

Methylphenidate-Related Improvements in Math Performance Cannot Be Explained by Better Cognitive Functioning or Higher Academic Motivation: Evidence From a Randomized Controlled Trial

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Abstract

Objective: This study investigated whether improvements in working memory, reaction time, lapses of attention, interference control, academic motivation, and perceived competence mediated effects of methylphenidate on math performance. **Method:** Sixty-three children (ADHD diagnosis; methylphenidate treatment; age 8-13; IQ > 70) were randomly allocated to a 7-day methylphenidate or placebo treatment in this double-blind placebo-controlled crossover study and compared with 67 controls. Data were collected at schools and analyzed using mixed-model analysis. Methylphenidate was hypothesized to improve all measures; all measures were evaluated as potential mediators of methylphenidate-related math improvements. **Results:** Controls mostly outperformed the ADHD group. Methylphenidate did not affect measures of cognitive functioning ($p = .082-.641$) or academic motivation ($p = .199-.865$). Methylphenidate improved parent ratings of their child's self-perceived competence ($p < .01$), which mediated methylphenidate efficacy on math productivity. **Conclusion:** These results question the necessity of improvements in specific cognitive and motivational deficits associated with ADHD for medication-related academic improvement. They also stimulate further study of perceived competence as a mediator. (*J. of Att. Dis.* 2020; 24(13) 1824-1835)

Keywords

academic performance, ADD/ADHD, cognition, methylphenidate, competence

Introduction

ADHD is a developmental disorder characterized by attentional problems, hyperactivity, and impulsivity (American Psychiatric Association, 2013). Children with ADHD often experience problems at school, varying from mild underperformance to the need for special education or school dropout (DuPaul, 2007). Academic underperformance is one of the main reasons for referral for treatment with stimulant medication being the most commonly prescribed treatment (Wright et al., 2015). Although behavioral improvements of stimulant medication are robust (MTA-group, 1999; Van der Oord, Prins, Oosterlaan, & Emmelkamp, 2008), effects on academic performance are often limited to mathematical performance, and improvements in quality (accuracy) are generally smaller than improvements in productivity (e.g., Benedetto-Nasho & Tannock, 1999; Froehlich et al., 2014; McGough et al., 2006; Murray et al., 2011). Effect sizes are small, and improvements in schoolwork quality are less evident.

Moreover, evidence for long-term improvement of academic performance is lacking so far (Arnold, Hodgkins, Kahle, Madhoo, & Kewley, 2015; Baweja, Mattison, & Waxmonsky, 2015; Froehlich et al., 2014; Kortekaas-Rijlaarsdam, Luman, Sonuga-Barke, Bet, & Oosterlaan, 2017; Langberg & Becker, 2012; Prasad et al., 2013).

In addition to ADHD symptoms, cognitive and motivational problems may further contribute to academic underperformance in children with ADHD (Luman, Oosterlaan, & Sergeant, 2005; Willcutt, Doyle, Nigg, Faraone, & Pennington, 2005). Cognitive problems of children with ADHD are especially apparent in attention, working memory, and response

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inhibition, all functions where deficits have previously shown to be associated with academic underperformance (Biederman et al., 2004; Mayes & Calhoun, 2007; Preston, Heaton, McCann, Watson, & Selke, 2009; Thorell, 2007). Given the robust evidence for these specific cognitive deficits in children with ADHD and the association of such deficits with academic underperformance, these deficits might also contribute to the academic problems of these children (Mullane, Corkum, Klein, & McLaughlin, 2009; Willcutt et al., 2005).

Several studies suggest that low academic motivation also contributes to the academic underperformance of children with ADHD (DuPaul et al., 2004; Langberg, Arnold, Hinshaw, & Swanson, 2012). For example, self-rated intrinsic academic motivation is lower for children with ADHD than for typically developing (TD) children. These motivational problems are also confirmed by lower parent and teacher ratings of these children's academic motivation (Carlson, Booth, Shin, & Canu, 2002). This lower intrinsic academic motivation is likely to negatively influence school performance for children with ADHD (Gut, Heckmann, Meyer, Schmid, & Grob, 2012). Supporting this, low motivation for schoolwork has been shown to mediate the relation between ADHD symptoms and academic underperformance by decreasing study skills (DiPerna, Volpe, & Elliott, 2005; Volpe et al., 2006). Besides lower intrinsic academic motivation, children with ADHD also show altered sensitivity to punishment and reward (Luman et al., 2005), which may alter the extrinsic motivation for schoolwork. Extrinsic motivation is important to perform well at school because rewards and punishments, such as feedback and grades, are widely used methods to enhance academic performance. Children with ADHD have been shown to depend more on external rewards than TD children in terms of optimal cognitive functioning (Luman et al., 2005). As the amount of feedback at school is usually comparable for all children, a lack in external rewards in class in addition to low intrinsic motivation may further impair academic performance.

In addition to motivation for schoolwork, perceived academic competence has been shown to influence academic performance (Skinner, Wellborn, & Connell, 1990; Spinath, Spinath, Harlaar, & Plomin, 2006; Steinmayr & Spinath, 2009). Perceived academic competence includes beliefs about one's own capacities and abilities, and has reciprocal relationships with academic performance, with higher competence improving performance and better performance increasing perceived competence (Guay, Marsh, & Boivin, 2003). Perceived competence is theorized to precede intrinsic motivation, suggesting that children with ADHD with lower intrinsic academic motivation may also perceive their own competence as lower than TD children (Deci & Ryan, 1985; Harter, 1981; Wigfield & Eccles, 2000). Indeed, a study by Scholtens, Rydell, and Yang-Wallentin (2013) showed that ADHD symptoms are negatively associated

with self-rated perceived academic competence in adolescents with ADHD. Together, these findings suggest that besides cognitive deficits and low academic motivation, a reduction in perceived academic competence may further explain academic underperformance in children with ADHD.

Accumulating evidence suggests that stimulant medication improves cognition, with small to medium effect sizes for working memory, large effect sizes for lapses of attention, and moderate effect sizes for response inhibition (Coghill et al., 2014; Pietrzak, Mollica, Maruff, & Snyder, 2006). Although studies into the effects of stimulants often report improvements in both cognition and academic performance, the relation between these is rarely studied. For example, both Murray et al. (2011) and Wigal et al. (2011) show that methylphenidate (MPH)-related improvements in reading and math are accompanied by improvements in attention, including fewer lapses of attention. However, it is unclear whether these improvements in attention mediate the effects of MPH on school performance. Studies into the effects of stimulant medication on motivational deficits and perceived competence in ADHD are scarce and inconsistent. One study showed no improvement in self-rated perceived academic competence with MPH compared with placebo (Ialongo, Lopez, & Horn, Pascoe, & Greenberg, 1994), whereas another study showed that MPH improved reward sensitivity for delayed rewards in children with ADHD, suggesting enhanced extrinsic motivation (Shiels et al., 2009). The lack of studies on the effect of stimulant medication on motivational deficits in ADHD, despite the abundant use of this type of medication to treat ADHD and the evidence that such pharmacological agents have substantial effects on the motivational attitude of healthy participants (Volkow et al., 2004), is striking. Stimulant medication is thought to affect the dopamine-based brain networks, which include structures such as the ventral striatum, which are active during reward processing (Volkow et al., 2004), and activity in these networks is found to increase the salience of outcomes and improve the motivation to perform (Shiels et al., 2009; Swanson et al., 2004). Thus, it is likely that stimulant medication improves aspects of academic motivation in children with ADHD.

The current study aimed to gain more insight into the effects of MPH on a number of specific cognitive processes known to be associated with ADHD, and deficits in both motivation and competence, factors that are important for academic performance. The acute effects of MPH on cognition (working memory, lapses of attention, and interference control), academic motivation (intrinsic and extrinsic), and perceived academic competence were investigated using a double-blinded, placebo-controlled crossover design. Previously, we demonstrated that MPH improved mathematical productivity and accuracy, and that improvements in mathematical productivity were mediated by symptom

improvements (Kortekaas-Rijlaarsdam et al., 2017). Here, we extended these findings to unravel the mechanism behind medication-related improvements in math performance. We therefore investigated the mediating role of these cognitive functions, motivation and competence, in MPH-related improvements in math. Performance of children with ADHD on placebo was compared with performance of TD children. We expected children with ADHD on placebo to show deficits in cognition, motivation, and perceived competence (Carlson et al., 2002; Luman et al., 2005; Mullane et al., 2009; Scholtens et al., 2013; Willcutt et al., 2005). Furthermore, we hypothesized MPH to improve math performance through (a) improvements in working memory, lapses of attention, and interference control (Coghill et al., 2014; Mayes & Calhoun, 2007; Pietrzak et al., 2006; Preston et al., 2009; Thorell, 2007) and (b) increases in intrinsic academic motivation, extrinsic motivation, and perceived academic competence (DuPaul et al., 2004; Gut et al., 2012; Langberg et al., 2012; Volkow et al., 2004).

Method

Participants

Sixty-five children with ADHD were recruited between 2012 and 2014 through four mental health clinics in the Netherlands, the Dutch parent association for children with developmental problems, and the study's website. Sixty-seven TD children were recruited in the same period through primary schools. Inclusion criteria for both groups were (a) age between 8 and 13 years, (b) at least 1 year of Dutch primary school education to ensure full understanding of test instructions, and (c) an estimated full-scale IQ of at least 70. Full-scale IQ was estimated using a short form of the Wechsler Intelligence Scale for Children, Third edition (WISC-III; including the subtest Information, Vocabulary, Block Design, and Symbol Search; Wechsler, 1991), with excellent validity ($r = .91$) and reliability ($r_{xx} = .93$) for estimating full-scale IQ (Sattler, 2001).

In addition, children with ADHD met the following criteria: (a) a clinical diagnosis of ADHD confirmed by the Diagnostic Interview Schedule for Children for *DSM-IV*, Parent version (DISC-P; Shaffer, Fisher, Lucas, Dulcan, & Schwab-Stone, 2000), and (b) a score >90th percentile on the Inattentive and/or Hyperactive/Impulsive scale of both parent and teacher version of the Disruptive Behavior Disorder Rating Scale (DBDRS; Oosterlaan, Scheres, Antrop, Roeyers, & Sergeant, 2000; Pelham, Evans, Gnagy, & Greenslade, 1992) to ensure symptom severity and pervasiveness, (c) treatment with MPH or indication for treatment with MPH, and (d) no concomitant (parent reported) neurological disorders or autism spectrum disorder. Children in the TD group were included if they had no

(parent reported) psychiatric or neurological disorder, including ADHD. To ensure the absence of ADHD, children in the TD group were required to obtain scores ≤ 90 th percentile on the Inattentive and Hyperactive/Impulsive scale of the parent version of the DBDRS. In addition, the chance of including children with ADHD in our TD group was minimized through screening for psychiatric morbidity using parental reports about psychiatric morbidity and reports about the consultation of mental health specialists. TD children were excluded if reported to have ever been diagnosed with a psychiatric disorder.

Two children in the ADHD group did not complete the trial due to adverse events unrelated to the intervention, resulting in 63 participants with ADHD completing the trial.

Medication Design

A randomized double-blind placebo-controlled crossover design was used to compare the direct effects of extended release MPH (Equasym XL®) with placebo. Equasym XL® has an 8-hr duration of action with a 30% component of immediate release and a 70% component of extended release 4 to 5 hr after dosing (Banaschewski et al., 2006). Although we accepted applications of stimulant-naïve children, children were only included after successful titration by their treating physician and after a period of stable treatment (at least 3 weeks; mean duration of treatment was 30.7 months, $SD = 19.1$). Titration was performed in a classical manner (increasing dose gradually until maximal symptom improvement is reached with tolerable side effects), in conformity with standard clinical practice (see, for example, NICE guidelines: "Attention Deficit Hyperactivity Disorder: Diagnosis and Management," 2016). Before enrollment in the study, medication washout was achieved using a period of at least 48 hr prior to the start of the first treatment week and between the two treatment weeks. Children were tested on the last day of each treatment week at their own primary school. Medication was prescribed by the treating physician. Doses were identical to those clinically titrated and currently prescribed. When a child was treated with immediate release MPH, the long-acting equivalents were calculated taking into account differences in plasma concentrations and duration of action between the different brands of long-acting MPH, as described in Banaschewski et al. (2006). Daily doses varied between 10 and 40 mg, with 27% of the children receiving 10 mg, 44% receiving 20 mg, 24% receiving 30 mg, and 5% receiving 40 mg. Both active MPH and placebo capsules were inserted in other capsules to ensure visual equality. Our academic pharmacist, who was not in contact with any participants, was responsible for randomization using predefined randomization blocks to determine medication or placebo sequence. Researchers, children, parents, and teachers were

blinded to the intervention. Due to the low dropout risk, randomization occurred without replacement.

Materials

Table 2 provides an overview of all cognitive and motivational variables.

Cognition. Verbal working memory was measured with Digit Span backward of the WISC-III, which has good reliability and validity (Wechsler, 1991). Participants repeated sequences, with increasing span, in reversed order. The task was terminated when a child made two errors on trials of the same sequence length, or when participants reached the maximum span of seven. The dependent variable was the total number of correct responses multiplied by the highest sublevel passed (Kessels, van Zandvoort, Postma, Kappelle, & de Haan, 2010).

In the visuospatial working memory task, participants reproduced (Nutley, Söderqvist, Bryde, Humphreys, & Klingberg, 2009), in backward order, sequences of yellow circles with increasing difficulty (one circle was added every four trials and the position of stimuli were manipulated every two trials from positions with low to high memory load), which were presented in a 4×4 grid on a computer screen. The task was terminated when the participant failed to accomplish both trials at a certain difficulty level. Reliability and validity of this task have been demonstrated (Nutley et al., 2009). The total number of correct responses multiplied by the highest difficulty level achieved served as the dependent measure.

Reaction time (RT) speed, lapses of attention, and interference control were measured with a modified version of the Flanker task, which has adequate reliability and validity (Eriksen & Eriksen, 1974; Fan, McCandliss, Sommer, Raz, & Posner, 2002). Participants pressed one of two buttons corresponding to the direction of a target arrow presented on a computer screen. The target arrow was flanked by identical arrows (congruent), arrows pointing in opposite direction (incongruent) or horizontal rectangles (neutral). Following practice, four blocks of 12 trials were completed. RT speed was calculated from the neutral trials and corrected for accuracy to control for speed accuracy tradeoff. For this purpose, inverse efficiency scores (mean RT divided by proportion correct) were used as dependent variables (Mullane et al., 2009). Lapses of attention (τ) were reflected in the exponential component of the RT distribution, calculated using the model of Lacouture and Cousineau (2008) excluding trials with extreme slow responses ($>3 SD$ above the mean). Interference control was measured by calculating the difference between inverse efficiency scores in congruent and incongruent trials (Mullane et al., 2009).

Motivation and perceived academic competence. Intrinsic motivation was measured using the Children's Academic

Intrinsic Motivation Inventory (CAIMI), which has adequate reliability (Gottfried, 1985, 1986). This is a self-report questionnaire about the enjoyment of learning, comprising three subscales: General (18 statements), and Math and Reading (each 26 statements). Items were scored on a 5-point Likert-type scale.

Extrinsic motivation (sensitivity to punishment and reward) was measured using the parent-rated Sensitivity to Punishment and Sensitivity to Reward Questionnaire for Children (SPSRQ-C; Colder & O'Connor, 2004; Luman, Van Meel, Oosterlaan, & Geurts, 2012). Punishment sensitivity (15 items; 5-point Likert-type scale) and Reward responsiveness scales (seven items; 5-point Likert-type scale) were used.

Self-perceived academic competence was measured using the School scale of the Self Perception Profile for Children (SPPC), which has adequate reliability and content validity (Veerman, Straathof, Treffers, van den Bergh, & ten Brink, 2004). Six statements were (self-)rated by children, their parents, and teachers on a 4-point Likert-type scale. For all questionnaires, raw scale scores were used as dependent variables.

Analyses

Participation of 63 children was sufficient to guarantee .80 power ($\alpha = .05$) to detect MPH effects (Twisk, 2013). Performance of the ADHD group was compared with the TD group using independent sample t tests or, in case of nonnormality, Wilcoxon Signed-Rank Tests, using SPSS version 21 (IBM, 2012). Outliers were rescaled to the nearest observation plus one unit. MPH effects on cognition, motivation, and competence were estimated using generalized linear mixed model (GLMM) analysis with a fixed effect for treatment and a random intercept to control for within-subject dependency of measurements.

For cognitive, motivational, and competence measures that improved significantly with MPH, the possible mediating effect of this variable on academic improvement with MPH was estimated. Elsewhere, we demonstrated positive effects of MPH on mathematical productivity and accuracy (for details see Kortekaas-Rijlaarsdam et al., 2017); thus, variables were selected as possible mediators if (a) there was a significant effect of MPH on the mediator and (b) there was a significant effect of the mediator on math performance when controlled for treatment condition. One case was missing for the CAIMI measuring intrinsic motivation, three cases were missing for parent-rated academic competence, and five cases were missing for teacher-rated academic competence. Using GLMM with a random intercept, we calculated the regression coefficients of the effects of MPH on the mediator (β_a) and of the mediator on math performance (β_b) when fixed effects of both MPH and the mediator were

Table 1. Group Characteristics of the ADHD and TD Group.

	ADHD (<i>n</i> = 63)		TD (<i>n</i> = 67)		ADHD vs. TD
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	
% boys (<i>n</i>)	68.25 (43)		59.70 (40)		$\chi^2 = 1.03$
Age	10.49	1.24	10.16	1.32	<i>t</i> = -1.43
Estimated IQ	97.68	13.82	106.10	12.93	<i>t</i> = 3.45**
DBD parents					
Inattention	17.46	4.40	3.78	2.98	<i>t</i> = -20.86**
Hyperactivity/impulsivity	13.21	5.32	3.06	2.75	<i>t</i> = -13.78**
ODD	7.21	4.28			
CD	1.68	2.43			
DBD teacher					
Inattention	16.40	4.88			
Hyperactivity/impulsivity	11.89	6.91			
ODD	4.92	4.82			
CD	1.14	2.24			
DISC parents					
Inattention	7.83	1.16			
Hyperactivity/impulsivity	6.22	2.40			
ODD	2.95	2.29			
CD	0.46	1.08			

Note. TD = typically developing controls; DBD = Disruptive Behavior Disorder Rating Scale; ODD = oppositional defiant disorder; CD = conduct disorder; DISC = Diagnostic Interview Schedule for Children.

***p* < .01.

entered in the model. To quantify the significance of the mediator, the product term $\beta_a \beta_b$ of the regression coefficients with accompanying confidence interval was calculated using the asymptotic normal distribution method (Krull & MacKinnon, 2001; Tofighi & Mackinnon, 2011), thereby assuming a covariance of zero between β_a and β_b (Tofighi, Mackinnon, & Yoon, 2009). If the 95% confidence interval (CI) did not include zero, the effect of the mediator was significant.

Procedure

The study was approved by the local ethics committee. All parents as well as children above the age of 11 provided written informed consent prior to enrollment in the study. For children with ADHD, after the screening procedure confirming the ADHD diagnosis and establishing sufficient intelligence ($IQ > 70$), testing took place on the last day of each treatment week and started 60 to 90 min after medication intake. Testing was done individually in a quiet room within the primary school of the child. Total testing time was 120 min (including breaks). Testing occurred during plasma peak levels of MPH (Banaschewski et al., 2006). On testing days, teachers and parents were asked to fill out the SPPC and SPSRQ-C covering behavior on the previous 7 days. In each medication condition, treatment duration was 7 days. This

allowed parents to observe their child's behavior when medication was active, particularly during weekends and during two additional afternoons on which children of 8 to 12 years are at home from school. Thus, parents observed their children for a total of three full days in each condition, including breakfast and dinner. Teachers observed their students for three full school days and two school mornings. After a short explanation of the procedure, testing started with the SPPC, followed by the Flanker task, visuospatial working memory task, CAIMI, and verbal Digit Span backward. The TD group was assessed only once. Testing procedures were identical in the ADHD and TD group, with the exception that the testing of the TD group was preceded by a short version of the WISC-III to estimate TD children's IQ as TD children were first seen on the day of the assessment. Participants with ADHD received a small gift.

Results

Group characteristics of the ADHD and TD group are shown in Table 1. In our ADHD group, we included 14 children in Grade 4 to 5 (age 8-9), 19 children in Grade 6 (age 9-10), 17 children in Grade 7 (age 10-11), and 13 children in Grade 8 (age 11-13). Our TD group included 19 children in Grade 4 to 5, 14 children in Grade 6, 16 children in Grade 7, and 18 children in Grade 8.

Comparisons of Cognition, Motivation, and Competence of ADHD and TD Group

Table 2 displays the results for the academic, executive functions (EF), motivational, and competence measures of the ADHD group during MPH and placebo and for the TD group. Three participants in the TD group and two participants in the ADHD group had missing data on the measure of accuracy for mathematical word problems. On the EF measures, data were missing for one ADHD participant for the verbal working memory task, the visuospatial working memory task, and the Flanker task. For the TD group, data were missing for one participant for the verbal working memory task and for two participants on the Flanker task. Missing values were not imputed.

ADHD (Placebo) Versus TD

The ADHD group on placebo showed worse performance on the visuospatial working memory task and more lapses of attention than the TD group, $t(128) = 3.52$, $p = .001$, $d = .63$, and $t(125) = 3.74$, $p < .001$, $d = .67$, respectively. Differences between the ADHD and TD group were not significant for performance on the Digit Span backward, RT speed and interference control. In addition, children with ADHD on placebo rated their intrinsic motivation for math on the CAIMI as significantly lower than TD children, $t(127) = 2.61$, $p = .01$, $d = .46$, whereas group differences in intrinsic motivation for schoolwork in general and for reading were not significant. Children with ADHD on placebo also showed higher reward responsivity and higher sensitivity to punishment on the SPSRQ-C, $t(125) = -3.73$, $p < .001$, $d = .67$ and $t(125) = 1.90$, $p = .06$, $d = .34$, respectively, although the latter just escaped conventional levels of significance. Children with ADHD on placebo perceived their own academic competence (SPPC) as significantly lower than TD children, a finding that was corroborated by competence ratings of both parents and teachers, $t(128) = 3.96$, $p < .001$, $d = .70$ and $t(125) = 7.18$, $p < .001$, $d = 1.28$ and $t(126) = 5.80$, $p < .001$, $d = 1.03$, respectively.

MPH Effects on Cognition, Motivation, and Competence

MPH failed to result in any significant beneficial effects on the performance on Digit Span backward, the visuospatial working memory task, RT speed, lapses of attention, and interference control (see Table 2). GLMM analysis showed that the effect of MPH on self-rated competence according to parents (SPPC) was significant with a medium effect, $t(60.6) = 2.93$, $\beta = -1.05$, $p = .005$, $d = .53$. MPH did not affect academic competence rated by the child or teacher, intrinsic academic motivation (CAIMI General, Math, and

Reading), or sensitivity to punishment or reward (SPSRQ-C; see Table 2).

Mediation Analysis

For parent-rated self-perceived competence, the first two criteria for mediation (Baron & Kenny, 1986) were met as MPH positively influenced math productivity and accuracy, as well as parent-rated self-perceived competence. To investigate whether the third criterion for mediation was met, GLMM was used to test whether parent-rated self-perceived competence affected math productivity and accuracy. Parent-rated self-perceived competence significantly affected math productivity but not accuracy when entered in a model with medication treatment: $t(74.1) = 3.30$, $\beta = .53$, $p = .001$ and $t(114.4) = 1.67$, $\beta = 1.34$, $p = .097$, respectively. The addition of parent-rated self-perceived competence to the model of the effects of MPH on math productivity reduced the influence of MPH: For math productivity, the effect of MPH reduced from $\beta = 1.95$ ($p < .001$) to $\beta = 1.41$ ($p = .007$). To ensure that age did not alter the effects of parent-rated self-perceived competence and MPH on math productivity, we also performed the analyses with age as a moderator. Age did not moderate the effects of MPH on any of the math outcomes (all p values $> .05$). To quantify the influence of parent-rated self-perceived competence as a partial mediator of the effects of MPH on math productivity, we performed multilevel mediation analysis using GLMM. The results showed that parent-rated self-perceived competence was a significant mediator of the effects of MPH on math productivity: For β_a (effect of MPH on parent-rated self-perceived competence) = 1.06 ($SE = .36$) and β_b (effect of parent-rated self-perceived competence on math productivity) = 0.53 ($SE = .16$), the product term $\beta_a \beta_b$ was 0.56 ($SE = .26$) with a 95% CI of [0.13, 1.15], not including zero.

Discussion

In the current study, we investigated the effects of MPH on cognitive functions important for learning, academic motivation, and perceived academic competence. To better understand the limited and selective academic medication-related improvements in children with ADHD (Langberg & Becker, 2012; Prasad et al., 2013), we aimed to identify possible mediators of MPH-related improvements in math performance. Our results corroborate with earlier studies in showing that children with ADHD not only underperform in comparison with their TD peers on school subjects (DuPaul, 2007; Kortekaas-Rijlaarsdam et al., 2017) but also perform worse on cognitive measures important for academic performance. More specifically, we found children with ADHD to be impaired in terms of visuospatial working memory and lapses of attention (Mullane et al., 2009;

Table 2. Effects of MPH on Cognition, Academic Motivation, and Perceived Academic Competence.

	ADHD									
	PLA		MPH		TD		PLA vs. MPH		PLA vs. TD	
	M	SD	M	SD	M	SD	t	d	T	d
Cognition										
Verbal working memory										
Number correct × Achieved level (DS)	13.98	9.81	16.22	12.89	15.58	9.02	486(W)		1779.5(U)	
Visuospatial working memory										
Number correct × Achieved level (Grid)	54.95	33.86	57.66	37.27	76.30	35.21	0.47		3.52**	0.63
RT speed										
IE (Flanker, neutral condition)	628.86	133.41	625.51	135.18	610.92	136.76	4284(W)		-0.75	
Lapses of attention										
Tau (Flanker, neutral condition)	150.33	74.72	135.57	88.06	100.52	75.14	-1.77 [†]	0.32	-3.74**	0.67
Interference control										
IE (Flanker, incongruent-congruent)	100.18	63.94	104.77	135.11	85.54	63.72	0.62 ^a		2339(U)	
Motivation and competence										
Intrinsic motivation General (CAIMI)	60.05	8.47	60.13	9.91	62.48	8.24	0.17		1.65	
Intrinsic motivation Math (CAIMI)	76.34	20.70	77.37	20.39	84.39	13.87	0.90		2.61*	0.46
Intrinsic motivation Reading (CAIMI)	80.08	19.99	81.33	19.85	83.75	17.21	1.04		1.12	
Reward responsivity (SPSRQ-C)	22.32	4.99	21.77	5.22	19.26	4.24	-0.98		-3.73**	0.67
Sensitivity to punishment (SPSRQ-C)	38.23	9.32	37.69	10.12	35.35	7.72	-0.94		-1.90 [‡]	0.34
Self-perceived competence (SPPC-S)	15.05	3.17	15.41	3.03	17.03	2.52	1.30		3.96**	0.70
Parent-rated self-perceived competence (SPPC-S)	14.40	2.82	15.44	3.37	17.97	2.78	2.93**	0.53	7.18**	1.28
Teacher-rated self-perceived competence (SPPC-S)	14.19	2.99	14.32	3.25	17.38	3.20	0.87		5.80**	1.03

Note. MPH = methylphenidate; TD = typically developing controls; PLA = placebo; W = Wilcoxon signed-rank test statistic; U = Mann-Whitney U test statistic; DS = Digit Span backward; RT = reaction time; IE = inverse efficiency calculated as mean RT/proportion correct; CAIMI = Children's Academic Intrinsic Motivation Inventory; SPSRQ-C = Sensitivity to Punishment and Sensitivity to Reward Questionnaire for Children; SPPC-S = Self Perception Profile for Children-School Scale; Accuracy = Items correct / Items completed × 100%; Productivity = Items completed / Items available × 100%.

^aTreatment (MPH versus placebo) by condition (congruent versus incongruent) interaction.

[†]p = .08. [‡]p = .06. *p < .05. **p < .01.

Willcutt et al., 2005). Furthermore, children with ADHD were found less motivated for schoolwork, specifically for math, in line with previous reports (Carlson et al., 2002). In addition, our results confirm that children with ADHD may be somewhat more sensitive to punishment and reward than TD children (Luman et al., 2005). Moreover, self-perceived competence (according to children, their parents, and their teachers) was lower for the ADHD group than for the TD group, which corroborates the previous finding of a negative relationship between ADHD symptoms and self-perceived competence (Scholtens et al., 2013).

Although group differences in cognitive performance and academic motivation between our ADHD group and the TD group were large and previous literature reports positive

effects of MPH on cognition and motivation for learning, our results tone down the importance of these variables in the explanation of MPH-related academic improvements. In spite of testing an elaborate set of relevant cognitive and motivational variables, overall, we found no improvements in cognition and motivation with MPH compared with placebo. As our ADHD group clearly underperformed on the selected variables in comparison with TD peers, it is unlikely that these results are due to lack of room for improvement in our ADHD group. We also trust that the absence of effects is not due to lack of power, as we had sufficient power to detect medium-sized effects which seems suitable for the selected cognitive variables based on a recent meta-analysis (Coghill et al., 2014). In addition,

standardized mean differences of the effects of MPH on cognition and motivation are small (mostly $<.05$), supporting the idea that our results are not due to a lack of power. Furthermore, we investigated a specific set of cognitive measures (working memory, RT, lapses of attention, and interference control), which are often affected in children with ADHD and related to academic underperformance (Biederman et al., 2004; Mayes & Calhoun, 2007; Preston et al., 2009; Thorell, 2007). There are, however, many more ADHD-related cognitive processes that we have not included in our study and that may show MPH-related improvements relevant for academic performance.

For self-perceived academic competence, differences between children with ADHD and TD children were large and corroborated by all informants (self-rated, parents, and teachers). However, only parent-rated self-perceived academic competence improved significantly with MPH. A possible explanation for this finding is that parent-rated self-perceived competence relies more on symptom improvements than on actual academic performance and that parents are more sensitive to detect such behavioral improvements in diverse settings than teachers (Shemmashian & Lee, 2012). In a previous study, we showed that parent-rated symptom improvements mediated math productivity (Kortekaas-Rijlaarsdam et al., 2017). There may have been room for bias here: If parents observed symptom improvements in their child, they may have been more prone to rate their child's self-perceived competence as higher. However, although parent-rated academic competence and parent-rated symptom improvements correlate significantly ($r = .53$) in our sample, parent-rated academic competence significantly predicted math performance over and above parent-rated symptom improvements when entered together in a model, $t(76.3) = 2.54$, $\beta = 0.48$, $p = .013$.

Our results show that parent-rated self-perceived academic competence mediates the positive effects of MPH on math productivity. This is an important finding, as motivation and self-perceived competence are especially important for school performance of children with ADHD (Gut et al., 2012). Given the reciprocal relationship between academic competence and performance (Guay et al., 2003), the finding that parent-rated self-perceived academic competence increases over such a short period (7 days) is promising; higher perceived competence is not only directly related to better academic outcomes (DuPaul et al., 2004; Volpe et al., 2006) but may also precede motivational changes in the child, which in turn, may improve study skills and thereby further improve academic performance (DiPerna et al., 2005; Wigfield & Eccles, 2000). The fact that parent-rated self-perceived competence only mediated MPH-related improvements in math productivity is also in line with the findings by Skinner et al. (1990). In that study, a relation was observed between self-perceived competence

and classroom participation. Such improved classroom participation is likely to directly result in higher productivity but does not necessarily result in higher accuracy. The fact that we found a mediating effect for self-perceived competence only is also in line with findings from Steinmayr and Spinath (2009), showing that self-perceptions of ability are a better predictor of academic performance than self-reported intrinsic values. However, previous research focused on child ratings (self-ratings) of self-perceived competence, whereas we find MPH-related improvements in parent-rated self-perceived competence. We focused on parent ratings because such ratings may be more reliable than ratings done by the young children included in the study. More research on this topic is necessary.

In addition, it is important to consider whether the way a cognitive process was assessed influenced our findings, that is, laboratory task measures versus parent-/teacher- or self-report questionnaires. Perhaps questionnaires are more sensitive in general compared with tasks. Future studies should include questionnaire-based measures tapping the same processes as the tasks. Furthermore, for ethical reasons, our trial had a limited duration of 2 weeks, and therefore, results do not necessarily generalize to long-term academic outcomes. However, within this short period, significant improvements in parent-rated self-perceived competence were apparent and MPH resulted in improvements on most cognitive, motivation, and competence measures. It might be speculated that a longer-term trial may result in additional improvements in cognition and motivation, for example, resulting from improved competence (Wigfield & Eccles, 2000). To maximize ecological validity, we included children after titration by their treating physician following current standard clinical guidance. This may, however, have resulted in lower MPH efficacy compared with double-blind titration procedures (MTA-group, 1999). Furthermore, all participants were already treated with MPH; therefore, it is hard to distinguish between acute and chronic effects of MPH. Baseline measures (without MPH or placebo) were not part of the current design. As placebo effects of MPH are usually strong in studies with comparable duration (Krogsbøll, Hróbjartsson, & Gøtzsche, 2009), this could explain the absence and magnitude (small) of effects in our study. Adding a baseline measure in future studies may help clarify the interpretation of MPH effects on cognitive performance further. In addition, although our questionnaires on motivation and perceived competence have good psychometric qualities, this is the first study that investigates the impact of stimulants on these questionnaire scores. Therefore, their sensitivity to detect stimulant effects is still unknown.

In conclusion, our results confirm that ADHD is associated with deficits in working memory, increases in lapses of attention, lower academic motivation, and lower perceived competence, variables that have proven important for

school performance. Our results tone down the importance of cognition and motivation in the explanation of MPH-related improvements in academic functioning. Short-term MPH-related improvements are apparent for parent-rated academic competence. More specifically, these improvements in parent-rated competence mediate the positive effects of MPH on math productivity which may be promising for longer-term improvements in motivation and academic performance.

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