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Executive Functions and Writing Skills in Children With and Without ADHD

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Abstract

Objective: Pediatric ADHD has been associated with impairments in executive functioning and academic writing skills. However, our understanding of the extent to which these children's writing difficulties are related to their underdeveloped executive functions – and whether this relation is attributable to specific executive functions – is limited.

Method: A clinically evaluated and carefully phenotyped sample of 91 children ages 8–13 (M=10.60, SD=1.25; 37 girls) were administered multiple, counterbalanced tests of the three core executive functions (working memory, inhibitory control, set shifting), assessed for ADHD symptoms via multiple-informant reports, and completed standardized, norm-referenced testing of three core writing skills (written expression, spelling, writing fluency).

Results: Bias-corrected, bootstrapped conditional effects modeling indicated that underdeveloped working memory exerted significant direct effects on all three writing skills, as well as indirect effects on written expression and spelling via the ADHD symptoms pathway (all 95%CIs exclude 0.0). In contrast, inhibitory control uniquely predicted spelling difficulties only, set shifting was not associated directly or indirectly with any assessed writing skill, and ADHD symptoms failed to uniquely predict writing skills after controlling for working memory. This pattern of results replicated across informants (parent vs. teacher ADHD symptom ratings), and was robust to control for age, sex, SES, majority/minority race/ethnicity status, IQ, decoding skills, language skills, and learning disability status.

Conclusion: These findings suggest multiple pathways to writing skill difficulties in children with ADHD, while suggesting that their overt behavioral symptoms may be less involved in their writing difficulties than their underlying neurocognitive vulnerabilities.

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Conflict of Interest:
The authors have no conflicts of interest to report.

Ethical Approval:
All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed Consent:
Informed consent was obtained from all individual participants included in the study.

Keywords

Executive function; ADHD; written expression; spelling; writing fluency

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Attention-deficit/hyperactivity disorder (ADHD) is a heterogeneous neurodevelopmental disorder present in approximately 5% of school-aged children (Polanczyk et al., 2014) and characterized by impairing symptoms of inattention, hyperactivity, and/or impulsivity (American Psychiatric Association, 2013). Children with ADHD consistently demonstrate impairments in executive functions (Willcutt et al., 2005) as well as across multiple domains of writing skills (Kent et al., 2014). However, little is known regarding the extent to which these findings are due to shared mechanisms as opposed to reflecting independent deficits in ADHD. Given the pervasiveness of both executive function deficits (e.g., up to 89% of children with ADHD may have deficits in at least one executive function; Kofler et al., 2018) and written expression deficits in ADHD (e.g., up to 65% of children with ADHD may meet criteria for a specific learning disability in writing; Mayes et al., 2000; Re & Cornoldi, 2010), it is imperative to examine the influence of executive functioning on writing skills in children with ADHD.

ADHD and Writing Skills

Academic impairment is pervasive in ADHD, with an estimated 33% to 80% of children with ADHD demonstrating academic and learning difficulties (DuPaul & Langberg, 2015; Mayes & Calhoun, 2006). Substantial research documents ADHD-related academic complications including higher incidences of grade retention, failed grades, school dropout and expulsion, special education referrals, and problematic relationships with school peers and teachers (Barkley et al., 2006; Batzle et al., 2010; Currie & Stabile, 2006; Frazier, 2007, 2014; Mannuzza et al. 1997; McGee et al. 2000). With regard to writing skills, replicated evidence implicates ADHD inattention and hyperactivity/impulsivity symptoms as significant risk factors for spelling and written expression difficulties in clinical and typically developing samples (Massetti et al., 2008; Kent et al., 2014), with stronger relations reported in samples of children diagnosed with ADHD (Carroll et al., 2005; Benedetto-Nasho & Tannock, 1999). In addition, specific learning disorders/disabilities (SLDs) in written expression may co-occur with ADHD approximately twice as often as any other learning disability (Mayes et al., 2000), and writing difficulties are often identified in children with ADHD who do not meet formal SLD criteria (Mayes & Calhoun, 2006). These difficulties are apparent across a broad range of writing skills including writing quantity, syntax, fluency, and spelling (Bledsoe et al., 2010; Cassas et al., 2013; Re & Cornoldi, 2010). Specifically, children with ADHD tend to write shorter and fewer sentences (Bledsoe et al., 2010; Cassas et al., 2013; Kent et al., 2014), make more structural and grammatical errors than their typically developing peers (Re et al., 2007; Re & Cornoldi, 2010; Resta & Eliot, 1994; Kim & Lee, 2009), use fewer connectors and subordinate clauses, have more incoherent sentences, exhibit lower syntactic complexity (Cassas et al., 2013), and have a greater number of spelling errors compared to their same-aged peers (Levy et al., 1989).

Two theoretical frameworks have been proposed to account for the relation between pediatric ADHD and deficits in writing skills. In the first model, attention deficits have been proposed as a common mechanism underlying the comorbidity between ADHD and underachievement in academic domains such as writing (Mayes et al., 2000; Mayes & Calhoun, 2006). In this framework, attention problems during academic instruction reduce the opportunities to benefit from classroom teaching and learning objectives, resulting in fewer opportunities to learn, practice, retain, and demonstrate knowledge of information, including class material related to bolstering writing skills (Posner & Rothbart, 2007). Evidence supporting this hypothesis includes the evidence reviewed above (Benedetto-Nasho & Tannock, 1999; Carroll et al., 2005; Massetti et al., 2008; Kent et al., 2014), as well as studies showing that attention problems predict spelling accuracy (Noda et al., 2013). In the second model, executive function abilities have been proposed as an underlying mechanism of writing impairments in ADHD, both independently and via the impact of executive dysfunction on ADHD behavioral symptoms (Eckrich et al., 2018). Evidence supporting this model includes emerging associations between executive functioning and writing skills as described below (Casas et al., 2013; Walda et al., 2014), as well as evidence that executive dysfunction may underlie, at least in part, inattentive and hyperactive/impulsive behavioral symptoms in children with ADHD (Kofler et al., 2010; Rapport et al., 2009; Alderson et al., 2010). However, no study to date has concurrently assessed all three core executive functions (Karr et al., 2018) and multiple components of writing skills in children with and without ADHD.

Executive Functions and Writing Skills

Executive functions refer to a set of interrelated, higher-order neurocognitive processes that facilitate and regulate goal-directed and problem-solving thoughts and behaviors (Baddeley, 2007; Miyake et al., 2000). Although many diverse models of executive functions have been hypothesized, theoretical and factor analytic work in children (Karr et al., 2018) and adults (Miyake et al., 2000) provide the most support for three distinguishable domains: *working memory* (i.e., top down, active manipulation of information held in temporary memory; Baddeley, 2007), *inhibitory control* (i.e., the ability to withhold or suppress a pre-potent behavioral response; Lewis & Carpendale, 2009), and *set shifting* (i.e., the ability to flexibly switch between mental sets; Pa et al., 2010). These core executive functions in turn enable goal-oriented behavior and support a host of secondary higher-level cognitive abilities including but not limited to planning (Jaroslawska et al. 2016; Kofler et al. 2018; Miyake et al. 2000), organizational skills (e.g., Kofler et al., 2017), pro-active and reactive interference control (Wiemers & Redick 2018), goal-maintenance (Engle & Kane 2004), vigilance (Raiker et al. 2012), response consistency (Kofler et al. 2014; Wiemers & Redick 2018), perseveration (Miyake et al. 2000), and delay tolerance (Patros et al. 2015).

Interestingly, all three core executive functions have been linked with children’s writing skills. Impairments in working memory have been linked to higher rates of semantic and mechanical errors and slower rates of writing (Chenoweth & Hayes, 2003; Morken & Helland, 2013) along with written expression difficulties in children (Cooke et al., 2006; McDonald, 2008). Preliminary research further suggests that experimentally reducing the burden on working memory resources during writing may enable these resources to be redistributed to other components of writing, including the creation of reader-friendly prose, which then increases the overall quality of writing samples (Carretti et al., 2016;

Peverly, 2006). Similarly, emerging evidence suggests that inhibitory control is associated with grammar skills (Cordeiro et al., 2019; Ibbotson & Kearvell-White, 2015; Puranik et al., 2019), and that children with writing problems demonstrate reduced performance on measures of set shifting (Hooper et al., 2002). However, no study to date has concurrently examined all three executive functions. Thus, it remains unclear whether these findings provide evidence linking all three executive functions with writing skills, or whether these links may be more parsimoniously attributable to one or more executive functions given their moderate interrelations and task impurity (Miyake et al., 2000; Snyder et al. 2015).

ADHD, Executive Functioning, and Writing Skills

In addition to evidence from the cognitive and developmental literatures, there is emerging evidence linking executive functions with writing skills specifically in children with ADHD. Extant research has shown working memory's association with spelling (Kroese et al., 2000) and written expression (Eckrich et al., 2018) in pediatric ADHD, and emerging experimental evidence indicates that children with ADHD commit more errors on spelling tasks as compared to neurotypical peers under high loads of working memory (Kroese et al., 2000; Re et al., 2014). Additionally, inhibitory control difficulties have been associated with decreased written expression skills in children with ADHD (Bledsoe et al., 2010; Semrud-Clikeman & Harder, 2010). Examining the relations among executive functions, ADHD, and writing skills is important as recent literature suggests that a majority of children with ADHD may exhibit deficits in at least one executive function (Fosco et al., 2020; Karalunas et al., 2017; Kofler et al., 2018). Furthermore, replicated evidence suggests that some, if not all, executive functions may underlie ADHD symptomatology (Barkley, 1997; Snyder et al., 2015; Willcutt et al., 2005) and functioning (Willcutt et al., 2005), with functional if not causal evidence based on experimental (e.g., Kofler et al., 2010; Rapport et al., 2009) and longitudinal studies (e.g., Karalunas et al., 2017). Taken together, the evidence base at this time implicates executive function deficits in ADHD behavioral symptoms (Karalunas et al., 2017; Kofler et al., 2010) and writing skill difficulties (Casas et al., 2013; Kent et al., 2014; Kim & Lee, 2009) separately. However, to our knowledge no studies have concurrently examined all three executive functions in relation to multiple components of writing performance in a pediatric ADHD sample.

Current Study

Taken together, the evidence base at this time indicates that children with ADHD consistently demonstrate deficits in executive functions and writing skills, but it remains unclear whether these areas of difficulty are interrelated or whether there is specificity in the relation between individual executive functions and writing skills in pediatric ADHD. The current study is the first to use conditional effects modeling to examine the extent to which each of the three core executive functions (Miyake et al., 2000) predicts three core writing skill domains (defined below), both directly and indirectly via the impact of executive dysfunction on ADHD symptom expression (e.g., Kofler et al., 2018), in a carefully-phenotyped, clinical child sample using a multi-trait, multi-method, multi-task, and multi-informant approach. We hypothesized that working memory would uniquely predict written expression, spelling, and writing fluency (Cooke et al., 2006; Hooper et al., 2002; McDonald, 2008) while inhibitory control and set shifting would uniquely predict written expression only (Ibbotson & Kearvell-White, 2015). In addition, we hypothesized that ADHD symptoms, specifically attention problems, would predict all three writing outcomes (Mayes & Calhoun, 2006), both independently and indirectly via their association with one or more executive functions. No predictions were made regarding the extent to which each executive function would predict writing skills via shared associations with ADHD symptoms (i.e., conditional effects) due to the paucity of previous literature.

Method

Participants

The sample comprised 91 children aged 8 to 13 years (*M*=10.60, *SD*=1.25; 37 girls) from the Southeastern United States, recruited by or referred to a university-based children's learning clinic (CLC) through community resources (e.g., pediatricians, community mental health clinics, school system personnel, self-referral) from 2015 to 2017 for participation in a larger study of the neurocognitive mechanisms underlying pediatric attention and behavioral problems. All parents and children gave informed consent/assent, and the Florida State University Institutional Review Board approval was obtained/maintained. The sample was mixed with 61 White Non-Hispanic (67.0%), 12 Black (13.2%), 7 Hispanic (7.7%), 10 Multiracial children (11.0%), and 1 Asian child (1.1%).

Group Assignment

All children and caregivers completed a detailed, semi-structured clinical interview using the Kiddie Schedule for Affective Disorders and Schizophrenia for School-Aged Children (K-SADS; Kaufman et al., 1997). The K-SADS (2013 Update) allows differential diagnosis according to symptom onset, course, duration, quantity, severity, and impairment in children and adolescents based on DSM-5 criteria (APA, 2013), and was supplemented with parent and teacher ratings scales from the Behavior Assessment System for Children (BASC-2/3; Reynolds & Kamphaus, 2004) and ADHD Rating Scale for DSM-4/5 (ADHD-RS-4/5; DuPaul et al., 2016). A psychoeducational report was provided to parents; children selected a small toy (<$5) from a prize box after each session.

Fifty-one children met all of the following criteria and were included in the ADHD group: (1) DSM-5 diagnosis of ADHD Combined (*n* = 31), Inattentive (*n* = 16), or Hyperactive/Impulsive Presentation (*n* = 4) by the CLC's directing clinical psychologist and multidisciplinary team based on K-SADS and differential diagnosis considering all available clinical information indicating onset, course, duration, and severity of ADHD symptoms consistent with the ADHD neurodevelopmental syndrome, (2) borderline/clinical elevations on at least one parent and one teacher ADHD subscale (i.e., > 90th percentile); and (3) current impairment based on parent report. Children with any current ADHD presentation specifiers were eligible given the instability of ADHD subtypes (Lahey et al., 2005; Valo & Tannock, 2010; Willcutt et al., 2012). To improve generalizability (Wilens et al., 2002), children with comorbidities were included. Our standard assessment battery also included norm-referenced child internalizing disorder screeners, and additional standardized measures were administered clinically as needed to inform differential diagnosis and accurate assessment of comorbidities (e.g., child clinical interviews, additional testing).

Comorbidities reflect clinical consensus best estimates and included oppositional defiant (11.8%)[1], depressive (5.9%), anxiety (25.5%), and high-functioning autism spectrum disorders (ASD, 9.8%). A total of 18 children screened positive for a single (n=10) or multiple (n=8) learning disabilities in reading (13.7%), math (13.7%), and/or writing (19.6%) in the ADHD group. Positive screens for learning disabilities were defined based on score(s) ≥ 1.5 SD below age-norms on one or more KTEA-3 academic skills battery subtests, as specified in DSM-5 (APA, 2013).

The Non-ADHD group comprised 40 consecutive case-control referrals (18 girls) who did not meet ADHD criteria and included both neurotypical children and children with psychiatric disorders other than ADHD. Neurotypical children (65.0%) had normal developmental histories and nonclinical parent/teacher ratings, were recruited through community resources, and completed the same evaluation as clinically-referred cases. Clinically referred and evaluated children who did not meet ADHD criteria were also included in the Non-ADHD group. These Non-ADHD disorders were included to control for comorbidities in the ADHD group, and included best estimate diagnoses of anxiety (20.0%), depressive (10.0%), and high -functioning autism spectrum disorders (12.5%). Two children in the Non-ADHD group screened positive for a specific learning disability in writing. Importantly, the ADHD and Non-ADHD groups did not differ in the proportion of children diagnosed with anxiety (p = .54), depression (p = .47), and ASD (p = .69). The ADHD group has a larger proportion of children with ODD and positive SLD screens as expected (both p<.05).

Children were excluded from the study if they presented with (a) gross neurological, sensory, or motor impairment, (b) history of a seizure disorder, psychosis, intellectual disability, or (c) non-stimulant medications that could not be withheld for testing. Psychostimulants ($N_{prescribed}$=25) were withheld for a minimum of 24 hours prior to both research testing sessions.

Procedures

Children participated in 2 research sessions following the baseline psychoeducational assessment (3 hours each). The executive function tasks were administered by trained examiners as part of a larger battery of laboratory tasks that were counterbalanced within and across sessions to minimize order effects. Psychoeducational testing was conducted according to standard clinical practice protocols. For the research sessions, performance was monitored at all times by the examiner, who was stationed just out of the child's view to provide a structured setting while minimizing performance improvements associated with examiner demand characteristics (Gomez & Sanson, 1994). All children received brief breaks after each task and preset longer breaks after every 2–3 tasks to minimize fatigue.

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[1] As recommended in the K-SADS, oppositional defiant disorder was diagnosed clinically only with evidence of multi-informant/multi-setting symptoms. ODD comorbidity is 39.2% in the ADHD group based on parent-reported symptoms counts.

Measures

Working Memory Tasks

Rapport working memory reordering tests.: The Rapport phonological and visuospatial working memory test and administration instructions are identical to those described in Kofler et al. (2018). Reliability and validity evidence for the Rapport et al. (2009) computerized phonological and visuospatial working memory tasks includes high internal consistency (α= .81–.97), 1–3-week test-retest reliability (.76–.90; Kofler et al., 2019; Sarver et al., 2015), convergent validity with criterion working memory complex span (*r*=.69) and updating tasks (*r*=.61; Wells et al., 2018), and large magnitude ADHD/Non-ADHD between group differences (Fosco et al., 2020; Kofler et al., 2018). Six trials per set size were administered in randomized/unpredictable order (3–6 stimuli/trial; 1 stimuli/second). Five practice trials were administered before each task (80% correct required). Task duration was approximately 5 (visuospatial) to 7 (phonological) minutes.

For the phonological working memory task, children were presented a series of jumbled numbers and a capital letter. The letter never appeared in the first or last position of the sequence to minimize potential primacy and recency effects, and was counterbalanced across trials to appear an equal number of times in the other serial positions (i.e., position 2, 3, 4, or 5). Children were instructed to verbally recall numbers in order from smallest to largest, and to say the letter last (e.g., 4H62 is correctly recalled as 246H). For the visuospatial working memory task, children were shown nine squares arranged in three offset vertical columns. A series of 2.5 cm diameter dots (3, 4, 5, or 6) were presented sequentially in one of the nine squares during each trial, such that no two dots appeared in the same square on a given trial. All but one dot presented within the squares was black—the exception being a red dot that was counterbalanced across trials to appear an equal number of times in each of the nine squares, but never presented as the first or last stimulus in the sequence to minimize potential primacy and recency effects. Children reordered the dot locations (black dots in serial order, red dot last) and responded on a modified keyboard. Partial-credit unit scoring (i.e., stimuli correct per trial) was used to index overall working memory performance at each set size 3–6 was used as recommended (Conway et al., 2005). Mean stimuli correct per trial were computed separately for the phonological and visuospatial working memory tests. Higher scores reflect better working memory.

Letter updating working memory.: The letter updating test and administration instructions are identical to those described in Fosco et al. (2019). The Miyake et al. (2000) letter memory test was adapted for use with children and involves the constant monitoring and rapid addition/deletion of working memory contents (Miyake & Friedman, 2012). Psychometric support for this version includes high internal consistency (α=.75), expected magnitude relations with other working memory tests (Kofler et al., 2018), and large magnitude ADHD/Non-ADHD between group differences (Fosco et al., 2020; Kofler et al., 2018). In this computerized task, letters were presented on the screen one at a time, and children were instructed to keep track of the last three letters presented. To ensure the task required continuous updating, children were instructed to rehearse out loud the last three letters by mentally adding the most recent letter and dropping the fourth letter back and then saying the new string of three letters out loud (Miyake et al., 2000). The number of letters presented (4–8 stimuli presented/trial, 1200 ms presentation, 2400 ms ISI) was varied randomly across trials to ensure that successful performance required continuous updating until the end of each trial. A practice block was administered; children advanced to the test phase following three correct practice trials. Four blocks of three test trials each were administered. Children responded via mouse click. Mean stimuli correct per trial across the 12 test trials was computed. Higher scores reflect better working memory.

Inhibitory Control

Stop-signal inhibitory control.: The stop-signal test and administration instructions are identical to those described in Alderson et al. (2008). Psychometric evidence includes high internal consistency (α= .80; Kofler et al., 2019) and three-week test–retest reliability (.72), as well as convergent validity with other inhibitory control measures (Soreni et al., 2009). Go-stimuli are displayed for 1000 ms as uppercase letters X and O positioned in the center of a computer screen (500 ms interstimulus interval; total trial duration = 1500 ms). Xs and Os appeared with equal frequency throughout the experimental blocks. A 1000 Hz auditory tone (i.e., stop-stimulus) was presented randomly on 25% of trials. Stop-signal delay (SSD)—the latency between presentation of go- and stop-stimuli—is initially set at 250 ms. Successfully inhibited stop-trials are followed by a 50 ms increase in SSD, and unsuccessfully inhibited stop-trials are followed by a 50 ms decrease in SSD. All participants completed two practice blocks and four consecutive experimental blocks of 32 trials per block (24 go-trials, 8 stop-trials per block) using a modified response pad. SSD across the four task blocks was selected based on conclusions from recent meta-analytic reviews that it is the most direct measure of inhibitory control in stop-signal tasks that utilize dynamic SSDs, given that SSDs change systematically according to inhibitory success or failure (Alderson et al., 2007; Lijffijt et al., 2005).[2] Higher SSD scores indicate better inhibitory control.

Go/no-go inhibitory control.: The go/no-go test and administration instructions are identical to those described in Kofler et al. (2019). Psychometric evidence includes high internal consistency (α=.95) as well as convergent validity with other inhibitory control measures (Kofler et al., 2019). Children were presented a randomized series of vertical (go stimuli) and horizontal (no-go stimuli) rectangles in the center of a computer monitor (2000 ms presentation, jittered 800–2000 ms ISI to minimize anticipatory responding). They were instructed to quickly click a mouse button each time a vertical rectangle appeared, but to avoid clicking the button when a horizontal rectangle appeared. A ratio of 80:20 go:no-go stimuli was selected to maximize prepotency (Kane & Engle 2003; Unsworth & Engle 2007). Children completed a 10 trial practice (80% correct required) followed by 4 continuous blocks of 25 trials each. Commission errors reflect failed inhibitions (i.e., incorrectly responding to no-go trials), and served as the primary index of inhibitory control during each of the four task blocks. Mean commission errors per block was computed; lower scores indicate better inhibition.

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[2] Stop-signal reaction time (SSRT) was also computed for each task block due to current debate in the literature regarding the optimal metric for estimating inhibitory control from the stop-signal task. When substituted for SSD, SSRT failed to load with the inhibitory control variable from the go/no-go task when factor analyzed and was therefore excluded from further analysis.

Set Shifting

Global-local set shifting.: The global-local test and administration instructions are identical to those described in Irwin et al. (2019). This task uses Navon (1977) figures, which feature a “global” shape (e.g., a circle) constructed using smaller, “local” figures (e.g., squares). Psychometric evidence includes high internal consistency (α = .86–.90) as well as convergent validity with other set shifting measures (Kofler et al., 2019). Figures were presented one at a time in one of four quadrants (clockwise rotation) on a computer monitor (jittered ISI 800–2000ms). To minimize memory demands, on-screen cues (“big shape,” “small shapes”) were positioned next to each quadrant. Following three blocks of 6 to 8 practice trials (100% correct required), children completed 4 consecutive blocks of 15 trials each. Children were required to shift their response between global and local features and use the mouse to click on their response depending on which quadrant the figures appeared (top quadrants: global; bottom quadrants: local). Trials with stimuli in the top left or bottom right quadrants involved set shifting (shift trials) because responses required a different rule than the previous trial; trials with stimuli in the top right or bottom left quadrants did not require shifting because they featured the same rule as the previous trial (non-shift trials). Following Miyake et al. (2000) and Irwin et al. (2019), set shifting abilities were operationalized as speed shift costs (Speed shift cost = $RT_{shift} - RT_{non\text{-}shift}$ for correct trials). Lower speed shift costs reflect better set shifting.

Number-color set shifting.: The number-color test and administration instructions are identical to those described in Kofler et al. (2019). Psychometric evidence includes high internal consistency (α = .87–.95) as well as convergent validity with other set shifting measures (Kofler et al., 2019). A pair of single-digit numbers appeared on the screen, and children were instructed to click either the larger or smaller value depending on the font color (colors selected for maximal discrimination across individuals with all types of color vision). Both digits were the same color on any given trial. To minimize memory demands, on-screen instructions (blue bigger, yellow smaller) remained visible throughout the task. Following an 8-trial practice block (100% correct required), children completed 4 consecutive blocks of 30 trials each (120 total trials; jittered ISI 80–200 ms). Trials were presented in a semi-random sequence to require shifting every other trial, with an equal number of bigger-smaller and smaller-bigger shifts. RT data was recorded and processed identically to the global-local data described above. Lower speed shift costs reflect better set shifting.

Executive Function Dimension Reduction—Task impurity was controlled by computing Bartlett maximum likelihood component scores based on the intercorrelations among all 7 of the executive function tests (DiStefano et al., 2009), which parsed the 3 working memory, 2 inhibitory control, and 2 set shifting tasks into three component scores (66.41% of variance explained; Supplementary Table 1). A three-component solution was specified *a priori* to derive separate estimates of working memory, inhibitory control, and set shifting based on theory and previous empirical work (e.g., Miyake et al. 2000). These principal components analysis-derived component scores provide estimates of reliable, construct-level variance attributable to domain-general working memory, inhibitory control, and set shifting, respectively. This formative method for estimating executive functioning was selected because (a) such methods have been shown to provide higher construct stability relative to confirmatory/reflective approaches (Willoughby et al., 2017); and (b) estimating executive functioning at the component- rather than measure-level was expected to maximize associations with the study's academic outcomes via the removal of task-specific and error variance. By design, the intercorrelations among the varimax-rotated working memory, inhibitory control, and set shifting components were $r_{\text{all}} = .00$ ($p > 0.99$).[3] These component scores were used in all analyses. Higher scores reflect better working memory and inhibitory control, but worse set shifting.

Writing Skills

Kaufman Test of Educational Achievement (KTEA-3).: The KTEA-3 (Kaufman & Kaufman, 2014) was used to assess children's academic writing skills (α = .97–.99; 1–2 week test-retest = .95–.96). The KTEA contains three writing skill subtests: Written Expression, Spelling, and Writing Fluency. *Written Expression* refers to the ability to communicate effectively in writing and is measured by hearing a story presented with pictures in a booklet and completing the story by adding/correcting punctuation/capitalization and writing words, sentences, and an essay. *Spelling* refers to how one applies phonetic principles and how sensitive one is to the relation of letters and patterns and is measured by writing words dictated by the examiner. *Writing Fluency* refers to the speed at which one can transcribe what they want to say and is measured by writing simple sentences, each one describing a different picture, within a time limit. Standard scores for each of these writing skills were obtained by comparing performance to the nationally representative standardization sample ($N = 3{,}000$) according to age. Higher scores indicate greater achievement in each writing skill domain.

ADHD Symptoms

ADHD Rating Scale (ADHD-RS-4/5).: The ADHD-RS-4/5 (Du Paul et al., 2016) was used to assess the frequency and severity of ADHD symptoms based on DSM criteria in children and adolescents aged 5 to 17 (18 items; 4-point Likert scale). The ADHD-RS-4/5 comprises two symptom subscales: Inattention (9 items) and Hyperactivity-Impulsivity (9 items). Psychometric support for the ADHD-RS-4/5 includes high internal consistency (α=0.94) and test-retest reliability (r=0.79 to 0.85; DuPaul et al., 2016). Teacher-reported ADHD symptoms were selected *a priori* given evidence that children's behavior at school may be more predictive of their academic achievement than their behavior in other settings (Verhulst, Koot, et al., 1994; Ban der Ende, 1994; Nadder et al., 2002). Sensitivity analyses were conducted using parent-reported ADHD symptoms to probe the robustness of results to this *a priori* methodological decision. Higher raw scores reflect greater quantity/severity of ADHD symptoms.

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[3] We also conducted exploratory analyses recommended during the peer review process to examine the impact of our *a priori* decision to maximally control for task impurity via the use of orthogonal (varimax) rotation. This involved repeating the principal components analysis, this time specifying an oblique rotation (direct oblimin) that allowed the derived executive function components to correlate with each other. The orthogonal and oblique components were redundant with each other (all $r \geq .99$, all $p < .001$), and substituting the obliquely rotated components into the primary analyses resulted in no changes to the significance, pattern, or interpretation of results.

Global Intellectual Functioning (IQ) and Socioeconomic Status (SES)—All children were administered the Verbal Comprehension Index of the WISC-V (Wechsler, 2014). Hollingshead (1975) SES was estimated based on caregiver(s)' education and occupation.

Data Analysis Overview—The current study tested the extent to which pediatric ADHD is associated with difficulties across each of the three broad domains of writing skills (written expression, spelling, writing fluency), and was the first to examine the extent to which difficulty with writing skills reflects the outcome of the interfering effects of ADHD symptoms, both independently and as an outcome of the well-documented association between underlying executive function deficits and elevated ADHD symptoms. Thus, our analytic plan was organized into two Tiers. In the first analytic tier, we conducted data screening/cleaning and examined the extent to which children with ADHD exhibit impairments in written expression, spelling, and writing fluency as hypothesized (Table 1).

In Tier 2, we conducted a series of conditional effects models, separately for each writing skill area (written expression, spelling, writing fluency) using jamovi 1.2.2 (Jamovi Project, 2020) with 10,000 bias-corrected, bootstrapped samples per model to analyze the relations among executive functions, ADHD symptoms, and each writing skill domain (Preacher, Rucker, & Hayes, 2007). Bias-corrected, bootstrapped conditional effects modeling was preferred because it allows shared variance among predictors to be parsed according to theory and previous research. As such, these analyses were used to determine whether each executive function predicted each of the three writing skill domains, and the extent to which these hypothesized relations were conveyed via expected associations between each executive function and ADHD symptoms. Executive functions were modeled to predict ADHD symptoms, rather than vice versa, based on prior theoretical work and experimental evidence that increasing executive function demands evokes inattentive and hyperactive behavior, at least for some executive functions (Alderson et al., 2010; Irwin et al., 2019; Kofler et al., 2010; Rapport et al., 2009), whereas impairments in specific executive functions such as working memory remain large when covarying attentive behavior during testing (Kofler et al., 2010). Additionally, ADHD symptoms were modeled as predictors of writing skills given conceptualizations of academic difficulties as secondary features of ADHD (Carroll et al., 2005; Benedetto-Nasho & Tannock, 1999). Our *a priori* plan called for modeling ADHD symptoms as a whole; sensitivity analyses were added to probe the extent to which the findings were driven by one or both ADHD symptom domains (inattention, hyperactivity/impulsivity). Of note, the cross-sectional design precludes testing of competing models regarding effect directionality (i.e., reversing arrows does not distinguish plausible models; Thoemmes, 2015). Effects are statistically significant if their 95% CI does not contain 0.0. Effect ratios (ER) for significant indirect effects indicate the proportion of the total effect (c pathway) that is conveyed via the indirect pathway (ab; i.e., ER=ab/c). Age and sex were controlled in all models; sensitivity analyses with SES and race/ethnicity (dummy coded as 0=White/Non-Hispanic, 1=Non-White/Hispanic) also covaried were highly consistent with the *a priori* specified models as described below.

Results

Tier 1: Preliminary Analyses & Group Differences

All independent and dependent variables were screened for univariate outliers, defined as values greater than 3 *SD* above or below the within-group mean. This process identified 0.00% (ADHD group) to 0.14% (Non-ADHD group) of data points that were corrected to the most extreme value 3 *SD* above or below the within-group mean. Missing data rates were low (0.22%) and were therefore imputed using the expectation-maximization (EM) algorithm (Shafer, 1997). Task data from subsets of the current battery have been reported for subsets of the current sample to examine conceptually unrelated hypotheses as detailed in Soto et al. (2020). Data for the study's primary outcomes (written expression, spelling, writing fluency) have not been previously reported. The sample size for the writing fluency analyses is n=71 due to a change in the larger study's protocol (N=91 for written expression and spelling). There were no differences on any Table 1 variables for the n=20 who did not receive this subtest vs. the n=71 who did receive it (all p>.11). Inspection of Table 1 indicated that the ADHD group exhibited significantly higher parent and teacher reported ADHD symptoms (d=0.57–1.19, p< .01) as expected. The ADHD group also demonstrated lower working memory performance (d=1.64, p< .001), whereas between-group differences did not reach significance for inhibitory control or set shifting (d=0.33–0.37, p=.08–.12). Interestingly, children with ADHD also exhibited medium-to-large magnitude deficits relative to the Non-ADHD group in all three writing skill domains: Written Expression (d=1.06), Spelling (d=0.83), and Writing Fluency (d=0.56, all p< .02).

Tier 2: Executive Functions, ADHD Symptoms, and Writing Skills

Results of the bias-corrected, bootstrapped conditional effects models are summarized here. Separate models were run for each writing skill, with the three executive functions as predictors in a path model. Reporting is truncated for readability and organized by pathway; full model outputs are shown in Tables 3–5. Variance in writing outcomes accounted for by these models was R^2=.27 for written expression, .35 for spelling, and .22 for writing fluency.

Executive functions and ADHD symptoms (a pathways).—Better-developed working memory predicted lower ADHD symptom quantity/severity across all tested models (β= −.33 to −.37, 95%CIs exclude 0.0). In contrast, neither inhibitory control nor set shifting were associated with ADHD symptom quantity/severity in any tested model (all 95%CIs include 0.0, indicating no effect).

ADHD symptoms and writing skills (b pathways).—Lower ADHD symptoms predicted higher skills attainment in written expression (β= −.19, 95%CI excludes 0.0) but not spelling or writing fluency (both 95%CIs include 0.0) when controlling for executive functioning.

Executive functions and writing skills (c and c' pathways).—Working memory predicted written expression, spelling, and writing fluency skills in all tested models (β=.48–.55, 95%CIs exclude 0.0). In addition, there were significant indirect effects of working memory on written expression and spelling (both β=.07, ERs=.13–.14) via the

ADHD symptoms pathway (ab pathways; both 95%CIs exclude 0.0); the direct effect of working memory on written expression (β==.44) and spelling (β=.48) remained significant after accounting for ADHD symptoms (c' pathways, both 95%CIs exclude 0.0). In other words, working memory predicts written expression and spelling skills both independently and, in small part, via its role in regulating ADHD symptom expression (i.e., approximately 13–14% of the relation between working memory and written expression/spelling was shared with ADHD symptoms). There was no evidence to suggest indirect effects of working memory on writing fluency via the ADHD symptoms pathway (ab pathways; 95%CIs include 0.0).

Interestingly, inhibitory control predicted spelling skills (c pathways; β=.27, 95%CI excludes 0.0) but not written expression or writing fluency (95%CIs include 0.0). In contrast, set shifting did not predict any assessed aspect of writing skills (95%CIs include 0.0). There were no indirect effects of inhibitory control or set shifting via the ADHD symptoms pathway (ab pathways; 95%CIs include 0.0).

Taken together, working memory predicted ADHD symptom severity and writing skills in all tested models, both directly and in most cases indirectly as well via its impact on ADHD symptom expression. Inhibitory control showed a more nuanced pattern, with direct effects specific to spelling but not written expression or writing fluency. Finally, there was no evidence to link set shifting abilities with children's writing skills across any assessed domain. ADHD symptoms were associated with written expression but not spelling or writing fluency.

Sensitivity Analyses

Sensitivity analyses fall into two categories: Analyses that were conducted based on questions raised by the study team prior to peer review, and additional analyses recommended during the peer review process. Reporting is truncated for readability; complete results are reported in Supplementary Tables 5–19.

A priori sensitivity analyses.—Additional analyses were conducted to probe the extent to which results were robust to our *a priori* methodological decisions to (a) model ADHD symptoms based on teacher report, and (b) conserve power by modeling a single ADHD Symptoms predictor rather than separate attention problems and hyperactivity/impulsivity subdomains. This exploratory process involved repeating the study's Tier 2 analyses twice: First with parent-reported ADHD symptoms substituted for teacher-reported ADHD symptoms, and second with separate teacher-reported ADHD symptom clusters (attention problems, hyperactivity/impulsivity) substituted for the overall ADHD Symptoms predictor. Using parent- instead of teacher-reported ADHD symptoms produced identical (written expression and writing fluency) or slightly lower (R^2=.32 vs. 35) variance accounted, and results that were highly consistent with the primary models, including direct effects of working memory on all three writing outcomes (β=.45–.53) and inhibitory control on spelling (β=.27) that remained significant after accounting for ADHD symptoms, and an indirect effect of working memory on written expression via the ADHD symptoms pathway (β=.06); the indirect effect of working memory on spelling failed to reach significance.

Separating teacher-reported ADHD symptoms into inattentive and hyperactive/impulsive symptom clusters did not change the variance accounted in any writing outcome, and suggested that the relations between working memory and ADHD symptoms reported in the primary models were conveyed specifically via the attention problems pathways; hyperactivity/impulsivity was not significantly related to any assessed executive function or writing skill outcome in any tested model. In contrast, neither ADHD symptom cluster predicted written expression, and there were no significant indirect effects via either ADHD symptom cluster, suggesting that these relations in the primary model were due to ADHD symptoms as a whole rather than either cluster uniquely.

Additional analyses added during peer review.—Additional analyses were added to test the hypothesis that (a) children's language skills, (b) ADHD diagnostic status, or (c) learning disability status – rather than executive functioning *per se* – would explain the primary findings reported above. First, we added the WISC-V Vocabulary subtest as an additional covariate given its use as a measure of language skills (Smith et al., 2005; Ripley & Yuill, 2005). Results were highly consistent with the primary analyses, including direct and total effects of working memory on all writing outcomes (β=.38–.52), indirect effects of working memory on written expression and spelling (β=.06–.07), and direct and total effects of inhibitory control on spelling (β=.27–.28; all 95%CIs exclude 0.0). WISC-V Vocabulary predicted written expression (β=.24) but not spelling or writing fluency (95%CIs include 0.0), and the variance accounted increased slightly (written expression: R^2=.33 vs. .27, spelling R^2=.36 vs. .35, writing fluency R^2=.23 vs. .22). WISC-V Vocabulary did not predict ADHD symptoms or exert indirect effects via ADHD symptoms on any assessed writing outcome (95%CIs include 0.0).

Taken together, it appeared that the primary findings were robust to control for children's language skills. However, recent evidence raises concerns about the extent to which WISC Vocabulary is a valid measure of language. For example, Canivez et al. (2015) showed that >70% of the variance in WISC Vocabulary scores is due to general intelligence (*g*), suggesting that our analyses instead indicated that the findings were robust to control for IQ. In turn, others have argued strongly that it is inappropriate to control for IQ when studying neurocognitive functioning in neurodevelopmental disorders such as ADHD (Dennis et al., 2009). Thus, we conducted additional analyses using other measures with significant language demands available in our dataset, including KTEA-3 listening comprehension (a measure of receptive language) and letter-word identification (a measure of decoding and expressive language). Adding receptive language (listening comprehension) to the model failed to increase the explained variance in spelling and writing fluency, and minimally increased the explained variance in written expression: (R^2=.29 vs. .27), and listening comprehension failed to predict ADHD symptoms or any assessed writing outcome (all 95%CIs include 0.0). Importantly, results were once again highly consistent with the primary models, including significant direct/total effects of working memory in all models (β=.39–.52), direct/total effects of inhibitory control in the spelling model (β=.28), and indirect effects of working memory on written expression and spelling (both β=.05; 95%CIs exclude 0.0).

In contrast, controlling for decoding and expressive language (letter-word identification) substantially increased the explained variance in spelling skills (R^2=.68 vs. .35), moderately increased explained variance for written expression (R^2=.35 vs. .27), and minimally increased explained variance for writing fluency (R^2=.23 vs. .22). Letter-word identification predicted written expression (β=.32–.33) and spelling (β=.66–.67), but not writing fluency or ADHD symptoms; there were no indirect effects of letter-word identification on any assessed writing outcome (95%CI includes 0.0). Importantly, results were once again highly consistent with the primary models in terms of direct/total effects of working memory on written expression and writing fluency (β=.29–.46), and inhibitory control on spelling (β=.24–.25). Working memory's effect on spelling remained significant but was smaller in magnitude relative to prior models (β=.19 vs. .48; 95%CIs exclude 0.0), and there were no significant indirect effects despite letter-word identification not significantly predicting ADHD symptoms (95%CIs include 0.0).

Next, we repeated the primary models once again, this time controlling for ADHD status. Explained variance increased minimally (written expression R^2=.29 vs. .27) or was identical (spelling, writing fluency) to the primary models. Interestingly, there was a total effect of ADHD diagnosis on written expression (c pathway; $\beta = -.27$), but this effect disappeared when controlling for the executive function variables (c' pathway; 95%CI includes 0.0); there were no significant total or direct effects of ADHD diagnosis on spelling or writing fluency. Importantly, direct/total effects of working memory on all writing outcomes (β=.31–.58) and inhibitory control on spelling (β=.26–.28) remained significant. As expected, ADHD status predicted ADHD symptoms (β=.41), and there were no indirect effects of executive functions on writing via ADHD symptoms after controlling for ADHD diagnostic status (all 95%CIs include 0.0).

Finally, we examined the extent to which the pattern of obtained results was related to our decision to include children with positive screens for learning disabilities in the sample. This involved repeating the primary analyses again, this time with the probable SLD cases removed. Explained variance decreased slightly (written expression R^2=.24 vs. .27, spelling R^2=.31 vs. .35, writing fluency R^2=.17 vs. .22), suggesting that restricting the range of outcome scores via exclusion of positive learning disability screens would have a small, negative effect on our ability to detect significant relations. Nonetheless, the pattern of results was again largely unchanged from the primary models, including significant direct/total effects of working memory in all models (β=.34–.49), direct/total effects of inhibitory control in the spelling model (β=.21), and an indirect effect of working memory on written expression (β=.08).

Discussion

The present study was the first to examine relations among all three core executive functions (working memory, inhibitory control, set shifting), ADHD symptoms, and three key components of writing skills (written expression, spelling, writing fluency). Additional strengths included the multi-trait, multi-method, and multi-task design, inclusion of a clinically-evaluated and carefully-phenotyped sample, and direct replication of study findings across multiple informants (parents, teachers). Overall, the results were generally consistent with prior evidence linking executive functions with ADHD behaviors and writing skills (Bledsoe et al., 2010; Casas et al., 2013; Kent et al., 2014; Kim & Lee, 2009; Kofler et al., 2018), and extended these findings by providing evidence for specificity in the relations between executive functions and children's writing skills. Working memory was implicated in written expression, spelling, and writing fluency; inhibitory control was related to spelling skills only; and set shifting failed to exhibit unique relations with any assessed writing skills.

Experimental and longitudinal evidence implicates working memory deficits as a potential causal mechanism underlying, at least in part, the phenotypic expression of ADHD-related inattentive and hyperactive/impulsive behaviors (e.g., Karalunas et al., 2017; Kofler et al. 2010; Rapport et al. 2009), and the current results are consistent with prior work that documented higher rates of writing difficulties in children with ADHD (Cassas et al., 2013; Kim & Lee, 2009; Re & Cornoldi, 2010). This study tested the hypothesis that working memory would predict ADHD symptom severity which would, in turn, predict writing across the three different writing skill areas. We found partial support for this prediction in the written expression and spelling models, with indirect effects of working memory on writing skills via teacher- and parent-reported ADHD symptoms, and direct effects of working memory remaining after accounting for ADHD symptoms. In contrast, there were significant direct effects of working memory in all tested models but no indirect effects via ADHD symptoms in the writing fluency model. Given that working memory's direct effects were replicated across the primary and sensitivity analyses, and robust to control for ADHD symptoms, age, sex, SES, race/ethnicity, IQ, language, and decoding skills, it appears that working memory is implicated in all three writing areas, though in somewhat different ways. That is, written expression and spelling difficulties appear to reflect, in small part, the behavioral expression of deficits in working memory that have been shown in prior experimental and longitudinal studies (e.g., Kofler et al., 2010) to be a causal factor in increased ADHD symptoms. In the current study, ADHD symptoms accounted for 13%–14% of working memory's total effects on these writing skills. Meanwhile, writing fluency difficulties appear to be related more directly to underlying working memory deficits, such that ADHD symptoms were not significantly related to difficulties in this core writing skill when controlling for working memory. These findings are consistent with evidence from adult and child community samples linking working memory deficits with writing difficulties in written expression, spelling, and writing fluency (Cooke et al., 2006; Eckrich et al. 2018; Ormrod & Cochran, 2010), and extend these findings by documenting that these associations are (a) robust to control for the other two primary executive functions, suggesting specificity in these relations; and (b) present in a clinically heterogeneous sample oversampled for ADHD and other clinical conditions linked with executive dysfunction (e.g., Kofler et al., 2018).

In terms of inhibitory control, the models were highly consistent and indicated that inhibitory control exerted significant direct effects on spelling but not written expression or writing fluency. These results are inconsistent with evidence linking inhibitory control with difficulties in grammar skills (Ibbotson & Kearvell-White, 2015) and written expression in previous studies (Bledsoe et al., 2010; Semrud-Clikeman & Harder, 2010). One possible explanation for this discrepancy is that the current study controlled for the other core executive functions when deriving each executive function component. As such, previous evidence linking inhibitory control and written expression may be explained more parsimoniously by the significant working memory and/or set shifting demands required for successful performance on inhibitory control tasks (Alderson et al., 2010; Irwin et al., 2019). In contrast, the current findings provide evidence linking inhibitory control with spelling skills, even when controlling for ADHD symptoms and the other two core executive functions. One possible explanation for the association between inhibitory control and spelling may be that children with inhibitory control deficits may not be able to stop their prepotent tendency to spell words phonetically to allow consideration of alternative phonemes, given that English is an orthographically dense/opaque language with a large number of exception words for which the phoneme- and grapheme-to-letter mapping is not one-to-one. For example, when asked to spell the word ‘phone,’ a child may use the phonetically correct sounding, but incorrect, letter F instead of the alternative grapheme ‘Ph.’ Similarly, children with inhibition difficulties may have difficulty pausing to consider context when spelling homophones (e.g., one vs. won). Of course, this hypothesis remains speculative, and process analysis studies are needed to determine which components of spelling are affected by inhibitory control difficulties in children.

With regard to set shifting, the models were highly consistent and indicated that set shifting failed to directly or indirectly predict any assessed writing skill. While few studies have examined relations between set shifting and writing skills, the results from this study are inconsistent with a prior study that linked set shifting with written expression difficulties in children (Hooper et al., 2002). As noted above, a parsimonious explanation may be that prior work in this area was unable to control for the other two core executive functions, suggesting that the relations detected previously may have been an artifact of task impurity (Booth et al., 2010; Miyake et al., 2000) rather than evidence for specific effects of set shifting on writing skill attainment.

Based on the current and previous findings indicating that academic attainment in writing skills may be modulated directly by higher-order working memory and inhibitory control processes (Spiegel et al., 2021), and potentially indirectly via working memory’s role in regulating attention (Cordeiro et al., 2019, Re & Cornoldi, 2010, Re et al., 2007), future work is needed to determine the extent to which these processes are implicated in more fine-grained aspects of writing performance such as structure, vocabulary, grammar, passage length, accuracy, quality, and quantity. Interestingly, emerging evidence suggests that written expression may itself be in part an outcome of other, more basic writing skills such as grammar and fluency, and that reducing demands on working memory may allow for more cognitive resources to be redistributed to attend to these foundational aspects of writing (Carretti et al., 2016; Peverly, 2006). For example, effective written expression requires a host of simultaneous mental processes that tax working memory capacity, including maintaining the main objective of what is being written in mind, formulating the logic on how to convey that objective, adhering to sentence formation and grammar rules, and remembering how to the spell words necessary to convey that objective (McCutchen, 1995, 1996; Kellogg, 1996, 1999). Writing strategies such as outlining key points, increased familiarity and mastery of grammar rules, and mastery of phonics may reduce working memory demands, which would in turn free up cognitive resources and allow for more complex and effective written communication (Dehn, 2011; Meltzer, 2018). Future research should investigate additional writing skill outcomes (e.g., grammar and fluency) as well as explore the moderating effects of writing strategies on the executive function/writing skill relations detected herein.

Limitations

The current study has several strengths, including a relatively large and clinically evaluated sample of children, cross-informant replication, and the multi-trait/method/task design. However, the following limitations should be considered when interpreting results. Although largely consistent, there were minor discrepancies between the parent- and teacher-reported ADHD symptom models that may reflect differences in symptom manifestation across settings and illustrate the importance of using multi-informant ratings of child symptoms. Next, another strength of this study was the inclusion of a relatively large sample of children with ADHD, given that the disorder's neurocognitive heterogeneity was expected to provide a wider range of scores on the executive function tests and as such a greater likelihood of uncovering associations among children's executive functioning abilities and writing skills. However, it stands to reason that the inclusion of children with and without ADHD may reduce specificity of the findings to either population specifically. Similarly, inclusion of common comorbidities in the ADHD group was a strength of the study given that comorbidities are the norm rather than the exception for these children (i.e., improved generalizability). At the same time, controlling for these comorbidities by recruiting children with these disorders into the Non-ADHD group may limit our ability to draw conclusions about neurotypicality. Independent replications with larger samples, naturalistic outcomes, and a broader sampling of children with other clinical disorders and/or additional writing skills are needed to assess the generalizability of the current findings.

The current study focused on the three core executive functions (working memory, inhibitory control, and set shifting), and explained a sizable minority of the variance in writing outcomes (R^2=.22–.35). Nonetheless, the majority of individual differences in children's writing skills remained unexplained, and a complete model of writing skills in children with ADHD will likely need to include additional cognitive abilities as well as non-cognitive academic and related skills (e.g., phonemic awareness, decoding, naming, fine motor skills) – some of which may also be outcomes, in part, of children's underlying executive functioning abilities as noted above (Mokobane et al., 2019; Sims & Lonigan, 2013; Willcutt et al., 2007). Similarly, we modeled ADHD symptoms as the behavioral pathway linking executive functions with writing difficulties, but did not examine additional interfering behaviors that may affect writing skill development. It remains possible that working memory's effects on writing skills are conveyed via behavioral mechanisms other than core ADHD symptoms despite the consistency between the current findings and previous studies documenting direct relations between working memory and writing skills in ADHD (Re et al., 2014; Re & Cornoldi, 2010) and non-ADHD samples (Carretti et al., 2016; Chenoweth & Hayes, 2003; Peverly, 2006). Future research is needed to assess this possibility and further clarify the specific mechanisms by which working memory difficulties and other underlying mechanisms result in lower writing skill attainment. Finally, we were unable to draw firm conclusions regarding effect directionality due to the cross-sectional nature of our data (Thoemmes, 2015). Thus, experimental and longitudinal studies are needed.

Clinical Implications

Taken together, the current results indicate that deficits in working memory predict less developed skills in written expression, spelling, and writing fluency, whereas deficits in inhibitory control predict spelling difficulties only. Set shifting was not associated with any assessed writing skill domain. In addition, the association between ADHD symptoms and writing skills appears to be attributable to the role of working memory in regulating behavior, such that only working memory predicted ADHD symptoms, relations between ADHD symptoms and writing were small or nonsignificant when controlling for working memory, and indirect effects – when detected – accounted for only a small proportion of the relation between working memory and writing skills. Thus, these findings suggest multiple, interdependent pathways to writing skill deficits in children with ADHD and provide possible implications for targeted intervention in writing skills. In line with these findings, extant literature has demonstrated that behavioral interventions targeting ADHD symptoms have shown limited effectiveness in academic areas of reading, writing, and mathematics (DuPaul & Eckert, 1998; Raggi et al., 2006). The results from this study suggest that this may be due to targeting overt behaviors that are markers for underlying neurocognitive vulnerabilities rather than targeting the underlying impairments directly (e.g., attention problems and writing difficulties may both be outcomes, at least in part, of underlying working memory difficulties, rather than one exerting a causal role on the other; Kofler et al., 2010; Rapport et al., 2009). In this case, the minimal impact that evidence-based treatments targeting ADHD symptoms have on academic achievement may be unsurprising (Rapport et al., 2001). Of course, this hypothesis is speculative because the current study did not assess intervention effects, but remains promising given the experimental evidence linking working memory with both ADHD symptom expression and writing skills as described above.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Key Points

Question:

ADHD is associated with executive function deficits and difficulties with academic writing skills, but are these links attributable to specific executive functions?

Findings:

Underdeveloped working memory abilities predicted written expression, spelling, and writing fluency, both directly and in most cases indirectly via working memory's role in regulating attentive behavior; inhibitory control predicted spelling only, whereas set shifting was not associated with any assessed academic writing skill.

Importance:

The association between ADHD symptoms and writing skills appears to be attributable to the role of working memory in regulating behavior, such that ADHD symptoms no longer predicted most assessed writing skills when controlling for working memory, and indirect effects – when detected – accounted for only a small proportion of the relation between working memory and writing skills.

Next Steps:

If replicated, these findings may help explain why evidence-based treatments that target overt ADHD symptoms have minimal impact on writing skills for children with ADHD.

Table 1.

Descriptive Statistics.

	ADHD (*N*=51)		**Non-ADHD (*N*=40)**					
Demographics	***M***	***SD***	***M***	***SD***	**Cohen's *d***	***t***	χ^2	***p***
N (Boys/Girls)	(32/19)		(22/18)		-	-	0.56	.46, *n.s.*
Age	10.32	1.48	10.85	1.54	-	1.65	-	.10, *n.s.*
SES	47.35	11.73	51.06	12.41	-	1.46	-	.15, *n.s.*
VCI	103.57	14.14	109.39	11.31	-	2.32	-	.02
Ethnicity (A, B, H, MR, W)	(0, 7, 3, 3, 38)		(1, 4, 4, 7, 23)		-	-	5.52	.24, *n.s.*
IQ$_{residual}$	99.36	15.91	100.82	13.26	-	0.47	-	.64, *n.s.*
ADHD Symptoms								
ADHD-R5 (raw scores)								
Total ADHD Symptoms	27.33	11.29	15.00	12.68	1.04	4.90	-	<.001
Attention Problems	17.31	6.40	9.23	7.25	1.19	5.64	-	<.001
Hyperactivity/Impulsivity	10.02	7.70	5.78	7.25	0.57	2.68	-	0.01
BASC Attention Problems (T-scores)								
Teacher	63.24	8.09	53.40	11.30	1.02	4.84	-	<.001
Parent	66.00	7.53	59.58	12.02	0.66	3.12	-	.002
BASC Hyperactivity (T-scores)								
Teacher	61.29	13.66	52.08	12.70	0.70	3.30	-	.001
Parent	67.28	12.63	57.70	13.03	0.75	3.54	-	<.001
Executive Functions (z-scores relative to the current sample)								
Working Memory	−0.56	0.77	0.71	0.79	1.64	7.74	-	<.001
Inhibitory Control	0.16	1.02	−0.20	0.94	0.33	1.57	-	.12, *n.s.*
Set Shifting	−0.14	1.04	0.18	0.93	0.37	1.75	-	.08, *n.s.*
Writing Skills (standard scores)								
Written Expression	96.08	10.79	107.08	9.91	1.06	5.00	-	<.001
Spelling	96.10	14.61	107.83	13.40	0.83	3.94	-	<.001
Writing Fluency	97.46	15.53	105.88	14.60	0.56	2.33	-	.02

Note: A = Asian; B = Black; H = Hispanic; MR = Multiracial; W = White/Non-Hispanic; IQ$_{residual}$ = WISC VCI scores covaried for executive function abilities given compelling evidence that executive functions such as working memory likely impact IQ test performance rather than vice versa (e.g., Tourva et al., 2016); SES = Hollingshead socioeconomic status total score; VCI = WISC-V Verbal Comprehension Index.

[1] Writing Fluency n = 71 (ADHD = 39, Non-ADHD = 32).

Table 2.

Zero-Order Correlation Matrix

Correlation Matrix

		Written Expression	Spelling	Writing Fluency	Working Memory	Inhibitory Control	Set Shifting	ADHD Symptoms	Age	Sex	SES	Race/Ethnicity
Written Expression	Pearson’s r	–										
	p-value	–										
Spelling	Pearson’s r	0.549 ***										
	p-value	<.001	–									
Writing Fluency	Pearson’s r	0.219	0.290 *	–								
	p-value	0.067	0.014	–								
Working Memory	Pearson’s r	0.448 ***	0.461 ***	0.437 ***	–							
	p-value	<.001	<001	<.001	–							
Inhibitory Control	Pearson’s r	0.145	0.255 *	−0.002	0.000	–						
	p-value	0.170	0.015	0.987	1.000	–						
Set Shifting	Pearson’s r	−0.010	0.009	−0.148	0.000	−0.000	–					
	p-value	0.925	0.936	0.217	1.000	1.000	–					
ADHD Symptoms	Pearson’s r	−0.322 **	−0.300 **	−0.097	−0.327 **	0.010	0.097	–				
	p-value	0.002	0.004	0.421	0.002	0.922	0.362	–				
Age	Pearson’s r	0.090	0.004	0.100	0.377 ***	0.089	0.020	−0.134	–			
	p-value	0.395	0.967	0.408	<.001	0.401	0.853	0.205	–			
Sex	Pearson’s r	0.005	0.057	−0.048	0.248 *	−0.094	0.094	0.112	0.154	–		
	p-value	0.960	0.593	0.690	0.018	0.377	0.377	0.289	0.144	–		
SES	Pearson’s r	0.123	0.086	0.033	0.243 *	−0.123	−0.052	−0.023	0.087	0.069	–	
	p-value	0.244	0.420	0.783	0.020	0.244	0.626	0.832	0.412	0.519	–	
Race/Ethnicity	Pearson’s r	−0.095	0.154	−0.052	0.094	0.190	−0.013	−0.011	0.068	0.009	−0.204	–
	p-value	0.370	0.145	0.666	0.375	0.072	0.906	0.916	0.522	0.929	0.053	–

Note.

* $p < .05$,

** $p < .01$,

*** $p < .001$

Table 3.

Written expression model

Indirect and Total Effects

Type	Effect	Estimate	SE	95% C.I. (a)		β
				Lower	Upper	
Indirect	Age ⇒ ADHD Symptoms ⇒ Written Expression	0.04707	0.1602	−0.20178	0.48369	0.00611
	Gender ⇒ ADHD Symptoms ⇒ Written Expression	−0.91861	0.7429	−3.14232	−0.00826	−0.03872
	Working Memory ⇒ ADHD Symptoms ⇒ Written Expression	0.81354	0.4772	0.09368	2.13295	0.06943
	Inhibitory Control ⇒ ADHD Symptoms ⇒ Written Expression	−0.07195	0.2403	−0.78985	0.30674	−0.00614
	Set Shifting ⇒ ADHD Symptoms ⇒ Written Expression	−0.17408	0.3191	−1.09724	0.23843	−0.01486
Component	Age ⇒ ADHD Symptoms	−0.28253	0.8240	−1.94676	1.32197	−0.03218
	ADHD Symptoms ⇒ Written Expression	−0.16659	0.0869	−0.34790	−7.12e-4	−0.18986
	Gender ⇒ ADHD Symptoms	5.51429	2.7734	0.00999	10.79343	0.20396
	Working Memory ⇒ ADHD Symptoms	−4.88356	1.5783	−7.86250	−1.72895	−0.36570
	Inhibitory Control ⇒ ADHD Symptoms	0.43193	1.2574	−1.96059	2.93785	0.03235
	Set Shifting ⇒ ADHD Symptoms	1.04498	1.5596	−1.96341	4.10188	0.07825
Direct	Age ⇒ Written Expression	−0.82086	0.7417	−2.31518	0.77009	−0.10656
	Gender ⇒ Written Expression	−1.26777	2.2789	−5.99838	3.19452	−0.05344
	Working Memory ⇒ Written Expression	5.15244	0.9769	3.26507	7.11963	0.43975
	Inhibitory Control ⇒ Written Expression	1.77565	0.9966	−0.32588	3.73705	0.15155
	Set Shifting ⇒ Written Expression	0.18068	1.1688	−2.29740	2.33055	0.01542
Total	Age ⇒ Written Expression	−0.77379	0.7703	−2.28350	0.73592	−0.10045
	Gender ⇒ Written Expression	−2.18638	2.2786	−6.65234	2.27958	−0.09217
	Working Memory ⇒ Written Expression	5.96598	1.1891	3.63535	8.29661	0.50919
	Inhibitory Control ⇒ Written Expression	1.70369	1.0877	−0.42822	3.83560	0.14541
	Set Shifting ⇒ Written Expression	0.00660	1.0820	−2.11412	2.12733	5.64e-4

Note. Confidence intervals computed with method: Bias corrected bootstrap

Note. Betas are completely standardized effect sizes

Table 4:

Spelling Model

Indirect and Total Effects

				95% C.I. (a)		
Type	**Effect**	**Estimate**	**SE**	**Lower**	**Upper**	**β**
Indirect	Age ⇒ ADHD Symptoms ⇒ Spelling	0.0577	0.196	−0.2432	0.6655	0.00578
	Gender ⇒ ADHD Symptoms ⇒ Spelling	−1.1261	0.932	−3.4819	0.1038	−0.03662
	Working Memory ⇒ ADHD Symptoms ⇒ Spelling	0.9973	0.597	0.0539	2.3601	0.06566
	Inhibitory Control ⇒ ADHD Symptoms ⇒ Spelling	−0.0882	0.318	−1.0441	0.3897	−0.00581
	Set Shifting ⇒ ADHD Symptoms ⇒ Spelling	−0.2134	0.387	−1.5072	0.2424	−0.01405
Component	Age ⇒ ADHD Symptoms	−0.2825	0.808	−1.9961	1.1658	−0.03218
	ADHD Symptoms ⇒ Spelling	−0.2042	0.113	−0.4236	0.0153	−0.17955
	Gender ⇒ ADHD Symptoms	5.5143	2.638	−0.3709	10.1621	0.20396
	Working Memory ⇒ ADHD Symptoms	−4.8836	1.543	−7.7853	−1.5937	−0.36570
	Inhibitory Control ⇒ ADHD Symptoms	0.4319	1.236	−1.8602	2.9316	0.03235
	Set Shifting ⇒ ADHD Symptoms	1.0450	1.469	−1.7605	3.9174	0.07825
Direct	Age ⇒ Spelling	−2.2996	0.939	−4.0711	−0.3956	−0.23029
	Gender ⇒ Spelling	0.4737	2.968	−5.4316	6.2527	0.01540
	Working Memory ⇒ Spelling	7.3651	1.516	4.2908	10.1782	0.48490
	Inhibitory Control ⇒ Spelling	4.2287	1.357	1.6209	6.9949	0.27841
	Set Shifting ⇒ Spelling	0.4406	1.316	−2.2828	2.8987	0.02901
Total	Age ⇒ Spelling	−2.2419	0.944	−4.0917	−0.3922	−0.22451
	Gender ⇒ Spelling	−0.6525	2.792	−6.1244	4.8194	−0.02122
	Working Memory ⇒Spelling	8.3625	1.457	5.5069	11.2180	0.55056
	Inhibitory Control ⇒ Spelling	4.1405	1.333	1.5284	6.7527	0.27260
	Set Shifting ⇒ Spelling	0.2272	1.326	−2.3712	2.8256	0.01496

Note. Confidence intervals computed with method: Bias corrected bootstrap

Note. Betas are completely standardized effect sizes

Table 5:

Writing Fluency Model

Indirect and Total Effects

				95% C.I. (a)		
Type	**Effect**	**Estimate**	**SE**	**Lower**	**Upper**	**β**
Indirect	Age ⇒ ADHD Symptoms ⇒ Writing Fluency	−0.0243	0.149	−0.523	0.167	−0.00248
	Gender ⇒ ADHD Symptoms ⇒ Writing Fluency	0.3694	0.802	−0.532	3.107	0.01166
	Working Memory ⇒ ADHD Symptoms ⇒ Writing Fluency	−0.3896	0.591	−1.915	0.523	−0.02565
	Inhibitory Control ⇒ ADHD Symptoms ⇒ Writing Fluency	0.0744	0.260	−0.208	1.081	0.00485
	Set Shifting ⇒ ADHD Symptoms ⇒ Writing Fluency	0.1118	0.317	−0.240	1.310	0.00797
Component	Age ⇒ ADHD Symptoms	−0.2777	0.937	−2.054	1.663	−0.03129
	ADHD Symptoms ⇒ Writing Fluency	0.0877	0.122	−0.180	0.310	0.07939
	Gender ⇒ ADHD Symptoms	4.2147	3.437	−3.285	10.601	0.14693
	Working Memory ⇒ ADHD Symptoms	−4.4449	1.809	−7.938	−0.673	−0.32313
	Inhibitory Control ⇒ ADHD Symptoms	0.8493	1.484	−1.948	3.917	0.06104
	Set Shifting ⇒ ADHD Symptoms	1.2758	1.629	−1.820	4.532	0.10038
Direct	Age ⇒ Writing Fluency	−0.4319	1.208	−2.922	1.779	−0.04409
	Gender ⇒ Writing Fluency	−4.5113	3.535	−11.550	3.160	−0.14243
	Working Memory ⇒ Writing Fluency	7.7329	2.009	3.579	11.621	0.50915
	Inhibitory Control ⇒ Writing Fluency	−0.1542	1.765	−3.740	3.254	−0.01004
	Set Shifting ⇒ Writing Fluency	−1.9948	1.331	−4.655	0.731	−0.14215
Total	Age ⇒ Writing Fluency	−0.4562	1.093	−2.599	1.687	−0.04657
	Gender ⇒ Writing Fluency	−4.1419	3.446	−10.895	2.611	−0.13077
	Working Memory ⇒ Writing Fluency	7.3433	1.727	3.959	10.727	0.48349
	Inhibitory Control ⇒ Writing Fluency	−0.0798	1.616	−3.248	3.088	−0.00519
	Set Shifting ⇒ Writing Fluency	−1.8830	1.490	−4.803	1.037	−0.13418

Note. Confidence intervals computed with method: Bias corrected bootstrap

Note. Betas are completely standardized effect sizes