1981)), the Wechsler Preschool and Primary Scale of Intelligence-Revised (WPPSI-R) block design task (an index of performance IQ emphasizing visuo-spatial abilities, Wechsler, 1989), and the Visually Cued Recall task (VCR; an index of short-term memory, Zelazo et al., 2002). The PPVT-R requires the child to identify one of 4 pictures in an array that represents a specific word. In the WPPSI-R block design task children are presented with two-dimensional patterns of red and white squares that they must reproduce. This task relies heavily on visuo-spatial reasoning and motor skill ability. The VCR involves several different arrays of 12 representational drawings. When an array is presented to the child the research assistant uses

a puppet to show which picture(s) the puppet prefers. The array is hidden for 2 s and then reintroduced to the child who is asked to show the picture(s) the puppet preferred in this array. A practice array with one 'preferred' picture is used for training. Then the span of 'preferred' pictures increases by 1 picture for each subsequent array. Each new array introduces new pictures. The task is discontinued after two consecutively failed arrays. Highest level achieved serves as the dependent variable. The task is not modality specific because the child may encode the information verbally (the puppet likes the 'tricycle'), visually (colors or shapes of object depicted), or spatially (position of picture). We show elsewhere on the same sample that this short battery is well validated and sensitive to perinatal and familial risk and protective factors (Huijbregts et al., 2006).

Data analysis

Of the 1,950 potential participants at age 41 months, 1,830 children completed the WPPSI-R block design test, 1,795 children completed the PPVT-R, and 1,768 children completed the VCR. Complete neurocognitive and behavioral data for multivariate analyses were available for 1,693 children, comprising 864 girls, 829 boys. A missing data analysis (see Appendix) suggests that included cases may be slightly better neurocognitively than non-included cases, although the bias across trajectories was rather small.

These two sets of trajectories (three for physical aggression and four for hyperactivity; described in Appendix) were related significantly but moderately to each other (Pearson's C = .24 and Cramer's V = .17, $\chi^2_{(4)} = 117.43$, $p < .0001$). Two significant weighted chi-square analyses indicated a higher proportion of boys than girls in high trajectories, and a lower proportion of boys than girls in low trajectories, than expected by chance, for both physical aggression ($\chi^2_{(2)} = 256.54$, $p < .0001$) and hyperactivity ($\chi^2 = 401.93$, $p < .0001$). Because this study focuses on the most at-risk children, the two elevated hyperactivity trajectories were joined together as well as the two lower trajectories for both physical aggression and hyperactivity, respectively (resulting trajectories are presented in Figures A1 and A2 in the Appendix). Trajectories for physical aggression were roughly one standard deviation apart and trajectories of hyperactivity were roughly 1.5 standard deviations apart. Combining trajectories allowed us to run a straightforward factorial model and avoid empty cells. After testing for invariance across sex, this resulted in a 2 × 2 physical aggression by hyperactivity analysis of variance (using SAS PROC GLM) with the three neurocognitive tests as dependent variables and sex and inattention as covariates. *N*s in each cell were Low aggression-low hyperactivity = 872, Low aggression-high hyperactivity = 454, High aggression-low hyperactivity = 115, and High aggression-high hyperactivity = 252, which sums to 1,693.

Results

Correlations among neurocognitive variables and inattention are presented in Table 1. The neurocognitive measures shared about 11–14% of variance with one another. Inattention was significantly negatively associated with all neurocognitive measures, albeit weakly.

The multivariate double interaction (physical aggression by hyperactivity) was not significant (Pillai's trace = .0004, $F_{(3,1685)} = 2.35$, $p < .07$). The multivariate main effects of physical aggression (Pillai's trace = .006, $F_{(3,1685)} = 3.17$, $p < .02$), hyperactivity (Pillai's trace = .008, $F_{(3,1685)} = 4.78$, $p < .003$), and sex (Pillai's trace = .036, $F_{(3,1685)} = 21.26$, $p < .0001$) were all significant. Inattention failed to reach significance (Pillai's trace = .033, F(3,1685) = 1.78, p = .15) and was therefore removed from the follow up analyses. Means, standard deviations, and Cohen's *d* effect size statistic are presented in Table 2. Effect sizes were mostly in the small to medium range. Multivariate tests of the first model were followed up with three models that examined the unique relation of physical aggression and

hyperactivity trajectories to each of the three neurocognitive abilities while also controlling for the two other neurocognitive abilities. Univariate statistics for these follow-up analyses are presented in Table 3. Across models, the strongest predictors of neurocognitive abilities were other neurocognitive abilities. Girls did better than boys on the VCR. All univariate interactions failed to reach significance, consistent with the multivariate test. Of greatest interest, language abilities, as measured by the PPVT-R, were specifically related to physical aggression (see Figure 1), whereas visuo-spatial abilities, as measured by the block design test, were specifically related to hyperactivity (see Figure 2). This pattern of results was maintained in follow-up analyses (not shown) that included perinatal covariates that were differentially related to physical aggression and hyperactivity and SES variables that were equally related to physical aggression and hyperactivity (see Appendix).

Discussion

In line with previous research conducted in childhood or adolescence, this study found that physical aggression and hyperactivity in preschool children share unique variance with neurocognitive abilities. Moreover, that unique variance was related to different neurocognitive abilities. Once the effects of sex and the common variance among neurocognitive domains were taken into account, high levels of physical aggression were uniquely associated with poor performance on our estimate of receptive vocabulary, the PPVT-R. In contrast, high levels of hyperactivity were associated with poor performance on measures of visuo-spatial abilities (block design). These relations held even after controlling for sociodemographic and perinatal factors.

The particular pattern of relations among physical aggression and neurocognitive function early in childhood – emphasizing the role of language skills – is consistent with the hypothesis that advances in linguistically mediated executive function normally play an important role in the regulation of physical aggression. Vocabulary has been shown to be highly correlated with executive function (e.g., Carlson & Moses, 2001; Hongwanishkul, Happaney, Lee, & Zelazo, 2005). Young children with better vocabularies may already be better at controlling or inhibiting aggressive responding, and they may be more likely to use a verbal strategy to express themselves or solve interpersonal problems. Physical aggression is more strongly social and interpersonal in nature than hyperactivity, and language skills would be particularly important for regulating social interactions. However, we could have expected that vocabulary, because of its relation with executive function, would have also been related to hyperactivity beyond its shared variance with both behavior problems, as found in research with young adults with childhood histories of physical aggression or hyperactivity (Séguin et al., 2004). Such was not the case in preschoolers in the current study, but a closer examination of effect sizes in the work with young adults shows a much stronger unique association of vocabulary with physical aggression than hyperactivity. Therefore, the findings are consistent across studies.

Some studies of preschoolers had suggested that visuospatial abilities could be key to the development of disruptive behavior (Cole et al., 1993), more so than verbal abilities (see also Raine et al., 2002). Neither study examined specific behavior problems. Our results contrast somewhat with those findings and suggest that visuospatial abilities were specifically related to hyperactivity in preschoolers. Visuospatial abilities, and particularly those measured by block design, have been found to be related to ADHD and its subtypes, at least in childhood and adolescence (Garcié-Sénchez, Estévez-Gonzé lez, Suérez-Romero, & Junqué, 1997). However, other visuospatial abilities, such as visuospatial orienting, were not found to be related to ADHD (Huang-Pollock & Nigg, 2003). In young adults, block design was uniquely related to childhood history of physical aggression, not to hyperactivity, although short-term memory was related uniquely to hyperactivity (Séguin et al., 2004).

These discrepancies in the continuity of the joint development of behavior and cognition are relatively common (Hughes & Ensor, 2008) and require further research with young children.

The current study provides a useful description of specific problem behaviors, but it does not in itself help explain why specific neurocognitive abilities were related to specific behavior problems. Possible roles of language in the development of physical aggression, were considered. The relation between visuospatial abilities and hyperactivity is less straightforward. If early visuospatial abilities are thought to be related to nonverbal aspects of social behavior and affect regulation, as proposed by Cole et al. (1993) and Raine et al. (2002), then our visuospatial measure would be sensitive to the social influences on hyperactivity. These influences would then need to be specified. A more parsimonious account, however, could be that the association operates through the executive function because many tests of visuospatial abilities (such as block design, mazes, or puzzles) require executive function (Zelazo, Carlson, & Kesek, 2008). Because executive function deficits relate in common and unique ways, but not necessarily in an equal manner (Séguin et al., 2004), to both physical aggression and hyperactivity, future studies could usefully employ more focused measures of executive function to better characterize the neurocognitive mechanisms associated with physical aggression or hyperactivity.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Abbreviations

ADHD	attention deficit-hyperactivity disorder
CD	conduct disorder
PPVT-R	Peabody Picture Vocabulary Test-Revised
VCR	Visually Cued Recall task
WPPSI-R	Wechsler Preschool and Primary Scale of Intelligence-Revised

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Key points

What is known

- There are strong parallels between early childhood and adolescent behavior problems.
- Related behavior problems, such as physical aggression and hyperactivity, associate differently with neurocognitive function in older children and adults. We do not know if this may be found in very young children.

What is new

- This study of 41-month-old children shows that the different neurocognitive correlates of physical aggression and hyperactivity problems observed during adolescence are apparent in early childhood. Whereas physical aggression problems are associated with language deficits, hyperactivity problems are related to non-verbal deficits

Clinical relevance

- Clinical studies of early problem behaviors tend to aggregate behavior problems into global scores. This study shows the advantage of examining specific behavior problems in early childhood.

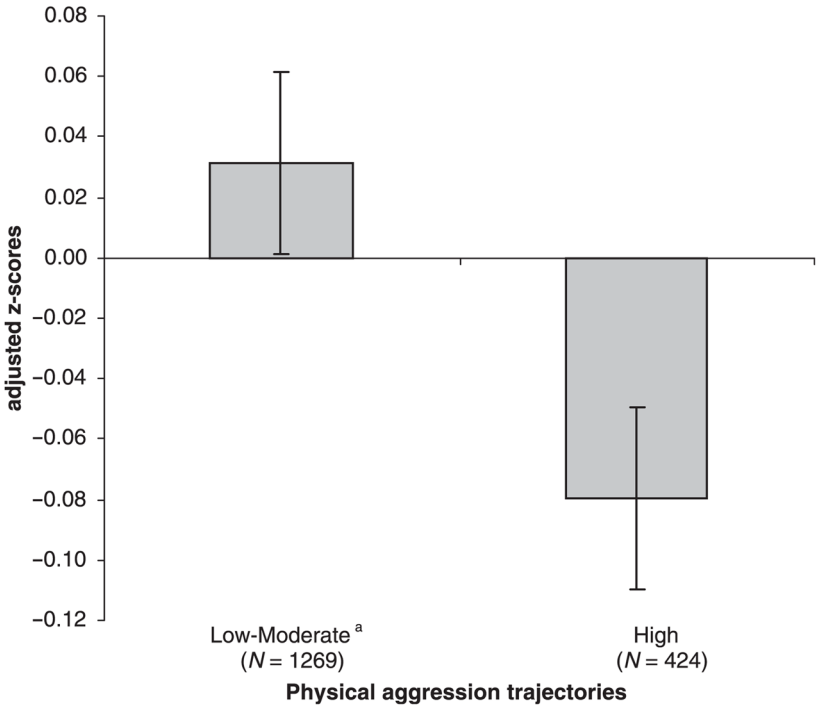

Figure 1.

Adjusted means and standard errors for the physical aggression main effect on the Peabody Picture Vocabulary Test (PPVT) score. [a]Significant difference between trajectories $F(1,1686) = 8.54$, $p < .004$

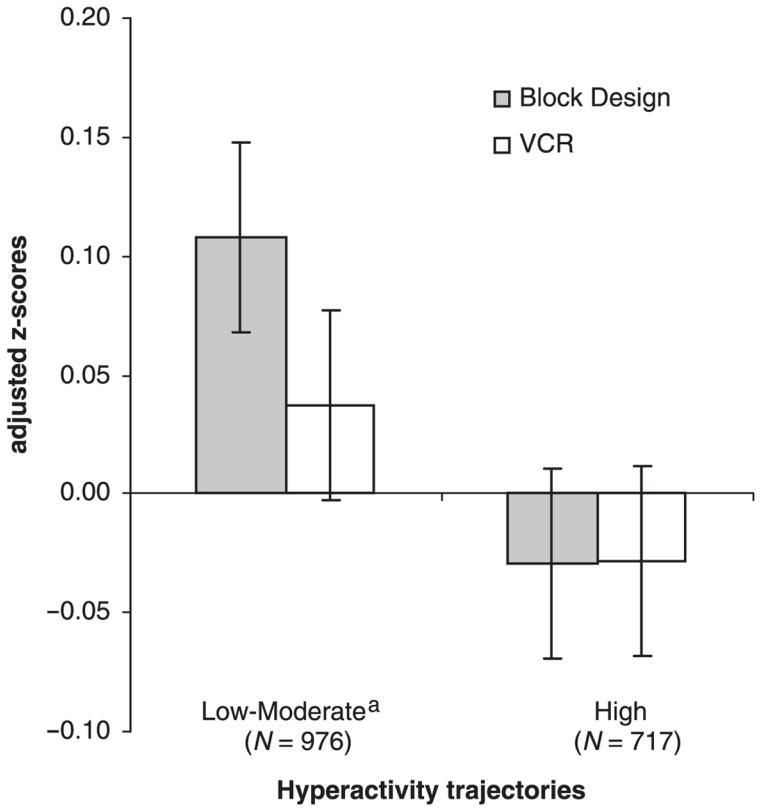

Figure 2.

Adjusted means and standard errors for the hyperactivity main effect on the Block Design (BD) and Visually Cued Recall (VCR) test scores. [a]Significant difference between trajectories for BD F(1,1686) = 13.24, $p < .0003$, not for VCR F(1,1686) = 0.76, $p = .38$

Table 1

Correlations among neurocognitive variables and inattention entered in the model

	PPVT	BD	VCR
BD	.32		
	$p < .0001$		
VCR	.37	.35	
	$p < .0001$	$p < .0001$	
Inattention	−.08	−.08	−.07
	$p < .002$	$p < .002$	$p < .01$

Note: BD: blocks design; PPVT: Peabody Picture Vocabulary Test-Revised; VCR: Visually Cued Recall. Data courtesy of the Institut de la Statistique du Québec.

Table 2

Uncorrected standardized means and standard deviations

	Physical aggression					Hyperactivity					Sex				
	Low-Moderate		High			Low-Moderate		High			Girls		Boys		
	M[1]	SD[1]	M	SD	*d*[1]	M	SD	M	SD	*d*	M	SD	M	SD	*d*
PPVT	.06	1.01	−.18	.94	.24	.11	1.00	−.13	.97	.24	.10	1.03	−.08	.95	.18
BD	.07	.99	−.06	.96	.14	.15	1.01	−.12	.93	.27	.14	1.01	−.06	.94	.20
VCR	.05	1.01	−.10	.94	.15	.12	1.02	−.13	.96	.25	.21	1.08	−.19	.87	.41

Notes:

[1]M: Mean; SD: Standard Deviation; *d*: Cohen's effect size statistic.

[2]BD: block design; PPVT: Peabody Picture Vocabulary Test–Revised; VCR: Visually Cued Recall. Data courtesy of the Institut de la Statistique du Québec.
[Correction added after online publication, 15 May 2009: Table 2 data amended.]

Table 3

Univariate statistics

Cognitive test	Effect[1]	F	p	R^2
PPVT-R[2]	Overall	63.52	<.0001	.18
	Physical aggression	8.54	.004	
	Hyperactivity	.08	.77	
	P x H[2]	3.14	.08	
	Sex	.00	.9511	
	Block Design	85.38	<.0001	
	VCR	141.90	<.0001	
Block Design[2]	Overall	54.53	<.0001	.16
	Physical aggression	.39	.53	
	Hyperactivity	13.24	.0003	
	P x H	2.79	.10	
	Sex	.97	.33	
	PPVT	85.38	<.0001	
	VCR	94.64	<.0001	
VCR[2]	Overall	74.96	<.0001	.21
	Physical aggression	.01	.91	
	Hyperactivity	.76	.3835	
	P x H	1.50	.22	
	Sex	47.31	<.0001	
	PPVT	141.90	<.0001	
	Block Design	94.64	<.0001	

Notes:

[1]Global df (7, 1685), main effects and interactions df (1,1685).

[2]H: Hyperactivity; P: Physical aggression, PPVT-R: Peabody Picture Vocabulary Test–Revised; VCR: Visually Cued Recall. Data courtesy of the Institut de la Statistique du Québec.

[Correction added after online publication, 15 May 2009: Table 3 data amended.]