Examining the Roles of Working Memory and Trait Anxiety on Math Achievement in Children with ADHD

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Abstract

Objective: Children with ADHD demonstrate deficits across academic domains including underachievement in math. Proposed models of math skill development suggest that math difficulties may be associated with both neurocognitive (e.g., working memory) and socioemotional factors (e.g., anxiety). Extant literature indicates a 25% co-occurrence rate between ADHD and anxiety, as well as a strong link between neurocognitive deficits in working memory and ADHD symptomology. However, it remains unclear how both trait anxiety and working memory uniquely or jointly relate to underachievement in math in children with ADHD.

Method: The sample comprised 275 clinically-evaluated children ages 8–13 (M_{years}=10.36, SD=1.44; 106 girls; 69% White/Non-Hispanic) with and without ADHD. Serial conditional effects models were utilized to 1) quantify the magnitude of math underachievement in children with ADHD relative to peers without ADHD, and 2) determine the extent to which these impairments are uniquely or jointly related to child self-reported trait anxiety and/or working memory abilities.

Results: The serial path analysis indicated that children with ADHD exhibited large magnitude deficits in math achievement relative to peers without ADHD (d=−0.76; β=−.34, 95% CI excludes 0.0). Furthermore, the ADHD/math achievement relation was uniquely accounted for by its shared association with working memory, whereas self-reported trait anxiety was not a significant predictor of math achievement. Together, ADHD status and working memory accounted for 65% of the variance in math achievement (R^2=.65).

Conclusions: These findings suggest that math difficulties in children with ADHD are largely associated with neurocognitive factors such as working memory, and do not appear to be associated with the frequency/severity of trait anxiety symptoms.

Keywords

ADHD; working memory; anxiety; math achievement

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Conflict of Interest:
The principal investigator (Michael Kofler) was awarded a patent for a neurocognitive intervention that targets central executive working memory. This intervention was not used in the current study, and there are no current licensing, financial, or other conflicts to report.

Attention-Deficit/Hyperactivity Disorder (ADHD) and anxiety are common forms of psychopathology present in childhood (APA, 2013). ADHD has been linked to difficulties across domains including impaired social functioning, deficits in working memory, and poorer academic outcomes, including math underachievement (Kofler et al., 2018; DuPaul et al., 2013), and some evidence suggests similar deficits in anxiety (Jarret et al., 2016; Vilaplana-Pérez et al., 2021). Amongst the diverse explanatory models of math achievement, cross-sectional and longitudinal evidence implicates working memory as one influential mechanism that, at least in part, underlies math difficulties in children with and without ADHD (Friedman et al., 2018; Rennie et al., 2014). Importantly, developmental models posit that socioemotional factors such as trait anxiety also influence math achievement (Finell et al. 2022), though evidence is mixed regarding the strength and direction (e.g., positive vs negative) of the relation between anxiety and achievement (Brumariu et al., 2022; Alfonso & Lonigan, 2021). Interestingly, despite the 25% co-occurrence rate between ADHD and anxiety (D'Agati et al., 2019), and reported/hypothesized working memory deficits associated with both disorders (Fosco et al., 2020; Moran 2016), little is known about how the phenotypic overlap between ADHD and trait anxiety is associated with working memory and math achievement in youth. To that end, the current study aims to examine the extent to which trait anxiety accounts for the relation between working memory and math achievement in a carefully phenotyped sample of children diagnosed with and without ADHD.

ADHD, Working Memory, and Math Achievement

Early math achievement, or the mastery of foundational math skills developed in primary school, has been linked to a host of important outcomes such as subsequent academic achievement, grade retention, and college entry (Claessens & Engel 2013). Importantly, children with ADHD evidence medium to large magnitude deficits in math achievement when compared to peers without ADHD (Gaye et al., 2024; Friedman et al., 2018). Approximately 5–30% of children with ADHD meet criteria for a specific learning disorder in math (DuPaul et al., 2013). Math difficulties in ADHD are characterized by impairment across math skills domains such as math calculation, fluency, and problem-solving (Lucangeli & Cabrele, 2006; Re et al., 2016), even amongst children who do not meet criteria for a specific learning disorder (Mayes et al., 2000; Czamara et al., 2013). Current school-based math interventions focus on remediating core math skills such as math computation and fluency (McKevett & Codding, 2021). Importantly, however, most interventions do not address underlying mechanisms (e.g., executive functions) that may influence math achievement (Jacob & Parkinson, 2015), though some literature suggests that lowered responsiveness to mathematical intervention is associated with behavioral and neurocognitive features of ADHD such as deficits in attention and working memory (Fuchs & Fuchs, 2006; Schulze et al., 2020; Platt, 2017). Thus, understanding mechanisms associated with math achievement in youth with ADHD remains paramount.

Extant literature implicates working memory deficits as one mechanism underlying math underachievement in ADHD (Friedman et al., 2018; Rogers et al., 2011). Working memory refers to the active, top-down manipulation of information held in short-term memory (Baddeley, 2007). Recent evidence suggests that working memory deficits are present in approximately 62–85% of children with ADHD (Fosco et al., 2020; Karalunas et al., 2017; Kofler et al., 2019, 2020), and are closely associated with ADHD behavioral symptom expression (Rapport et al., 2009; Kofler et al., 2010). Furthermore, replicated evidence from two carefully controlled clinical trials demonstrates that training-related improvements in working memory abilities lead to increased math achievement in children with ADHD (Singh et al., 2022), thus positioning working memory as one promising mechanism to consider when determining factors that influence math achievement and prognostic outcomes for children with ADHD.

Anxiety and Math Achievement in Children with ADHD

In addition to neurocognitive factors that influence math outcomes in children with ADHD, co-occurrence with other psychological symptoms/disorders is a crucial consideration, as increased symptomology can influence clinical presentation, patterns of impairment, and prognostic outcomes across the lifespan (Kieling & Rohde, 2012). Anxiety disorders are among the most common and impairing mental health conditions in children, with a prevalence rate of approximately 9% (Bitsko et al., 2022; CDC, 2023) and 25% co-occurrence rate with ADHD (D'Agati, Curatolo & Mazzone, 2019). Interestingly, co-occurring ADHD and anxiety disorders may be associated with increased working memory deficits relative to a diagnosis of ADHD alone (Jarret et al., 2016; Schatz & Rostain, 2006; cf. Marsh et al., 2023). Thus, positioning anxiety as an important consideration when examining the mechanisms and processes underlying adverse outcomes, including math underachievement, for children with ADHD. Studies employing a categorical approach to trait anxiety have linked generalized and social anxiety disorders with increased school-related worry and learning problems (Jarrett et al., 2015), premature school withdrawal (Van Ameringen et al., 2003), and lower rates of passing classes in core subjects (e.g., math; Vilaplana-Pérez et al., 2021). Studies taking a dimensional approach have also linked anxiety symptoms with reduced math performance (Justicia-Galiano et al., 2017; Hooda & Saini, 2017).

Importantly, there is great variability in the types of anxiety measures utilized in studies of math achievement. Trait anxiety represents a general propensity for worry, which can be characterized by emotional responses to pervasive fearful situations or cognitions (Sylvers et al., 2011). On the other hand, math anxiety is often defined as worry that occurs specifically in the context of math problem solving (Finlayson, 2014), and is often explored in relation to math achievement. However, the extent to which math anxiety is distinct from a more general tendency toward anxiety (i.e., trait anxiety) is an active area of inquiry. Several studies suggest that scores on math anxiety measures are driven primarily by trait anxiety (Mammarella et al., 2018) and that math-specific anxiety does not predict math achievement after accounting for trait anxiety (Hill et al., 2016). Additionally, studies have found that the shared variance between trait anxiety and math anxiety is predictive of math achievement (Di Lonardo Burr & LeFevre, 2020), and that general and math-specific anxiety appears to assess the same construct in the current sample's age range despite being more differentiated in older children/adolescents (Carey et al., 2017; cf. Justicia-Galiano et al., 2017; Szczygiel, 2020). To that end, the current study focuses on the broad clinical feature of trait anxiety; we return to issues related to the distinction between trait anxiety and math anxiety, in the Limitations/Future Directions section. We also examine the extent to which individual differences in aspects of neurocognitive functioning (e.g., working memory) may contribute to mixed findings in the area of anxiety and achievement (Vukovic et al., 2013).

Anxiety, Working Memory, and Math Achievement

Working memory is a primary neurocognitive process implicated in the association between anxiety and math difficulties (Chang & Beilock, 2016). Processing efficiency theory (PET) and its successor, attention control theory (ACT), are influential models positing that anxiety disrupts working memory processes by diverting cognitive resources to task-irrelevant stimuli (e.g., worry thoughts, external distractors), which in turn reduces working memory processing and storage capacity, ultimately reducing the cognitive resources available to attend to a given task (Eysenck & Calvo, 1992; Eysenck et al., 2005; 2007). These mechanisms may manifest in school as worry during academic instruction, class assignments, and tests, leading to a decrease in performance efficiency for those with higher levels of trait anxiety. Applications of PET and ACT to math performance have typically focused on measures intended to assess math-specific anxiety, which as noted above has received mixed evidence regarding the extent to which it is a distinct construct as opposed to reflecting more general, trait-level anxiety. Consistent with model predictions, high levels of math anxiety predicted poorer working memory abilities, which in turn predicted lowered math performance across multiple studies (Ashcraft & Krause, 2007; Ramirez et al., 2013; Skagerlund et al., 2019). To our knowledge, very few studies have concurrently examined trait anxiety in relation to both working memory and math outcomes. For example, one study found that relations between trait anxiety and math achievement were mediated by working memory, albeit on only one of two working memory tasks used (Owen et al., 2008). Furthermore, Alfonso and Lonigan (2021) found that working memory mediated associations between trait anxiety and math achievement in a community sample of adolescents. However, more research is needed to fully understand the extent to which PET/ACT applies to math performance in youth with ADHD given the prevalence and associated impairments of anxiety during this developmental period.

ADHD, Anxiety, Working Memory, and Math

Despite the high rates of co-occurrence between ADHD and anxiety, questions remain regarding whether the two factors uniquely or jointly influence working memory as it relates to math achievement in youth. In a study examining these relations in school-aged children, ADHD symptoms were found to be negatively correlated with working memory, whereas math anxiety was not (Orbach et al., 2020). Furthermore, an analysis examining intermediate effects revealed that inattentive symptoms accounted for a significant proportion of the variance in the association between math anxiety and math achievement, with both factors accounting for 19% of the variance in math achievement. However, conclusions regarding the extent to which *trait* anxiety exacerbates working memory and/or math difficulties for children with ADHD specifically are limited because the study recruited a non-clinical sample and focused exclusively on math anxiety. Importantly, there is no clear evidence illustrating how *trait* anxiety relates to math achievement in children with ADHD diagnoses, although evidence from college samples indicate that individuals with ADHD report greater math anxiety (Canu et al., 2017; Di Lonardo Burr & LeFevre, 2020, 2021). Therefore, it remains unclear if childhood anxiety symptoms exerts a unique influence on math achievement, or if the observed relations are better explained by associated working memory difficulties common in ADHD, leaving a gap in our knowledge of how pediatric ADHD and anxiety symptoms concurrently impact cognitive functions and achievement.

Current Study

Taken together, few clinical child studies have examined the concurrent associations between ADHD and anxiety symptoms while objectively evaluating working memory abilities and math achievement. Furthermore, it remains unclear if anxiety uniquely influences math achievement above and beyond the influence of working memory. The current study addresses these limitations by examining the extent to which trait anxiety is associated with the well-documented working memory and math achievement difficulties exhibited by children with ADHD. With a large and carefully phenotyped sample of children with and without ADHD, we investigated several hypotheses related to the relative associations between anxiety, working memory processes, and math difficulties in school-aged children with ADHD. Specifically, we hypothesized that (1) children with ADHD would demonstrate medium to large magnitude deficits in math achievement relative to their peers without ADHD, (2) working memory would uniquely predict math achievement, even after accounting for ADHD diagnostic status and trait anxiety, and (3) consistent with PET/ACT, trait anxiety's influence on ADHD/Non-ADHD between-group differences in math achievement would be conveyed via trait anxiety's hypothesized negative association with working memory. No hypotheses are offered regarding the potential unique associations of trait anxiety on ADHD-related math difficulties due to the paucity of literature.

Method

Transparency and Openness

We report how we determined our sample size, all data exclusions (if any), all manipulations, and all measures in the study. Data were analyzed using Mplus (Version 8.8; Muthén & Muthén, 2017). All measure inclusion/exclusion decisions and analytic plans were made *a priori*, prior to accessing the data, however the study was not publicly pre-registered. Anonymized data/code and results output are available from the authors by request; a correlation matrix is provided in Table 2 to allow replication of results. Descriptions in the Methods section are reproduced/adapted from our standard research/clinic recruitment and testing protocols licensed under CC BY 4.0.

Participants

The sample comprised 275 children aged 8–13 years (M=10.36, SD=1.44; 106 girls) from the Southeastern United States consecutively recruited through community resources to a university-based training clinic for a larger clinical research study of the neurocognitive mechanisms underlying pediatric attention and behavior problems. Recruitment began in 2015 and stopped mid 2022 (with a pause during the COVID-19 shutdown) due to the removal of the primary anxiety measure of interest (i.e., MASC-2) from the task battery. The Children's Learning Clinic (CLC) is a research-practitioner training clinic known to the surrounding community for conducting developmental and clinical child research and providing *pro bono* comprehensive diagnostic and psychoeducational services. Its client base consists of children with suspected learning, behavioral, or emotional problems, as well as typically developing children (those without a suspected psychological disorder) whose parents agreed to have them participate in developmental/clinical research studies. IRB approval from Florida State University was obtained/maintained, and all parents and children provided informed consent/assent. Race/ethnicity data were collected via a free-response/fill-in-the-blank item on a paper-and-pencil form. Mapped to U.S. census categories, sample race/ethnicity was mixed with 189 White, Non-Hispanic (68.7 %), 38 Black (13.8 %), 26 multiracial (9.5 %), and 21 Hispanic (7.6%) children, and 1 Asian child (0.4 %; Table 1). All study procedures were conducted in English.

Group Assignment

Children and caregivers completed a comprehensive psychoeducational evaluation which included detailed parent 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). Its psychometric properties are well established, including interrater agreement of .93 to 1.00, test-retest reliability of .63 to 1.00, and concurrent (criterion) validity between the K-SADS and psychometrically established parent rating scales (Kaufman et al., 1997). This semi-structured clinical interview was supplemented with age- and sex-normed parent and teacher ratings on the attention problems and hyperactivity subscales from the Behavior Assessment System for Children (BASC-2/3; Reynolds & Kamphaus, 2015) and ADHD Rating Scale for DSM-4/5 (ADHD-RS-4/5; DuPaul et al., 2016). One hundred and eighty-four children (35.9% girls) were diagnosed with ADHD based on the following criteria: (a) clinical elevations in the following domains based on the K-SADS: ADHD combined (n=125), inattentive (n=51), hyperactive/impulsive (n=6), or other-specified ADHD (n=2) presentations; (b) borderline or clinical elevations on at least one parent and one teacher ADHD symptom subscale on BASC-2/3 or ADHD-RS-4/5 (i.e., >90th percentile); and (c) current impairment based on parent report. Children with any current ADHD presentation specifiers (i.e., predominantly inattentive, predominantly hyperactive/impulsive, combined) were eligible and included in the ADHD group given the instability of ADHD presentations (Lahey et al., 2005; Willcutt, 2012).

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 co-occurring disorders (e.g., child clinical interviews, additional testing). Several children with ADHD also met criteria for common co-occurring clinical disorders based on this comprehensive psychoeducational evaluation, including anxiety disorders (generalized anxiety disorder, n=27; social anxiety disorder, n=17; separation anxiety disorder, n=6; specific phobia, n=10; other specified anxiety disorder, n= 4), oppositional defiant disorder (n=17), autism spectrum disorder (n=17), and depressive disorders (n=11). To improve generalizability given that having co-occurring disorders is the norm rather than the exception for children with ADHD (Wilens et al., 2002), these children were retained in the sample. In addition, 33 children with ADHD screened positive for specific learning disorders in math (n=27) and/or reading (*n*=22). Positive screens for learning disorders were defined based on scores ≥ 1.5 SD below age norms on one or more KTEA-3 academic skills battery reading and math subtests, as specified in DSM-5 (APA, 2013). Given the epidemiological evidence for high co-occurrence between ADHD and math disability (Capano et al., 2008; DuPaul et al., 2013; Zentall, 2007), and because positive screens in the current study were defined based on scores on our primary outcome variables, these children were retained to provide a broader range of math scores. Forty-five (24.5%) of the 184 children with ADHD were prescribed psychostimulant medication. Medication was withheld for ≥24 hours prior to their research days (i.e., when the working memory tasks were administered) due to empirical evidence that psychostimulant medication temporarily improves working memory abilities, including performance on the current study's working memory tests (Campez et al., 2022). However, children received their medication as usual on the psychoeducational testing day (i.e., when the math achievement tests were administered) because results were included in the psychoeducational report provided to families.

Additionally, 91 children (44.0% girls) completed the same comprehensive psychoeducational assessment and did not meet criteria for ADHD. To control for co-occurring diagnoses in the ADHD group, participants in this group included both neurotypical children (*n*=26) and children with anxiety disorders (generalized anxiety disorder, *n*=19; social anxiety disorder, *n*=15; separation anxiety disorder, *n*=3; specific phobia, *n*= 3; other specified anxiety disorder, *n*=1), autism spectrum disorders (*n*=14), and depressive disorders (*n*=10). Neurotypical children had normal developmental histories and nonclinical parent/teacher ratings, were recruited through community resources, and completed the same evaluation as clinically referred children. Eight Non-ADHD children screened positive for specific learning disorders in math (*n*=6) and/or reading (*n*=3) based on the criteria described above. The ADHD and Non-ADHD group did not differ significantly in the proportion of children with clinical diagnoses other than ADHD (i.e., anxiety, depression, ASD; p>.13), with the expectation that the ADHD group had higher proportions of ODD and SLD than the Non-ADHD group, as expected (p<.01). Exclusion criteria for the study included: 1) gross neurological, sensory, or motor impairments that would preclude valid test administration, 2) history of seizure disorder, 3) intellectual disability, 4) psychosis, and 5) use of non-stimulant medication (e.g., guanfacine) that could not be withheld for testing during the initial screening or evaluation phase.

Procedures

Working memory testing occurred as part of a larger battery that involved 1–2 sessions of approximately 3 hours each. All tasks were counterbalanced across sessions to minimize order effects. Children received brief breaks after each task and preset longer breaks every 2–3 tasks to minimize fatigue. Performance was monitored by an examiner at all times, who was seated just outside of the testing room (out of the child's view) to provide a structured setting while minimizing performance improvements associated with demand characteristics. Anxiety symptoms and math skills were evaluated during a separate 3-hour psychoeducational testing session administered according to standard clinical practice protocols. Due to the COVID-19 pandemic, testing procedures were modified for 93 participants according to COVID-19 safety protocols (e.g., face masks, increased physical distancing during testing, increased cleaning/sanitation procedures). Sensitivity analyses indicated that the pattern and interpretation of results reported below were unchanged when covarying COVID-19 testing status as described below.

Measures

Anxiety Symptoms—The Multidimensional Anxiety Scale for Children, Second Edition was used to assess the presence and severity of anxiety symptoms (MASC-2; March, 2013). The MASC-2 is a child self-report measure comprised of 50 items scored on a 4-point Likert scale. An anxiety latent variable was created using total raw scores from 5 subscales on the MASC-2: Separation Anxiety/ Phobias, Social Anxiety, Obsessions and Compulsions, Physical Symptoms, and the modified GAD index. These subscales were chosen given their moderate to high interrelations (r=.40-.68; March, 2013). The modified GAD index was created by removing GAD index items that are also included on other MASC-2 subscales; none of the other subscales feature overlapping items with each other. Raw scores were used as recommended for research purposes (Achenbach & Edelbrock, 1991). Psychometric support for the MASC-2 includes high internal consistency (α=.92) and test-retest reliability (r=.80-.94; Fraccaro et al., 2015). Higher scores indicate higher quantity and severity of anxiety symptoms. Intercorrelations among these subscales in the current sample (r=.39-.62) were highly consistent with those reported above based on the standardization sample.

Working Memory—A latent working memory variable was created from the three working memory tasks described below: phonological working memory, visuospatial working memory, and letter updating tasks.

Phonological and Visuospatial Working Memory Tasks: The Rapport et al. (2009) computerized working memory tasks were used to assess children's working memory abilities. Evidence for reliability and validity includes high internal consistency (α=.82-.97; Kofler et al., 2018), 1–3-week test-retest reliability (.76-.90; Sarver et al., 2015), and expected magnitude relations with criterion working memory complex span (r=.69) and updating tasks (r=.61; Wells et al., 2018). Additionally, these tasks demonstrate large magnitude differences between children with and without ADHD, and performance on these tasks has predicted ADHD-related impairment in objectively measured inattention and hyperactivity (Kofler et al., 2010; Rapport et al., 2009). Six trials per set size were administered in randomized/unpredictable order (3–6 stimuli/trial; 1 stimuli/second) as recommended (Kofler et al., 2017). Five practice trials were administered before each task (80% correct required). Higher scores indicate better performance at each set size for both tasks.

In the phonological working memory task, children were presented with a series of jumbled numbers and one letter that was never presented first or last to minimize primacy/recency effects. The letter was counterbalanced to appear equally in each of the other positions. Children were instructed to recall the numbers from least to greatest and the letter last (e.g., 4H62 recalled as 246H).

In the visuospatial working memory task, children were shown nine squares arranged in three offset vertical columns on a computer monitor. A series of 2.5 cm dots (3,4,5, or 6) were presented sequentially (1 stimuli/second). No two dots appeared in the same square on a given trial. All dots were black except one red dot that was never presented first or last to minimize primacy/recency effects. Using a modified keyboard, children were instructed to recall the serial position of the black dots and put the red dot last.

Letter Updating Task: Participants completed the letter updating task which demonstrates high internal consistency (α=0.75) and expected magnitude relations with other working memory tests (Kofler et al., 2018). In this computerized task, children were presented with letters on the screen one at a time and 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, 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. After a practice block (three correct trials required), four blocks of three trials each were administered (12 trials total). Children responded via mouse click.

Math Achievement—The Kaufman Test of Educational Achievement (KTEA-3; Kaufman & Kaufman, 2014) was used to assess children's mathematical achievement (α=.95-.98; 1–2-week test-retest=.87-.95). A latent math variable was created using the 3 math subtests of the KTEA-3: Math Concepts & Applications, Math Computation, and Math Fluency. *Math Concepts & Applications* encompasses children's skill at applying mathematical calculation principles to real-life situations. Application skills are measured in areas such as number concepts, operation concepts, time, money, measurement, geometry, fractions, decimals, data investigation, and higher math concepts. *Math Computation* refers to children's skill at completing math calculations and is assessed across multiple skill domains including counting, number identification, arithmetic operations, fractions, decimals, square roots, exponents, and algebra. *Math Fluency* refers to children's skill at quickly solving simple arithmetic problems, and is measured by the accuracy of addition, subtraction, multiplication, and division problems completed within one minute. Standard scores (age norms) for each mathematical skill were obtained by comparison to the nationally representative standardization sample (N=2,050). Higher scores indicate greater math achievement.

Intellectual Functioning (IQ) and Socioeconomic Status (SES)

IQ was estimated using the 4-subtest WISC-V Short-Form IQ (Similarities, Vocabulary, Matrix Reasoning, Figure Weights; Sattler et al., 2016). SES was estimated using the Hollingshead scoring based on caregiver(s)' occupation and education (Cirino et al., 2002).

Data Analysis Overview

Analyses were conducted using structural equation modeling (SEM) via Mplus software (Version 8.8; Muthén & Muthén, 2017). For all confirmatory models, absolute and relative fit were tested. Adequate model fit is indicated by CFI and TLI ≥ .90, and RMSEA ≤ .10. All items showed the expected range of scores and were screened for normality (all skewness < |1.2|; all kurtosis < |1.3|). Delta scaling with maximum likelihood estimation with robust standard errors (MLR) was used to handle any non-normality (Kline, 2016). Standardized residuals were inspected for magnitude (all positive and <1, indicating no evidence of localized ill fit). Directionality of parameter estimates was inspected.

Our primary analyses are organized into two analytic tiers. Age, sex, and SES were included as covariates in all Tiers/models. In the first Tier, we built our measurement models for anxiety, working memory, and math achievement using the indicators for each construct described above. In Tier 2, we created our serial conditional effects model, which evaluated the extent to which children with ADHD exhibit impairments in math achievement (path c) relative to children without ADHD, as well as the extent to which these hypothesized impairments are uniquely related to anxiety (path ab_1), uniquely related to working memory (path ab_2), and/or jointly related to (associated with variance shared between) anxiety and working memory (path ab_3). For brevity, we use the term ‘ADHD-related difficulties’ to refer to the magnitude of ADHD/Non-ADHD between-group differences in each outcome/mechanism of interest.

Pathway directionality was specified a priori given the theoretical framework of the attentional control theory reviewed above (Eysenck et al., 2007) along with evidence from prior studies (Owens et al., 2008; 2012), which collectively suggest that anxiety may be an underlying factor accounting for relations between working memory difficulties and academic achievement. ADHD diagnostic status (No/Yes) was modeled as a predictor of all other variables given that the current study aims to examine factors that account for the math difficulties experienced by children with ADHD. In addition, working memory was modeled as a predictor of math achievement given compelling evidence supporting a causal effect in this direction (Singh et al., 2022; Chen et al., 2021). Bias-corrected bootstrapping with 5,000 resamples was used as recommended (e.g., Preacher et al., 2007). For all pathways, effects are considered statistically significant if their 95% confidence intervals (Cis) do not contain zero. Effect ratios for significant indirect effects indicate the proportion of the total effect (c pathway) that is conveyed via the indirect pathway (ab; i.e., effect ratio=ab/c).

Results

Preliminary Analysis & Group Differences

All independent and dependent variables were screened for univariate outliers, defined by values above or below 3 standard deviations of the within-group mean. This process identified 0.25% (ADHD group) and 0.30% (non-ADHD group) of data points, which were corrected to the most extreme value 3 SD above or below the within-group mean. Missing data rates were low (1.45%) and were addressed using full information maximum likelihood estimation.

All parent and teacher rated ADHD scales were higher for children with ADHD relative to children without ADHD as expected (Table 1). In addition, children with ADHD demonstrated impairments on all three working memory tests (d=0.64–1.19; all p<.001) and all three math tests (d=0.62–0.75; all p<.001) relative to children without ADHD. Within the ADHD group, there were no differences in working memory performance (p=.11-.95) or math achievement (p=.06-.72) based on psychostimulant medication status. Children with ADHD evidenced higher symptoms of anxiety than children without ADHD based on teacher report (p=.03), but not parent or child report. Furthermore, there were no differences in sex (p=.20) or SES (p=.54), whereas children with ADHD were slightly younger (M_{age}=10.15 vs 10.77, p <.001) and had slightly lower IQ scores than children without ADHD (M_{SFIQ}=101.14 vs 106.22, p=.01). As noted above, age, sex, and SES were controlled in all analyses. IQ was not included as a covariate based on compelling statistical, methodological, and conceptual rationale against covarying IQ when investigating cognitive processes in ADHD (Dennis et al., 2009), and because IQ appears to reflect, in part, an outcome rather than a cause of ADHD and working memory abilities (e.g., Engle et al., 1999). In other words, covarying IQ would preclude conclusions regarding working memory by fundamentally changing our primary predictor variables and removing significant variance associated with our predictors and outcomes of interest (Dennis et al., 2009).

Tier 1: Measurement Model

The measurement model consisted of latent variables for our three primary constructs of interest. The latent anxiety variable was comprised of raw scores from the five MASC-2 subscales described above. The latent working memory variable was comprised of performance on the three working memory tests described above. The math achievement latent variable was comprised of the three KTEA-3 subtext scores described above. The measurement model showed excellent fit (CFI=.98; TLI=.98; RMSEA=.04; SRMR=.04), and all indicators loaded significantly onto their hypothesized factors (all p < .001).

Tier 2: Serial Latent Path Analysis

Serial latent path analysis was used to evaluate the extent to which anxiety and working memory uniquely or jointly account for the expected relation between ADHD diagnostic status and math underachievement. First, we interpret the total effect of ADHD on math achievement. Results indicated that ADHD diagnostic status predicted large magnitude deficits in math achievement (c pathway, d=−0.76; β=−.34, 95% CI excludes 0.0). Next, we interpret the direct effects of ADHD status on trait anxiety and working memory. Notably, there was no significant association between ADHD diagnostic status and child-reported anxiety symptoms (a_1 pathway, 95% CI includes 0.0), indicating that children with ADHD did not report experiencing more anxiety symptoms than their non-ADHD peers. However, children with ADHD exhibited large magnitude deficits in working memory as expected (a_2 pathway, d=−1.13; β=−.46, 95% CI excludes 0.0). Next, we interpret the direct effects of trait anxiety on working memory and math achievement, controlling for ADHD status. Results indicated no significant associations between trait anxiety and working memory (d pathway, 95% CI includes 0.0) or between trait anxiety and math achievement (b_1 pathway, 95% CI includes 0.0). Then, we interpret the direct effect of working memory on math achievement, controlling for ADHD status and trait anxiety. Results indicated that working memory was a significant predictor of math achievement (b_2 pathway, β=.94, 95% CI excludes 0.0).

Finally, we examined the intermediate effects of working memory and/or anxiety on the ADHD/math achievement relation. Inspection of the indirect pathways revealed that a significant proportion of the relation between ADHD diagnostic status and math underachievement was shared with working memory (ab_2 pathway, $d=-1.04$; $\beta=-.43$; Effect Ratio [ER]=1.0, 95% CI excludes 0.0), but not with trait anxiety (ab_1 pathway, 95% CI includes 0.0). There was also no joint association between working memory and trait anxiety on ADHD-related math underachievement (ab_{12} pathway, 95% CI includes 0.0). The relation between ADHD diagnostic status and math achievement was no longer significant after accounting for the indirect effect of ADHD status on math achievement via the working memory pathway (c' pathway, 95% CI includes 0.0). Altogether, ADHD status and working memory accounted for 65% of the variance in math achievement ($R^2=.65$).

For completeness, we also examined the additional intermediate effects contained in the serial path model. Trait anxiety symptoms did not significantly account for the ADHD/working memory relation (a_1d pathway, 95% CI includes 0.0). In addition, working memory did not significantly account for an association between anxiety symptoms and math achievement (db_2 pathway, 95% CI includes 0.0).

Tier 3: Sensitivity Analyses

Taken together, the primary analyses reported above indicate that a large proportion of the difficulties in math achievement exhibited by children with ADHD are related to their large magnitude working memory deficits but not their co-occurring trait anxiety symptoms. To probe the robustness of these results, we conducted a series of sensitivity analyses to determine the extent to which results may have been impacted by our a priori decisions to (1) model anxiety based on child-report; and (2) include participants who were tested under our modified COVID-19 safety protocol described above.

First, we repeated the Tier 2 analysis using parent- and teacher-rated anxiety symptoms instead of child-rated anxiety symptoms. Meta-analytic evidence indicates generally modest agreement between parent and teacher ($r=.18$), parent and child ($r=.33$), and teacher and child ratings ($r=.19$) ratings of the child's internalizing symptoms (Huang, 2017). Similarly, findings from the current study are consistent in demonstrating low to moderate correlations ($r=.15$-$.36$, $p=.001$-$.047$) between parent, teacher, and child ratings of anxiety symptoms. We thus created separate single-indicator latent variables for parent-reported and teacher-reported anxiety symptoms using total raw scores from the parent and teacher versions of the BASC-2/3, respectively, with their error variances fixed based on the anxiety subscales' published test-retest reliability estimates ($r=.85$ and $r=.86$, respectively), as recommended (Kline, 2016)[1].

When modeling anxiety symptoms based on parent report, the pattern of results and interpretation were largely consistent including that 1) ADHD diagnostic status was not predictive of parent-rated anxiety (a_1 pathway, 95% CI includes 0.0), 2) parent-rated anxiety was not associated with working memory (d pathway, 95% CI includes 0.0) or math

[1]Consistent with these modest intercorrelations, our attempts to model a latent multi-informant anxiety factor were unsuccessful, resulting in a model with failed convergence.

achievement (b_1 pathway, 95% CI includes 0.0), and 3) a significant proportion of the ADHD/math achievement relation was shared with working memory (ab_2 pathway, d=−.99; β=−.42; Effect Ratio [ER]=1.0, 95% CI excludes 0.0), but not anxiety (ab_1 pathway, 95% CI includes 0.0).

When modeling anxiety symptoms based on teacher report, the results were similar in that 1) anxiety did not directly predict math achievement (b_1 pathway, 95% CI includes 0.0), and 2) a significant proportion of the ADHD/math achievement relation was shared with working memory (ab_2 pathway, d=−.93; β=−.40; Effect Ratio [ER]=1.0, 95% CI excludes 0.0), but not anxiety (ab_1 pathway, 95% CI includes 0.0). However, the results differed from the primary model such that 1) children with ADHD exhibited significantly higher levels of teacher-rated anxiety symptoms than children without ADHD (a_1 pathway, d=0.35, β=.16, 95% CI excludes 0.0), 2) teacher-rated anxiety predicted lower working memory abilities (d pathway, d=−0.35, β=−.16, 95% CI excludes 0.0), and 3) there was a significant, albeit small, shared pathway by which working memory and anxiety jointly accounted for the ADHD/math achievement relation (ab_{12} pathway; d=−0.04, β=−.02, Effect Ratio [ER]=.06, 95% CI excludes 0.0). Taken together, teacher report of children's anxiety symptoms appeared to be more strongly associated than parent or child report with children's ADHD diagnostic status and working memory abilities.

Finally, as discussed previously, 93 of our 275 participants were tested using a modified safety protocol during the COVID-19 pandemic. We thus examined whether the protocol modifications influenced the pattern of results. To do so, we repeated the Tier 2 model using protocol type as a covariate (dichotomized as pre/pari COVID). Results indicate that there was no significant effect of testing during COVID-19 on any of our analyzed variables, including ADHD status, anxiety, working memory, and math achievement. Notably, the magnitude of the indirect effect of working memory on the ADHD/math achievement relation (ab_2 pathway, d=−.93; β=−.40; Effect Ratio [ER]=1.0, 95% CI excludes 0.0) was highly consistent with the primary Tier 2 results, supporting our *a priori* decision to include children tested under the modified COVID-19 safety protocol.

Discussion

The present study investigated the potential unique and joint associations between trait anxiety, working memory, and math achievement in a clinical sample of children with and without ADHD. In support of our first two hypotheses, we found that 1) children with ADHD evidenced large magnitude deficits in math achievement relative to peers without ADHD and 2) working memory uniquely predicted math achievement, even after accounting for ADHD diagnostic status and trait anxiety. There was mixed evidence for our third hypothesis, which proposed that trait anxiety's influence on the ADHD/Non-ADHD between group differences in math achievement would be conveyed via anxiety's hypothesized negative impact on working memory. Our findings indicated that there were no associations between trait anxiety and math achievement based on parent and child report of anxiety symptoms, and as such there were no joint associations of trait anxiety and working memory on math achievement. However, there was a small, yet significant shared association between working memory and teacher-rated trait anxiety on math achievement as discussed below.

Anxiety and Math Achievement in Pediatric ADHD

Despite the relatively common co-occurrence between ADHD and anxiety disorders (i.e., 25% rate of co-occurrence; D'Agati at al., 2019), potential differences in trait anxiety symptom expression between children with and without ADHD is poorly characterized. Our findings indicated that neither parent-reported or child self-reported anxiety symptoms were associated with ADHD diagnostic status, meaning that there were no differences in the frequency or severity of reported trait anxiety symptoms between children with and without ADHD. Of exception, we found that teacher ratings of trait anxiety were significantly higher for children diagnosed with ADHD compared to peers without ADHD, which aligns with prior literature suggesting higher teacher-reported anxiety ratings for children with ADHD relative to peers without ADHD (Kitchens et al., 1999). Indeed, anxiety symptoms are associated with observable difficulties in social functioning such as poorer social skills and increased peer rejection in children with and without ADHD (Mikami et al., 2011). These apparent social difficulties with peers, along with general impairment associated with ADHD symptoms at school (e.g., academic underperformance, emotion dysregulation) may enhance teacher's perceptions of anxiety symptoms in children with ADHD when present. Though prior evidence suggests that teachers outperform parents with regard to the sensitivity, specificity, and overall classification accuracy of ADHD in school-aged children (Tripp et al., 2006), little is known about the classification accuracy of anxiety symptoms based on multiple reporters. Available meta-analytic evidence indicates low correspondence between parent, teacher, and child-report of internalizing symptoms (mean r=.25; De Los Reyes et al., 2015) and future work is needed to determine the classification accuracy and reliability of associations with secondary outcomes (e.g., academic achievement) between multiple informants.

Given these discrepancies between parent and child vs. teacher ratings of anxiety, findings from the current study generally provided evidence against proposed ADHD/Non-ADHD between group differences in trait anxiety levels in the mid-childhood/early adolescent developmental period. However, this may be consistent with a proposed developmental trajectory of ADHD and anxiety symptoms, which indicates an increased co-occurrence between ADHD and anxiety following puberty into adulthood, compared to childhood (D'Agati et al., 2019). This developmental model suggests that impairment associated with ADHD symptoms increases over time, and thus increases the likelihood of co-occurring anxiety and executive function deficits. As such, our current sample (ages 8–13) may predominantly capture the peripubertal phase prior to major transformations in impairment and insight related to ADHD symptoms expression, and in turn associated anxiety. Indeed, available evidence from undergraduate samples indicate 1) positive associations between ADHD symptoms and trait anxiety (Di Lonardo Burr & LeFevre, 2021), and 2) that individuals with ADHD evidence significantly higher symptoms of trait anxiety compared to non-ADHD peers (Canu et al., 2017). Together, these findings suggest that, while children with and without ADHD experience similar levels of trait anxiety in the current sample, these subjective levels of anxiety may diverge in adolescence such that individuals with ADHD experience increased anxiety and associated impairment.

Importantly, we also tested several predictions from the PET/ACT models (Eysenck & Calvo, 1992; Eysenck et al., 2007), including the proposal that 1) trait anxiety is associated with math achievement and 2) the relations between trait anxiety and achievement are in part explained by anxiety's influence on working memory. Our findings generally provided evidence against a relation between trait anxiety and math achievement in children. This finding adds to a mixed literature indicating small negative associations between trait anxiety and math achievement across the lifespan (for review see Brumariu et al., 2022), and in some cases a small positive association between trait anxiety and academic achievement in adolescents (Alfonso & Lonigan, 2021). Interestingly, some previous studies have demonstrated negative associations between math anxiety and achievement through their relations with working memory (Skagerlund et al., 2019; Ashcraft & Krause, 2007). However, these results were not replicated with regard to trait anxiety in the current study, as we found only partial support for ACT such that only higher teacher ratings of anxiety predicted worse working memory performance. These findings may reflect true behavioral differences in anxiety expression at school (vs home) and meaningful associations with executive function and academics. Alternatively, these apparent associations between ADHD and trait anxiety based on teacher report may reflect an overall level of impaired functioning experienced by children with ADHD at school. Finally, the discrepant findings with regard to ACT may be explained in part by the varying extant conceptualizations of trait anxiety and math anxiety. As described above, our read of the literature is that the evidence is currently mixed regarding the extent to which math anxiety is a unique construct as opposed to reflecting trait anxiety, and the evidence is also mixed regarding the strength of the relations between trait vs. math anxiety and math achievement. As such, among studies that do not control for trait anxiety, it remains unclear if associations between math anxiety and math achievement reflect a true domain-specific link or if the association is driven by math anxiety's underlying association with trait anxiety. Evidence from the current study suggests that trait anxiety is generally not associated with cognitive disturbance during working memory or math tasks.

Working Memory and Math Achievement in Pediatric ADHD

Our findings are consistent with developmental and clinical literature indicating positive associations between working memory and math achievement (Friso-Van den Bos et al., 2013), as well as negative associations between ADHD and math achievement (Tosto et al., 2015). Importantly, these findings extend previous literature by demonstrating that working memory accounted for 100% of the ADHD-related deficits in math achievement, and that ADHD status no longer predicted math achievement when working memory was included in the model. Given the cross-sectional nature of our data, these findings indicate that there is no shared variance between ADHD and math achievement that is not also shared with working memory. Other cross-sectional studies have also provided evidence for negative associations between ADHD symptoms and math achievement (Loe & Feldman, 2007; Czamara et al, 2013), though these studies often do not account for potential neurocognitive factors such as working memory that may reflect a more parsimonious explanation for the ADHD and math achievement link. Our findings provide preliminary evidence that the negative associations between ADHD and math difficulties may be an artifact of these children's well-documented working memory deficits, rather than primarily related to their ADHD behavioral symptoms alone. Consistent with this hypothesis, experimental evidence indicates that increasing working memory demands produces differential increases in inattention and hyperactivity for children with versus without ADHD, suggesting that working memory may exert a functional if not causal influence on the behavioral manifestation of these symptoms in children with ADHD (Rapport et al., 2009; Kofler et al., 2010). Similarly, experimental studies suggest causal effects of working memory on math achievement such that 1) increasing demands on working memory leads to slower arithmetic problem solving in dual task designs (Chen et al., 2021), and 2) training-related improvements in working memory produce clinically significant improvements in math outcomes across two clinical trials that were superior to the gains observed for children in the behavior therapy and active neurocognitive training control groups (Singh et al., 2022). Taken together, working memory appears to play an influential and likely causal role in the expression of both ADHD behavioral symptoms and associated math underachievement, and that ADHD behavioral symptoms may be less involved in these children's well-documented math difficulties than previously hypothesized.

Joint Effects of Anxiety and Working Memory on Math Achievement in Pediatric ADHD

Finally, we examined potential joint effects of anxiety and working memory on math achievement. Our findings overwhelmingly suggest that trait anxiety based on child and parent report does not significantly account for the ADHD/Non-ADHD between group differences in math achievement. On the other hand, lower working memory abilities significantly predicted math underachievement and fully accounted for the ADHD/math relation in the intermediate effects model. While extant literature posits multiple factors associated with math underachievement in childhood including math self-concept, working memory, spatial abilities, and anxiety (Justicia-Galiano et al., 2017; Hamid et al., 2013; Gilligan et al., 2017), evidence from the current study suggests that working memory abilities fully account for these deficits in children with ADHD. However, of note, we found a small shared pathway by which working memory and teacher-rated anxiety jointly accounted for the ADHD/math achievement relation. This suggests that, among children with ADHD, those demonstrating more overtly anxious patterns of behavior in school performed worse on working memory tasks and standardized math achievement testing during the current study. These apparent differences in teacher versus parent and child ratings of anxiety may also be influenced by additional factors such as child medication usage (Coughlin et al., 2015), participant age (van der Ende et al., 2012), and reporter anxiety sensitivity (Francis, 2014). Taken together, though the current study did not examine all possible factors that may be related to math achievement, our results provide evidence for a strong negative association between working memory and math achievement, as well as evidence that was generally unsupportive of a link between trait anxiety and math achievement, with the exception of the teacher-rated anxiety/math achievement association mentioned previously.

Limitations

The current study has several strengths, including a relatively large and clinically evaluated sample of children, as well as a multi-method, multi-informant, and multi-task design. However, the following limitations should be considered when interpreting results. First, although the current study includes robust measurement of trait anxiety, we did not collect data on math-specific anxiety. Thus, we were unable to provide empirical evidence to inform the extent to which math-specific anxiety reflects an independent construct relative to trait anxiety in clinically-evaluated children or test for potential unique predictors of working memory and math achievement. The extent to which academic-specific anxieties are unique constructs as opposed to reflective of the more general trait anxiety construct assessed in the current study remains unclear. Notably, there is ongoing work regarding the extent to which math anxiety is a distinct construct from more general trait anxiety as noted above. A more comprehensive evaluation of the associations between anxiety and math achievement may warrant measurement of various hypothesized types of anxiety including math-specific anxiety, as well as differentiating among anxiety subcomponents (e.g., cognitive symptoms such as worry, physiological symptoms such as hyperarousal; Owens at al., 2012; NoackLeSage et al., 2019). Furthermore, future examinations should consider distinctions between trait anxiety and state anxiety (Leal et al., 2017). State anxiety is thought to be a situational manifestation of trait anxiety, though some findings suggest discrepant within-person ratings of the two (Bieg et al., 2015), and evidence is mixed regarding their relations to academic achievement (Orbach et al., 2020; Yokus, 2013). Despite commonalities among state and trait anxiety, it remains possible that state anxiety differentially relates to working memory and math achievement as it taps into the worries experienced more proximally to the performance situations (i.e., math testing). This state-like conceptualization may more closely align with the anxiety/ performance interference hypothesis proposed by ACT (Eysenck et al., 2007). With regard to ADHD classification, we recommend that future studies consider utilizing continuous measures of each ADHD symptom cluster to examine potential differential associations with anxiety, working memory, and math achievement.

Next, the current study's cross-sectional design limits the conclusions we can make regarding the direction and potential causal relations between our constructs of interest. Thus, statements that working memory 'accounted for' or 'explained' math achievement should be interpreted in the context of shared variance and not reflecting implied causality. With regard to working memory and math achievement, experimental studies (Singh et al., 2022; Chen et al., 2021) suggest that working memory exerts a causal influence on math achievement in children with ADHD. However, some evidence suggests that the relations between working memory and math achievement may be bidirectional (Peng & Kievit, 2020). Furthermore, the nature of the relations between anxiety and executive function deficits remains unclear, as some propose bidirectional relations between executive dysfunction and anxiety symptoms in individuals with ADHD (Gair et al., 2021). To that end, longitudinal and experimental studies are needed to examine the developmental trajectory of concurrent ADHD and anxiety symptoms as well as associations with outcomes of interest such as executive functioning and academic achievement. Furthermore, a more complete model of how anxiety and memory impacts math achievement would benefit from consideration of additional factors such as sleep difficulties, given some evidence that these factors influence outcomes for clinical populations with anxiety (Alvaro et al., 2013). However, some evidence suggests that amongst children with and without ADHD, parent and teacher ratings of children's sleep were not significantly associated to working memory functioning (Kofler et al., 2019).

Finally, the demographic composition of the sample and measurement of SES poses limitations for consideration. For instance, despite the study's relatively large sample size, participants that identified as White or reported higher maternal education (i.e., bachelor's degree or higher) were disproportionally represented relative to other racial identities and education levels. Therefore, this study's generalizability to other populations including historically underrepresented racial minority groups and those with mothers of lower education levels is limited. Future studies would benefit from increased efforts to recruit from underrepresented group through community outreach. Furthermore, SES was estimated from caregiver education and occupation, which may not comprehensively assess cultural, socio-demographic, and economic factors that impact SES. Although some evidence suggests high levels of agreement between the Hollingshead measure and more recently developed measures (Cirino et al., 2002), future studies my benefit from utilizing a measure of SES that considers additional sociodemographic factors. Regarding study outcomes, the magnitude of associations between working memory and math achievement may be underestimates given that a subset of the ADHD group was prescribed psychostimulant medication that was withheld for working memory but not academic testing. Further, the nature of our non-ADHD group, comprised of neurotypical children and those with other clinical diagnoses, should be considered. This approach of recruiting children with other diagnoses for the control group was deliberate and intended to increase the generalizability of findings, since clinically co-occurring disorders are diagnosed more often than not in ADHD (Wilens et al., 2002). However, equating for the proportions of these disorders across groups may not provide perfect control, and it is possible that our estimates of ADHD/Non-ADHD between group differences would have differed in magnitude if the ADHD group was compared to only neurotypical controls.

Conclusions and Clinical Implications

Taken together, the current results indicate that up to 100% of the ADHD/Non-ADHD between-group differences in math achievement may be explained by group differences in their working memory abilities. These findings add to a growing literature suggesting that working memory is likely an important prognostic factor to consider in the academic and intervention planning for children with ADHD (Fuchs et al., 2013). Importantly, we also found that trait anxiety does not appear to be a robust predictor of working memory abilities or math achievement. While contrary to our a priori hypotheses, these findings appear more consistent with recent meta-analytic and experimental evidence that pediatric anxiety disorders/symptoms do not appear to be associated with working memory difficulties (Shi et al., 2019; Majeed et al., 2023; Marsh et al., 2023). These findings do not support models suggesting that anxiety exerts a negative influence on working memory processes and/or has negative downstream effects on task performance (Eysenck et al., 2007).

Finally, while direct instruction in math skills remains the current gold standard approach to intervention (Raggi & Chronis, 2006), the robust relations between working memory and math achievement suggest promise for continued development/testing of training interventions that directly target these neurocognitive vulnerabilities. These interventions show promise particularly given replicated evidence from two clinical trials suggest that training the central executive components of working memory (i.e., the 'working' components of working memory) may bolster math achievement and classroom success/productivity for children with ADHD (Singh et al. 2022). Notably, however, most 'working memory' training interventions, which largely target short-term memory, have shown minimal efficacy in improving targeted domains and non-significant far-transfer effects to academic achievement (Aksayli et al., 2019; Rapport et al., 2013). We also would not expect working memory training to be a viable intervention for anxiety given the minimal to non-significant relations in the current study and recent meta-analyses (Marsh et al., 2023; Majeed et al., 2023; Shi et al., 2019). Thus, this should not be interpreted as a broad endorsement of 'working memory' training for children with math difficulties, especially since the aforementioned promising intervention is a research protocol that is not publicly available. As noted above, evidence-based, direct instruction in math skills remains the first line intervention for children with math difficulties. Evidence-based treatment for clinically elevated symptoms of anxiety (e.g., exposure-based cognitive behavioral therapy; Schwartz et al., 2019) is recommended to address core symptoms of anxiety and associated impairment, including school functioning, though we would speculate based on evidence from the current study that reducing anxiety alone is unlikely to produce downstream improvements in math achievement or working memory.

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Key Points

Question:

ADHD is associated with deficits in working memory and increased prevalence of internalizing symptoms such as anxiety, but do these factors uniquely or jointly account for impairment in math achievement?

Findings:

There were no associations between child-reported trait anxiety and math achievement, and the large magnitude deficits in math exhibited by children with ADHD were largely accounted for by their lower working memory abilities.

Importance:

Math achievement appears to be largely associated with neurocognitive vulnerabilities in ADHD and not associated internalizing pathology such as anxiety, thus informing appropriate targets for academic intervention.

Next steps:

Experimental and/or longitudinal work is needed to evaluate the potential causal relations between working memory and math performance, as well as the extent to which other forms of anxiety (e.g., state anxiety) influence math performance in children with and without ADHD.

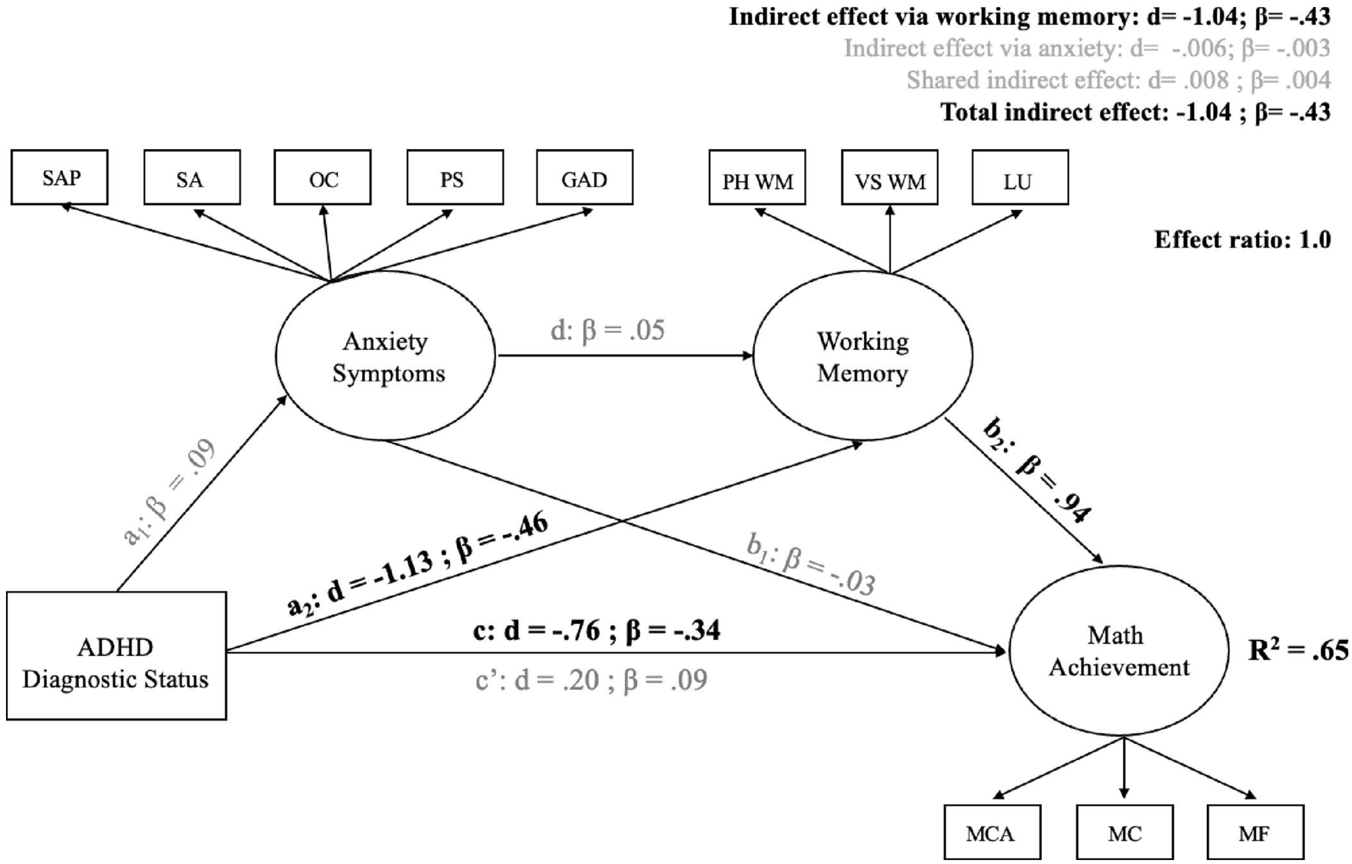

Figure 1.

Serial latent path analysis predicting math achievement. Bolded values reflect significant pathways (95% CIs exclude 0.0). Age, sex, and SES are controlled for but not depicted for clarity.

Table 1.

Sample and Demographic Variables

Variable	ADHD (N = 184)		Non-ADHD (N= 91)		Cohen's *d*	*p*
	M	SD	M	SD		
Sex (Males/Females)	118/66		51/40		--	.20, *ns*
Ethnicity (A/B/W/H/M)	0/29/129/12/14		1/9/60/9/12		--	.16, *ns*
Age	10.15	1.41	10.77	1.41	0.44	<.001
SES	47.60	10.23	48.44	11.04	0.08	.54, *ns*
Maternal education level (P/HS/A/B/G)	1/2/15/32/73/60		0/0/3/14/35/37		--	.22, *ns*
SFIQ	101.36	14.89	106.22	12.02	0.35	.01
COVID-19 Protocol (Y/N)	67/117		26/65		--	.20, *ns*
Non-ADHD Diagnoses (No/Yes)	72/112 (57 ANX, 17 ASD, 11 DEP, 17 ODD)		26/65 (35 ANX, 14 ASD, 10 DEP, 0 ODD)		--	(.22, .13, .14, .003)
ADHD Symptoms (T scores)						
Attention Problems						
Parent	68.37	7.17	61.29	10.00	−0.86	<.001
Teacher	66.10	8.04	55.64	11.89	−1.10	<.001
Hyperactivity						
Parent	69.34	12.89	58.76	12.80	−0.82	<.001
Teacher	64.31	14.80	51.87	11.51	−0.90	<.001
Anxiety Symptoms (T scores)						
Parent	55.55	11.57	57.56	12.01	0.17	.19, *ns*
Teacher	56.01	13.62	52.84	13.36	−0.23	.07, *ns*
Child	55.95	10.64	54.47	10.42	−0.14	.28, *ns*
Analyzed Variables						
Anxiety Symptoms (Raw Scores)						
Parent	15.19	7.15	16.48	7.33	0.18	.17, *ns*
Teacher	6.19	5.03	4.78	4.62	−0.29	.03
Child						
Separation Anxiety/ Phobias	11.34	5.35	10.68	4.60	−0.13	.32, *ns*
Social Anxiety	11.33	6.81	10.82	7.18	−0.07	.57, *ns*
Obsessions and Compulsions	11.25	6.79	10.26	6.39	−0.15	.25, *ns*
Physical Symptoms	11.50	6.68	10.50	6.26	−0.15	.23, *ns*
GAD Index	11.92	5.40	11.11	5.33	−0.15	.24, *ns*
Working Memory						
Phonological Working Memory	75.43	15.18	88.74	11.60	0.94	<.001
Visuospatial Working Memory	53.22	18.65	74.09	15.11	1.19	<.001
Letter Updating	21.10	7.87	25.86	6.26	0.64	<.001
Math Skills						
Math Concepts and Applications	94.44	14.91	104.04	13.93	0.66	<.001

Variable	ADHD (N = 184)		Non-ADHD (N= 91)		Cohen's *d*	*p*
	M	SD	M	SD		
Math Computation	93.42	13.52	101.84	14.02	0.62	<.001
Math Fluency	90.25	12.52	99.54	12.36	0.75	<.001

Note. Ethnicity (A = Asian, B = Black/African American, H = Hispanic/Latino, M = Multiracial, W = White/Non-Hispanic). Maternal education level (A = At least 1 year of college/ Associate degree or specialized training, B = Bachelor's/ 4-year college degree, G = Graduate School degree, HS = High School diploma or equivalent, P = Partial High School) SFIQ = Full Scale Intelligence (WISC-V Short Form), SES = Hollingshead socioeconomic status. Non-ADHD diagnoses counts do not sum to total cases due to cases with multiple co-occurring diagnoses (ANX = anxiety, ASD = autism spectrum disorder, DEP = depressive disorders, ODD = oppositional-defiant disorder). ADHD symptom T-scores derived from the Behavior Assessment for Children- 2nd/ 3rd Edition (BASC-2/3). Parent and Teacher anxiety scores derived from the BASC 2/3 anxiety total T-score and anxiety total raw score, respectively. Child anxiety T-score derived from the Multidimensional Anxiety Scale for Children- 2nd Edition (MASC-2) total anxiety T-score. Child anxiety raw scores derived from MASC-2 subscales: separation anxiety/ phobias, social anxiety, obsessions and compulsions, physical symptoms, GAD index. Working memory task performance is measured as stimuli correct per trial (PHWM, VSWM) and total stimuli correct (Letter updating). Math skills reflect standard scores (age norms) on the Kaufman Test of Educational Achievement- 3rd Edition (KTEA-3).

Table 2.

Zero-order correlations among variables

	MASC SAP	MASC SA	MASC OC	MASC PS	MASCGAD	BASC PAR	BASC TEA	PHWM	VSWM	LUWM	KTEA-MCA	KTEA-MC	KTEA-MF	Age	Sex (F/M)	SES	ADHD (N/Y)
MASC Separation Anxiety	--																
MASC Social Anxiety	.40**	--															
MASC Obsessions and Compulsions	.39**	.53**	--														
MASC Physical Symptoms	.39**	.48**	.62**	--													
MASC GAD Index	.57**	.71**	.66**	.76**	--												
BASC Anxiety: Parent-report	.17**	.16*	.01	.06	.15*	--											
BASC Anxiety: Teacher-report	.11	.07	.10	.14*	.12*	.30**	--										
Phonological Working Memory	−.08	.01	.02	.01	.03	<.01	−.17**	--									
Visuospatial Working Memory	−.05	.06	−.02	.03	.05	>-.01	−.21**	.58**	--								
Letter-Updating Working Memory	−.07	.01	−.06	−.03	.05	−.05	−.13*	.59**	.49**	--							
KTEA-3 Math Concepts & Application	.02	.01	.02	.10	.08	−.03	−.24**	.47**	.46**	.43**	--						
KTEA-3 Math Computation	−.04	−.05	−.04	.05	.03	−.03	−.17**	.49**	.42**	.40**	.77**	--					
KTEA-3 Math Fluency	−.12	−.14*	−.05	−.01	−.10	.04	−.19**	.50**	.42**	.34**	.53**	.63**	--				
Age	−.15*	.04	−.04	.03	.04	−.06	−.01	.42**	.43**	.36**	.03	.11	.13*	--			

	MASC SAP	MASC SA	MASC OC	MASC PS	MASCGAD	BASC PAR	BASC TEA	PHWM	VSWM	LUWM	KTEA-MCA	KTEA-MC	KTEA-MF	Age	Sex (F/M)	SES	ADHD (N/Y)
Sex (Female/Male)	.02	.06	−.002	−.01	.02	.03	.13*	−.02	−.07	−.02	−.12*	−.08	−.08	−.02	--		
Socioeconomic Status	−.01	.02	.06	.06	.05	−.16**	−.15*	.16**	.12*	.10	.28**	.29**	.27**	−.02	−.04	--	
ADHD Status (No/Yes)	.06	.03	.07	.07	.07	−.08	.14*	−.41**	−.49**	−.29*	−.30**	−.28**	−.33**	−.20**	−.08	−.04	--

Note: MASC=Multidimensional Anxiety Scale for Children Second Edition-2nd Edition (raw scores). BASC= Behavior Assessment System for Children -2nd/3rd Edition (raw scores). KTEA-3=Kaufman Test of Educational Achievement-3rd Edition (standard scores). Sex (Female=0, Male=1); SES=Hollingshead socioeconomic status; ADHD (No=0, Yes=1).

* p≤.05,

** p≤.01