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ADHD inattentive symptoms mediate the relationship between intelligence and academic performance in children aged 6-14

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Objective: Fluid intelligence and the behavioral problems of attention-deficit/hyperactivity disorder (ADHD) are related to academic performance, but how this association occurs is unclear. This study aimed to assess mediation and moderation models that test possible pathways of influence between these factors.
Methods: Sixty-two children with ADHD and 33 age-matched, typically developing students were evaluated with Raven's Colored Progressive Matrices and the spelling and arithmetic subtests of the Brazilian School Achievement Test. Dimensional ADHD symptomatology was reported by parents.
Results: Our findings suggest that fluid intelligence has a significant impact on academic tests through inattention. The inattentive dimension was the principal behavioral source of influence, also accounting for the association of hyperactive-impulsive manifestations with school achievement. This cognitive-to-behavioral influence path seems to be independent of diagnosis related group, and gender, but lower socioeconomic status might increase its strength.
Conclusion: Fluid intelligence is a relevant factor in the influence of ADHD behavioral symptoms on academic performance, but its impact is indirect. Therefore, early identification of both fluid intelligence and inattentive symptoms is of the utmost importance to prevent impaired academic performance and future difficulties in functioning.

Keywords: Academic performance; attention-deficit/hyperactivity disorder; inattention; intelligence; mediation

Introduction

Attention-deficit/hyperactivity disorder (ADHD) is the most common neurodevelopmental disorder of childhood identified by cognitive-behavioral deficits. It may affect up to 5% of the population.[1] The core characteristics of ADHD at the behavioral level involve hierarchically interrelated domains: a general ADHD dimension and distinct traits of inattention and hyperactivity-impulsivity.[2,3] ADHD patients may exhibit cognitive impairment in several specific cognitive domains, including response inhibition, working memory, short-term memory, processing speed, vigilance, and response variability.[4] These multiple cognitive deficits manifest as the mild intellectual inefficiency typical of ADHD, as fluid intelligence – a more general cognitive function related to solving new problems – is related to all of the aforementioned cognitive domains.[5-10]

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Both the cognitive and the behavioral aspects of ADHD have a major impact on patient functionality, and understanding how fluid intelligence and ADHD symptoms are related to ADHD outcomes is of the utmost relevance.[6,11]

Poor academic performance, particularly in written language and mathematics, is a usual feature of children with ADHD.[12-14] ADHD, intelligence, and reading and mathematical disabilities are heritable, and their association may primarily be explained by shared genetic influences.[15,16] Nevertheless, how this association occurs at different levels remains controversial.

The hyperactive-impulsive symptoms of ADHD appear to be associated with academic failure, but behavioral inattentive symptoms are more strongly related to school performance.[4] Reading and math abilities exhibit stronger phenotypic and genetic associations with the inattentive dimension than with the hyperactive-impulsive dimension.[15] In fact, the genetic association between hyperactivity-impulsivity and academic performance seems related to shared genetic influences between the hyperactive-impulsive and inattentive traits.[15] In this sense, inattention is likely to be the core source of lower academic performance in ADHD.

Although there is no consensus about the nature of the relationship between the cognitive and behavioral aspects of ADHD (the influence may be bidirectional),[17] cognitive characteristics alone are strongly related to academic success.[18] Fluid intelligence is itself one of the strongest predictors of school performance.[9] At any rate, the common inverse correlation between neuropsychological domains and hyperactivity-impulsivity does not remain significant when controlling for inattentive symptoms, suggesting that behavioral inattention is more closely associated with cognitive level in ADHD.[4] As the cognitive characteristics of ADHD are often pointed out as intermediate features between clinical and genetic levels (cognitive endophenotypes),[16,19] it is possible that the inattentive dimension accounts for the cognitive influence of ADHD on educational outcomes (cognitive-to-behavioral influence). However, few studies have addressed the way in which the cognitive aspects and behavioral dimensions of ADHD influence academic performance.

Previous studies have found no impact of intelligence level on the association between ADHD symptoms and school achievement after statistically controlling for IQ in predictive models.[20,21] On the other hand, cognitive impairment may lead to more severe ADHD symptoms, suggesting a clear relationship between the cognitive and behavioral aspects of ADHD.[22,23] Still, these results are not necessarily opposites. When strongly associated variables are taken simultaneously in predictive models, some of the predictors may not appear to exert a significant influence on outcomes. However, when each variable is viewed separately as a unique predictor, all of them may show significant predictive power. This might suggest that, in a simultaneous model, an indirect effect is at play – i.e., one of the variables does not hold as a significant predictor because its predictive power is accounted for by the other independent variable.[24] Therefore, the effect of cognitive variables such as intelligence on school performance in ADHD may be mediated by the behavioral symptoms of the disorder. However, to the best of our knowledge, no studies have directly examined this mediation model at the phenotypic level.

With this investigation, we aim to test whether a mediational relationship exists between fluid intelligence and the influence of ADHD symptoms on written language and mathematic performance. We test both cognitive-to-behavioral and behavioral-to-cognitive influences on academic performance, as no clear directionality for these influences has been established thus far. In addition, the present study addresses the role of hyperactivity-impulsivity on academic performance by investigating whether the inattentive dimension of ADHD accounts for its influence. Another question that arises from the previous one is whether the influence of ADHD symptoms on academic performance is conditional to the fluid intelligence level. The models we employ have the potential to explain how fluid intelligence and ADHD symptoms predict school performance. Since the relationship between ADHD symptoms and school performance is evident when these are regarded as continuous traits,[25] our investigation comprises both ADHD and typically developing (TD) children. Additionally, considering that the magnitude of ADHD symptoms differs according to gender and social class,[26,27] we investigate the extent to which our models might be dependent on these variables (i.e., whether they are moderators of the relationship between cognitive and behavioral features of ADHD and academic performance).

Methods

Participants

Sixty-two children with ADHD (age range, 6-14 years) were recruited from an ongoing study conducted at Hospital das Clínicas da Universidade Federal de Minas Gerais (UFMG), Belo Horizonte, Brazil. This study was approved by the local Ethics Committee. Participants in the clinical group underwent a semi-structured psychiatric diagnostic interview with the Brazilian version of the K-SADS-PL,[28] and the diagnosis of ADHD was established in accordance with the DSM-IV criteria.[29] Nineteen children were diagnosed with the inattentive subtype (ADHD-I), three with the hyperactive subtype (ADHD-H), and 40 with the combined subtype (ADHD-C). Of the 62 participants, 53% met criteria for comorbid psychiatric conditions, including oppositional defiant disorder (ODD) (n=27) and mood or anxiety disorder (n=12). Six of these 33 patients with comorbid conditions had both ODD and a mood or anxiety disorder. Their families had spontaneously sought the psychiatry service of the hospital concerned by inattentive and/or externalizing behavior, but with no previous behavioral diagnosis. At the time of the diagnostic interview, families of children in the ADHD group were invited to take part in a cognitive-behavioral study, and none refused to participate. Assessment of the children was part of the routine screening process for general cognitive abilities and academic performance before starting treatment. Therefore, no child was receiving any pharmacological treatment at the time of assessment.

Thirty-three age-matched TD students with no evidence of psychiatric or neurological disorders were also recruited from two public primary schools with similar socioeconomic background from ADHD patients. Subjects were excluded if they had a history or current evidence of psychosis, autism, brain disorders, or any genetic or medical disorder associated with externalizing behavior that might mimic ADHD, or general intelligence measured by Raven's Colored Progressive Matrices (CPM)[30] below the 6th percentile.

Measures and procedures

ADHD symptom assessment

Parents completed the Brazilian version of the Swanson, Nolan, and Pelham – version IV (SNAP-IV) for evaluation of ADHD symptoms in their children.[31] The SNAP-IV is an 18-item measure, each item of which is rated from zero to three. The sum of the first nine items of this scale describes the total level of inattentive behaviors, and the sum of the last nine items reflects hyperactive-impulsive problems.

Intelligence assessment

We assessed fluid intelligence with the Brazilian version of Raven's CPM.[30] This is a well-established non-verbal test of inductive reasoning and often regarded as a good marker of general intelligence.[9] Raven's CPM is a standardized test consisting of visual analogy problems of increasing difficulty. Each problem presents a matrix of patterns in which one pattern is missing. The task is to select the missing pattern among a set of given response alternatives.

Academic performance assessment

To evaluate academic performance, we used two subtests of the Brazilian School Achievement Test (SAT): single-word spelling and arithmetic.[32] The single-word reading subtest was not included in this study due to lack of appropriate normative data for the school population.[33] The SAT subtests evaluate academic performance according to the expected educational achievement from the 1st to the 6th grades. The spelling subtest consists of 34 individual words that are read by the examiner and must then be written down by the children, presented in gradual order of difficulty. The arithmetic subtest comprises 38 calculations of varying degrees of complexity. Three calculations are presented orally (a simple single-digit addition, a simple single-digit subtraction and a comparison of two numbers), and 35 calculations must be solved and worked out, including addition, subtraction, multiplication, calculation of fractions, and exponentiation. Each correctly spelled word and solved math problem is scored one point. Reliability coefficients (Cronbach's α) of SAT subtests are 0.93 or higher.[32]

Socioeconomic status

This measure was assessed using the Brazilian Criterion of Economic Classification (CCEB) published by the Brazilian Association of Research Companies (Associação Brasileira de Empresas de Pesquisa, ABEP).[34] The CCEB estimates the purchasing power of families living in urban areas. It includes nine items that assess the resources available at the respondent's household and one item that evaluates the education level of the head of household, resulting in a scale ranging from 0 to 46 points; scores are stratified into eight economic classes. In our study, the CCEB was completed by participants' parents. Scores ranged from 6 to 33 (mean = 20.19; SD = 5.11), with 83% of families classified as middle class (B2, C1, and C2), 9% of families as high class (B1), and 8% classified as low class (D, and E). The mean (SD) number of people per household was 4.71 (1.94). To improve the power for detecting differences due to economic level, we pooled the first and last four CCEB classes into high and low categories respectively. This means that middle-class families were distributed between groups.

Data analysis

Data modeling

Prior to all analyses, we calculated the z scores for Raven's CPM, spelling, and arithmetic data using the age-stratified population-based norms for Raven's CPM and grade-stratified norms for the Brazilian SAT subtests.[30,32]

Sample characterization

Descriptive statistics for age, gender, socioeconomic level, diagnosis status, fluid intelligence, and academic performance were first used to describe the characteristics of the study population. As the sample has both ADHD and TD children with different levels of ADHD symptom severity, we carried out a Student *t*-test for independent samples to assess between-group differences in sociodemographic data and Raven's CPM and Brazilian SAT scores. We used chi-square tests to assess differences in the frequency of dichotomous variables. The effect sizes of the differences observed were calculated with Cohen's *d* and the phi coefficient for continuous and dichotomous variables, respectively.

Simple mediation analysis

In general, a variable M is considered a mediator if (1) X (predictor) significantly predicts Y (outcome), (2) X significantly predicts M, and (3) M significantly predicts Y controlling for X, i.e., all variables must be related.[35] Pearson correlation analysis was conducted to examine whether fluid intelligence, ADHD behavioral symptoms (inattention and hyperactivity-impulsivity), and academic performance (spelling and arithmetic) were associated. Since ADHD symptom data were not normally distributed and data transformations were unsuccessful, the association between variables was investigated by a resampling approach ($k = 5000$). Next, we performed linear regression analyses between the main outcomes (spelling and arithmetic performance) and their relevant correlates. First, the direct effects of fluid intelligence (Raven's CPM) and ADHD behavior on academic performance were estimated one factor at a time (OFAT). Then we entered fluid intelligence and ADHD symptoms simultaneously in one step as relevant correlates of academic performance in the linear regression model by the forced-enter method, to test the indirect effect of ADHD symptoms (M) on academic performance (Y) controlling for intelligence (X) or vice-versa ($X \leftrightarrow M$). Finally, we applied the Sobel test to determine the effect size and significance of the difference between indirect and direct effects (the change was reported as a z score effect).[35] We conducted the previous analysis by standard path-analytic approaches described by Preacher & Hayes[36] and MacKinnon.[37]

Moderation and moderated mediation analysis

When the strength of the relationship between two variables is dependent on a third variable, this represents a moderation effect.[38] We assessed the extent to which the effect of fluid intelligence on academic performance was moderated by diagnostic status, gender, or socioeconomic status (SES) using moderated ordinary least-squares (OLS) regression analysis.[39,40] We then combined the moderation and mediation results by estimating the conditional indirect effects of the predictor (X) on academic performance (Y) through the mediator (M) as a function of group, gender, or SES, using the moderated mediation method described by Preacher et al.[41] Finally, moderation analysis (OLS regression) was also performed to test whether the influence of ADHD symptoms on academic problems was conditioned to fluid intelligence level. The moderator effect of fluid intelligence on academic performance was estimated using the "pick-a-point" approach: dimensional scores were split into three groups according to the fluid intelligence level of the sample – high (plus one standard deviation from the mean or higher), average (scores between one standard deviation from the mean), or low (scores minus one standard deviation from the mean or lower).

We carried out all statistical procedures in SPSS version 20.0. Moderated mediation analyses were done in an SPSS macro (PROCESS) developed by Hayes[38] to model mediation, moderation, and conditional processes.

Results

Descriptive analysis

Table 1 shows sociodemographic characteristics, Raven's CPM, and Brazilian SAT scores for the sample overall and stratified by diagnostic groups. There were no statistically significant between-group differences in age or SES. The frequency of males was significantly higher in the ADHD group. The ADHD group had higher SNAP-IV inattentive and hyperactive-impulsive scores, as well as worse performance on Raven's CPM, spelling, and arithmetic compared to TD students. As shown in Table 2, we found a significant relationship of fluid intelligence with inattentive symptoms, spelling, and arithmetic performance, but not with hyperactivity-impulsivity. Therefore, we entered only the inattentive dimension in the mediation models.

Table 3 presents all effects on academic performance. Fluid intelligence and inattention had significant direct effects on spelling performance. When simultaneously entered in the regression model, fluid intelligence and inattention were still significant predictors, accounting for 25% of spelling score variance. However, both measures were less influent when taking together, with a higher decrease in fluid intelligence predictive power. The mediation model testing the influence of fluid intelligence on spelling performance through inattention was the only statistically significant one. Mediation analysis for the opposite model (influence of inattention on spelling performance through fluid intelligence) was marginally significant ($p = 0.07$). Therefore, the results suggest that behavioral inattention was a partial mediator of intelligence influence on spelling performance.

We tested whether the significant mediation model was conditioned to diagnostic groups (ADHD vs. TD), gender, or SES. Table 4 shows these results. A 95% bootstrap confidence interval for the moderator effect was entirely above zero (significant) only for students in the low SES group. Thus, the impact of fluid intelligence level on spelling performance through phenotypic inattention was further evident for low-SES children in our sample. However, the direct effect of fluid intelligence on spelling performance (i.e., independent of inattentive behavior) was stronger for TD children and girls, as well as for students at the low SES group.

Table 1 Participant characteristics and between-group comparisons

	All (n=95)	ADHD (n=62)	TD (n=33)	t/χ^2	p-value	d/φ
Age (years), mean ± SD	9.62±1.66	9.60±1.77	9.67±1.45	0.19	0.850	-0.04
Male gender*	60 (63)	49 (79)	11 (33)	19.33	0.001	0.45
High SES	30 (32)	20 (32)	10 (30)	0.10	0.750	0.03
ADHD subtype						
Inattentive	19 (20)	19 (31)	-	-	-	-
Hyperactive	3 (3)	3 (5)	-	-	-	-
Combined	40 (42)	40 (64)	-	-	-	-
Psychiatric comorbidity						
Oppositional defiant disorder	27 (28)	27 (44)	0 (0)	-	-	-
Mood/anxiety disorder	12 (13)	12 (19)	0 (0)	-	-	-
ADHD behaviors						
Inattention, mean ± SD*	15.85±7.87	20.53±4.00	7.06±5.43	11.51	0.001	3.00
Hyperactivity-impulsivity, mean ± SD*	13.84±8.12	18.40±5.79	5.27±3.70	11.80	0.001	2.57
Fluid intelligence, $mean_{z\ score}$ ± SD†	0.20±0.87	0.04±0.90	0.50±0.75	2.52	0.010	-0.55
Academic performance						
Spelling, $mean_{z\ score}$ ± SD*	0.07±1.10	-0.23±1.05	0.65±0.96	4.02	0.001	-0.87
Arithmetic, $mean_{z\ score}$ ± SD*	-0.13±1.23	-0.43±1.27	0.42±0.96	3.38	0.001	-0.73

ADHD = attention-deficit/hyperactivity disorder; SD = standard deviation; SES = socioeconomic status; TD = typically developing.
Results presented as n (%), unless otherwise noted.
* Difference was significant at $p < 0.001$; † difference was significant at $p < 0.01$.

Table 2 Correlations between all independent variables and the outcome variables (standard errors in parentheses)

Measures	2	3	4	5
1. Fluid intelligence	-0.25* (0.10)	-0.08 (0.10)	0.37† (0.08)	0.27* (0.10)
2. Inattention	-	0.74† (0.05)	-0.45† (0.08)	-0.36† (0.08)
3. Hyperactivity-impulsivity		-	-0.36† (0.09)	-0.26* (0.09)
4. Spelling			-	0.62† (0.07)
5. Arithmetic				-

5000 bootstrap samples.
* Correlation was significant at the 0.05 level (two-tailed); † correlation was significant at the 0.001 level (two-tailed).

Relationship between fluid intelligence and ADHD dimensions on arithmetic performance

We found significant direct effects on arithmetic performance for fluid intelligence and inattention (OFAT). In the full model, however, only behavioral inattention remained a significant predictor, accounting for 12% of variance in arithmetic performance. The difference between the direct and indirect effects was significant, suggesting that the influence of fluid intelligence on arithmetic performance is completely mediated by inattentive symptoms. For arithmetic performance only, this mediation model (and not the model testing fluid intelligence as mediator instead of inattentive problems) had a significant effect size.

Similar to the mediation model for spelling performance, the moderated mediation analysis for arithmetic performance was significant only for students in the low SES group. This means that the behavioral inattentive phenotype might be a mechanism of fluid intelligence influence on arithmetic performance, especially in children in the low SES group of this sample. Even the direct effect of fluid intelligence on arithmetic performance was only significant for children with low SES, but it seems to be homogeneous between ADHD and TD children, and also between genders.

Figure 1 presents the mediation model of intelligence influence on academic performance through behavioral inattention.

The influence of hyperactivity-impulsivity on academic performance

Regardless of moderate direct effects of hyperactivity-impulsivity on spelling and arithmetic performance,

Table 3 Direct and indirect effects of independent variables on outcome variables and significance of mediation models

Condition/Outcome (Y)/Predictor(s)	β	t	SE_{boot}	p-value	R^2_{adj}	Mediation model	z	p-value
OFAT/Spelling								
Gf	0.37	3.78	0.11	< 0.001	0.12	X = Gf; M = INATT	2.12	0.03
INATT	-0.45	-4.87	0.01	< 0.001	0.19	X = INATT; M = Gf	1.85	0.07
Simultaneous/Spelling								
Gf	0.27	2.91	0.11	0.005	0.25			
INATT	-0.38	-4.16	0.01	< 0.001				
OFAT/Arithmetic								
Gf	0.24	2.41	0.15	0.02	0.05	X = Gf; M = INATT	1.92	0.05
INATT	-0.36	-3.69	0.01	< 0.001	0.12	X = INATT; M = Gf	1.30	0.19
Simultaneous/Arithmetic								
Gf	0.16	1.63	< 0.001	0.11	0.12			
INATT	-0.32	-3.18	0.02	0.002				
OFAT/Spelling								
INATT	-0.45	-4.87	0.01	< 0.001	0.19	X = HYP-IMP; M = INATT	-2.84	0.005
HYP-IMP	-0.36	-3.70	0.01	< 0.001	0.12	X = INATT; M = HYP-IMP	-0.42	0.67
Simultaneous/Spelling								
INATT	-0.41	-2.97	0.02	0.004	0.19			
HYP-IMP	-0.06	-0.43	0.02	0.67				
OFAT/Arithmetic								
INATT	-0.36	-3.69	0.01	< 0.001	0.12	X = HYP-IMP; M = INATT	-2.49	0.01
HYP-IMP	-0.26	-2.54	0.01	0.01	0.06	X = INATT; M = HYP-IMP	0.12	0.90
Simultaneous/Arithmetic								
INATT	-0.37	-2.57	0.02	0.01	0.11			
HYP-IMP	0.02	0.12	0.02	0.9				

5000 bootstrap samples.
Gf = fluid intelligence; HYP-IMP = hyperactivity-impulsivity; INATT = inattention; M = mediator; OFAT = one factor at a time; SE = standard error; X = predictor.

Table 4 Moderator effects of group diagnosis, gender, socioeconomic status, and hyperactivity-impulsivity

Academic domain/Moderator (W)/Group (n)	Direct effect*	p-value	Indirect effect†	SE_{boot}	CI
Spelling					
Group					
ADHD (n=62)	0.25	0.07	0.002	0.03	-0.06 to 0.07
TD (n=33)	0.57	0.01	0.08	0.07	-0.01 to 0.28
Gender					
Male	0.19	0.23	0.03	0.05	-0.05 to 0.15
Female	0.45	0.01	0.09	0.07	-0.02 to 0.28
SES					
Low‡	0.37	0.01	0.17	0.08	0.05 to 0.36
High	-0.07	0.73	0.06	0.12	-0.15 to 0.34
HYP-IMP level					
Low	0.54	0.01	0.12	0.09	-0.01 to 0.34
Average	0.37	0.002	0.06	0.05	-0.004 to 0.19
High	0.21	0.21	-0.01	0.04	-0.09 to 0.06
Arithmetic					
Group					
TD	0.18	0.51	0.06	0.07	-0.01 to 0.28
ADHD	0.24	0.15	0.00	0.03	-0.05 to 0.07
Gender					
Male	0.06	0.75	0.03	0.05	-0.04 to 0.15
Female	0.37	0.08	0.09	0.08	-0.02 to 0.28
SES					
Low‡	0.34	0.05	0.14	0.07	0.03 to 0.34
High	-0.31	0.23	0.05	0.10	-0.12 to 0.29
HYP-IMP level					
Low	0.42	0.07	0.15	0.11	-0.01 to 0.42
Average	0.25	0.08	0.07	0.06	-0.002 to 0.23
High	0.08	0.67	-0.01	0.05	-0.12 to 0.08

5000 bootstrap samples.
CI = confidence interval; SE = standard error; SES = socioeconomic status; HYP-IMP = hyperactivity-impulsivity; TD = typically developing.
* Magnitude of the effect of "intelligence" on "academic performance" as a function of the moderator; † magnitude of the effect of "intelligence" on "academic performance" through "behavioral inattention" as a function of the moderator.
‡ The indirect effect was significant at the 0.05 level.

these effects were completely reduced when inattention was inserted in the simultaneous regression models. This means that the influence of hyperactivity-impulsivity on academic performance was fully accounted for by inattentive problems. We report the significance and effect size of these mediation models in Table 3. In addition, we tested hyperactivity-impulsivity as a moderator of the influence of fluid intelligence on academic performance through behavioral inattention (see Table 4), to investigate whether the strength of this indirect effect changes as a function of the level of hyperactivity-impulsivity. Both for spelling and arithmetic performance, we found no moderator effects on the mediation model. However, the direct influence of fluid intelligence on academic performance was stronger for children in the average and low hyperactive-impulsive level groups. Among children in the high (plus one standard deviation from the mean or higher) hyperactive-impulsive symptoms group, there was no significant effect, which suggests that fluid intelligence, as a marker of general cognitive abilities, might be not related to problems in academic performance in this group.

Influence of inattentive symptoms on academic performance depending on fluid intelligence level

Table 5 shows the moderator effect of fluid intelligence on the association between behavioral inattention and academic performance. The effect of inattentive symptoms on academic performance seems to be marginally significant for children in the low range of fluid intelligence, but remains largely significant for students at the average and high fluid intelligence levels.

Discussion

In this study, we observed a significant mediation model in which inattentive symptoms mediate the relationship between fluid intelligence and academic performance. The direct influence of fluid intelligence on spelling performance was stronger for TD children than for ADHD children, but we found no differences depending on diagnostic status for arithmetic performance. The same moderator pattern was shown for gender and general cognitive abilities, where girls were more impaired than boys, but only in the spelling test. On the

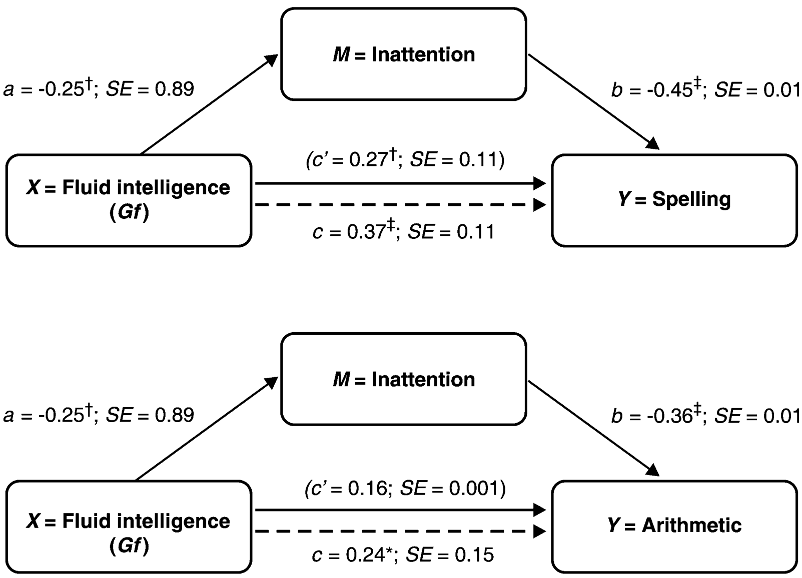

Figure 1 Mediation model of fluid intelligence influence on academic performance through inattentive symptoms in ADHD dimensional behavior. Gf = fluid intelligence; SE = standard error; M = mediator; X = predictor; Y = outcome. Fluid intelligence (c) and inattentive symptoms (b) were strong individual predictors of spelling and arithmetic performance. However, fluid intelligence (c′) had an indirect effect on academic performance through behavioral inattention (a). * $p < 0.05$; † $p < 0.01$; ‡ $p < 0.001$.

other hand, both direct (fluid intelligence) and indirect (fluid intelligence through behavioral inattention) effects on academic performance were stronger for the low SES group compared with the high-SES group.

These results reinforce that, among ADHD behavioral traits, the inattentive dimension is particularly important for educational achievement, since the association between hyperactivity-impulsivity and academic performance is mediated by behavioral inattention.[4,15] Additionally, the influence of inattentive symptoms on academic performance tends to be homogeneous across fluid intelligence levels. The nature of inattentive problems at the low end of the typical intelligence distribution is controversial in the literature, but even in ADHD cases in which a comorbid intellectual disability is present, there are few treatment differences.[42]

This investigation has important implications, as it supports behavioral inattention as a central target to avoid academic problems in childhood. Math performance may be especially sensitive to interventions focusing on inattentive symptoms,[43] since, according to our results, the general cognitive underpinnings of math performance are likely to be fully mediated by behavioral inattention. Although some studies have argued that intelligence may not influence the relationship between ADHD and academic performance,[20,21] the mediation analyses used in the present study suggest that this could be a misinterpretation of the direct and indirect effects of these variables. Considering a cognitive-to-behavioral influence on academic problems, fluid intelligence evaluation in the context of inattentive problems would be extremely relevant for better prediction of academic outcomes.[18,44] Poorer cognitive performance and high levels of inattention may increase the need for special education.[45] However, it is worth noting that the academic performance of children with the highest levels of hyperactivity-impulsivity in our sample might be explained by other abilities besides fluid intelligence. Unlike the majority of cognitive aspects related to ADHD, affective motivational features (e.g., delay aversion/

Table 5 Moderator effect of fluid intelligence on inattentive symptoms and academic performance association

Outcome/fluid intelligence level	Effect	SE_{boot}	t	p-value	CI
Spelling	-0.04	0.02	-1.90	0.06	-0.08 to 0.002
Low					
Average*	-0.05	0.01	-3.85	< 0.001	-0.08 to -0.03
High*	-0.06	0.02	-3.84	< 0.001	-0.10 to -0.03
Arithmetic	-0.04	0.02	-1.76	0.08	-0.09 to 0.006
Low					
Average*	-0.05	0.02	-3.02	0.003	-0.08 to -0.02
High*	-0.05	0.02	-2.68	0.009	-0.09 to -0.01

5000 bootstrap samples.
CI = confidence interval; SE = standard error.
* The direct effect was significant at the 0.01 level.

discounting) are equally associated with both ADHD behavioral dimensions, and affective regulation might be important to academic outcomes independently of intelligence.[4,46] Shared environmental influences, in addition to overlapping genetic factors, might be responsible for associations between hyperactivity-impulsivity and academic performance.[15] Future research should investigate how high levels of hyperactivity-impulsivity, apart from inattention, may predict school achievement.

As noted above, SES was the only moderator of the cognitive-to behavioral mediation model of dimensional ADHD trait influence on academic performance. This is not surprising, as low SES is a known risk factor for ADHD independently of other variables.[47] Furthermore, fluid intelligence is itself positively correlated with SES factors.[48] Usually, environmental conditions or peculiar features closely related to low-income individuals (which could overwhelm higher mental processes) explain outcomes associated with low SES.[49] Therefore, our study adds to the robust body of evidence for low SES as a moderator of ADHD features.

In general, our findings also highlight a methodological issue. It may be difficult to control for intelligence in ADHD school achievement research, as the inattentive dimension of ADHD mediates the association of fluid intelligence effect on academic performance. Only considering intelligence scores as a covariate in predictive models might be quite inaccurate.[50] Since a systematic negative relationship between ADHD symptoms and intelligence exists, controlling for differences in intelligence may remove variance that is due to ADHD in the measures under investigation.[5] Even recommending a significant discrepancy between intelligence and specific measures of academic performance in ADHD as a diagnostic criterion for comorbid learning disabilities may be problematic, as 1) at least in some contexts, general cognitive abilities might be etiologically associated with academic performance; and 2) specific cognitive functions intrinsically related to ADHD and school success are also powerful predictors of performance in formal tests of general intelligence.[18]

This study has limitations, which we must address. We relied on a single type of informant report (parent reports) to assess ADHD-related symptoms. Another important limitation was the use of only one measure of intelligence, focusing on its fluid aspect. Raven's CPM assesses general aspects of reasoning, such as mental arithmetic and non-verbal reasoning. However, since other measures, such as the widely used Wechsler IQ tests, may require knowledge of vocabulary, numbers, and arithmetic – abilities frequently impaired as outcomes in the context of ADHD – tests requiring only spatial and reasoning skills might be a methodological strength.[51] Further studies applying additional sources of behavioral information (e.g., teacher ratings) and different measures of intelligence are required to expand our results. The absence of control for comorbid disorders was another weakness of our work. Comorbid psychiatric disorders are a potential factor of impact on general cognitive abilities in ADHD, as comorbid groups may have lower IQ scores than pure ADHD groups.[52] Furthermore, we did not exhaust possible relationship explanations. At least for language abilities, reading problems themselves may play a causative role in inattentive behavior, notably for children at the beginning of formal education.[53] On the other hand, our sample included TD learners and children identified as ADHD who were not under any pharmacological treatment, which are major strengths of the present study.

In conclusion, this study showed how fluid intelligence and behavioral ADHD symptoms relate to academic performance. Given the importance of academic development in future outcomes,[51] its underlying mechanisms should be investigated.

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Disclosure

The authors report no conflicts of interest.

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