Journal of Psychopathology and Behavioral Assessment
https://doi.org/10.1007/s10862-022-09979-3

Attention-Deficit/Hyperactivity Disorder (ADHD) and Forgetfulness: Does Time-Related Decay Reflect Deficient Rehearsal?

Mark D. Rapport[1] · **Lauren M. Friedman**[2] · **Cameron Pothoven**[3] · **Catrina Calub**[3]

Accepted: 18 April 2022

Abstract

The diminished ability to maintain verbal information in short-term memory—*forgetfulness*—mitigates the ability to follow instructions and acquisition of knowledge. Despite its acknowledged importance and involvement in multiple DSM-5 ADHD clinical symptoms, the construct remains under scrutinized in children with the disorder. The present study examined the extent to which children with ADHD (n = 15) were able to maintain multiple length word lists (2, 4, and 6 words) in phonological short-term memory (STM) for prolonged time intervals (12-s and 21-s) relative to typically developing (TD) children (n = 18). More crucially, it is the first to utilize a conventional suppression paradigm to determine whether deficient rehearsal contributes to diminished word recall by children with ADHD over time. Children with ADHD exhibited clear evidence of forgetting when tasked with remembering a greater number of words and maintaining the words over longer time intervals relative to TD children. Follow-up analyses, however, revealed that the imposition of articulatory suppression (repeating an irrelevant syllable throughout recall intervals) diminished the recall performance of children in both groups to a similar degree relative to their performance under the recall only (non-suppression) conditions. Collectively, findings indicate that inadequate use of overt/covert rehearsal to refresh/maintain verbal memoranda in phonological STM is an unlikely explanation for the higher rates of forgetting in children with ADHD. Consideration of other sources that may contribute to higher rates of forgetfulness in ADHD, such as reduced attention control and/or higher susceptibility to internal interference, warrant attention in future investigations.

Keywords ADHD · Forgetting · Short-term memory · Word recall · Articulatory suppression

The neurodevelopmental disorder—ADHD—is characterized by an early onset and clinically impairing levels of inattention, hyperactivity, and impulsivity (American Psychological Association, 2013). It is estimated to affect 5–7% of children worldwide (Polanczyk et al., 2014). ADHD has been scrutinized for over a century, and extant research reveals significant near- and long-term learning related disadvantages associated with the disorder, such as deficient academic performance/underachievement (Cherkasova et al., 2021; DuPaul et al., 2016; Friedman et al., 2017), lower rates of high school graduation/college matriculation (Jangmo et al., 2019; Klein et al., 2012; Loe & Feldman, 2007), and lower job performance/socioeconomic status in early adulthood (Döpfner et al., 2020; Erkshine et al., 2016).

Considerable research has substantiated the involvement of specific brain regions (primarily frontal/prefrontal cortices) in the disorder (Arora et al., 2020; Shaw et al., 2007, 2018), and complementary investigations confirm that higher-order executive functions associated with these regions—predominantly working memory (WM)—are underdeveloped and contribute instrumentally to its symptom presentation and learning-related negative outcomes. Collectively, these studies (Dekkers et al., 2020; Fosco et al., 2020; Kofler et al., 2010; Rapport et al., 2008a, b) and complementary meta-analytic reviews (Kasper et al.,

✉ Mark D. Rapport
mdrapport@gmail.com

Lauren M. Friedman
Lauren.Friedman@asu.edu

Catrina Calub
catrinacalub@gmail.com

[1] Department of Psychology, University of Central Florida, Orlando, Fl 32816, USA

[2] Department of Psychology, Arizona State University, Tempe, AZ 85281, USA

[3] Department of Psychology, University of Central Florida, Orlando, FL 32816, USA

Published online: 13 August 2022

2012; Kofler et al., 2016; Martinussen et al., 2005) provide incontrovertible evidence of large magnitude, domain general WM cognitive processing deficits in ADHD, and have stimulated interest concerning their involvement in overall (Calub et al., 2019) and specific areas of academic achievement (Eckrich et al., 2019; Friedman et al., 2016, 2017; Kofler et al., 2018; Swanson & Fung, 2016; Tamm et al., 2021).

Despite the accretion of evidence cited above, a paucity of information exists concerning the integrity of other WM-related cognitive functions that may impact ADHD-related foundational learning and related behavioral functioning adversely. A conspicuous example is *forgetfulness*—the expected degradation of memory representations over a brief time interval (Ebbinghaus, 1885). Examples of forgetfulness and forgetfulness-related behaviors are invoked commonly during caregiver clinical interviews (Barkley, 2015) and peppered throughout the DSM-5 ADHD inattention symptom list to include *being forgetful in daily activities*, *losing things necessary for tasks and activities*, *not following through on instructions,* and *failing to finish schoolwork and chores* (American Psychiatric Association, 2013). If present, accelerated short-term memory decay relative to same age peers would likely compound extant clinical symptoms and WM-related organizational difficulties experienced by children with ADHD (Irwin et al., 2021). Emerging evidence, based on a network analytic approach, supports this premise and reveals a robust relation between adult ratings of forgetfulness in children with ADHD and later impaired functioning at school and at home (Goh et al., 2020).

The construct *forgetfulness* was introduced in memory research over 60 years ago (Brown, 1958), and refers to a diminution of memoranda that can be maintained in a heightened state of availability in short-term memory (STM) for a brief time interval. It remains one of the most important yet difficult aspects of memory to investigate due to confounds that may occur during the presentation-to-recall interval—viz., the ability to verbally rehearse/refresh information to maintain its availability in STM, and an increased susceptibility to non-relevant information (interference) competing for entrance into the limited capacity STM store (Ricker & Cowan, 2010). The two processes are interdependent yet anatomically separate. Children engage in articulatory rehearsal, a process associated with the left prefrontal region (Broca's area; Awh et al, 1996; Paulesu et al, 1993; Smith & Jonides, 1999), to minimize the displacement of to-be-remembered information stored temporarily in phonological STM and allied with the left parietal cortex (Awh et al., 1996; Jonides et al., 1998).

Very young children characteristically use overt repetition of verbal memoranda to maintain information within the phonological STM store, but transform to covert rehearsal by six years of age (Baddeley et al., 1998; Gathercole & Baddeley, 2014). Both functions are operative prior to age 6, and approach full maturity by 12 years of age (Kail & Ferrer, 2007; Tillman et al., 2011). Two prominent models proposed to explain forgetfulness emphasize different aspects of the phenomenon: (a) time-based factors due to the decay or interference of memory traces over time, and (b) deficient rehearsal-based processes that result in the failure to actively maintain memoranda in active attention.

Previous research examining forgetfulness components in children with ADHD has focused nearly exclusively on the phonological STM storage component, using digit span task performance (i.e., recall of progressively longer single number lists following a 1-s delay) to estimate storage capacity. Meta-analytic reviews of the findings consistently reveal mild to moderate storage deficits in ADHD relative to typically developing children (Kaspar et al., 2012; Martinussen et al., 2005; Willcutt et al., 2005). These findings were extended to word recall performance by Bolden et al. (2012), and expanded to demonstrate deficits in both primary functions (storage and maintenance) over extended (12-s, 21-s) time intervals based on recall accuracy of a single length word list. Children with ADHD forgot significantly more words relative to typically developing children during the extended recall intervals despite controlling for group differences in reading speed. Unanswered, however, was whether similar results would materialize using word lists of varying lengths, and more critically, whether increased ADHD-related forgetfulness occurs due to inadequate articulatory rehearsal to refresh/maintain information in STM during extended recall intervals rather than storage deficiencies alone.

Despite the paucity of studies examining rehearsal processes among children with ADHD, widely used and well-validated experimental procedures exist to study this phenomenon. The articulatory suppression paradigm is a time-honored means of examining articulatory rehearsal dating back to the seminal work by Brown (1958) and Peterson and Peterson (1959), and has been used in studies involving typically developing children (Yang et al., 2014). The paradigm requires the continuous oral repetition of an irrelevant word or sound (e.g., the syllable, 'la, la, la') throughout the duration of a recall interval to minimize active rehearsal of to-be-remembered information (Oberauer et al., 2012; Ricker et al., 2016). Recall performance under the suppression condition is conventionally contrasted with a delay-only (no suppression) condition to estimate the extent to which minimizing the ability to articulatory rehearse information contributes to the loss of information in phonological STM over time.[1] For example,

[1] Other types of rehearsal—viz., attentional refreshing and elaborative rehearsal—can also be used to forestall memory decay; however, we focus on articulatory rehearsal because it represents a key process

a similar decrease in recall performance in both groups over time under the suppression condition would indicate that between-group differences in delayed recall without suppression likely reflect time-based factors contributing to forgetfulness rather than rehearsal-related mechanisms. A standardized measure of each child's phonological STM as a covariate is also used in the present investigation. This statistical control minimizes the potential influence of any between-group, pre-existing differences in children's STM capacity on word recall performance over time, and simultaneously allows effects related to the multiple word list length conditions to be scrutinized.

The present study, conducted concurrently with the Bolden et al. (2012) study and with the same participants, examines the extent to which children with ADHD are able to maintain multiple length word lists (2, 4, and 6 words) in PH STM for prolonged time intervals (3 s vs 12 s and 21 s) relative to typically developing (TD) children. More crucially, the present study is the first to utilize a conventional suppression paradigm to determine whether deficits in rehearsal processes contribute to the deficient recall ability of children with ADHD relative to typically developing children over time. Building on the Bolden et al. (2012) findings, we hypothesized that word recall performance of all children would decrease as a function of increasing word list length and time, and that children with ADHD would recall significantly fewer words in the longer (4-, 6-word) word length conditions over time relative to typically developing children. The performance of both groups was also hypothesized to deteriorate over time under the articulatory suppression relative to the delay recall only condition. Finally, we analyzed for possible group by condition (recall only vs suppression) interaction effects based on our hypothesis that higher rates of ADHD-related forgetfulness occur due to inadequate articulatory rehearsal to refresh/maintain information in STM during extended recall intervals. Findings are expected to contribute both theoretical and applied value to the field by elucidating mechanisms and processes that may contribute to ADHD-related forgetting, and informing the design of novel interventions to strengthen these capabilities if warranted. For example, given the distinctiveness of the phonological STM store and articulatory rehearsal mechanism noted earlier, documenting underdevelopment in one or both processes may require different albeit complementary training interventions or compensatory approaches (e.g., behavioral intervention strategies).

Footnote 1 (continued)

inherent to the PH STM component of Baddeley's WM model, and its predominant use by pediatric age children.

Methods

Experimental Participants The sample comprised 33 boys ages 8 to 12 ($M = 9.67$, $SD = 1.32$) selected by or referred to a university-based children's research-practice clinic through community resources (e.g., referrals from pediatricians, community mental health clinics, school systems, and self-referral). Sample race and ethnicity included 19 Caucasian Non-Hispanic (58%%), 7 Hispanic or Latino (21%), 2 African American (6%), and 5 multiracial/ethnic (15%) children. All parents and children provided their informed consent/assent prior to participating in the study, and approval from the university's Institutional Review Board was obtained prior to the onset of data collection. Two groups of boys participated in the study: boys with ADHD combined presentation (n = 15), and Typically Developing (TD) boys (n = 18) without a psychological disorder. Boys with a history of (a) gross neurological, sensory, or motor impairment by parent report, (b) history of a seizure disorder by parent report, (c) psychosis, or (d) Full Scale IQ score < 85 were excluded. A psychoeducational evaluation was provided at no charge to the parents of all participants.

All children and their parents participated in a detailed, semi-structured clinical interview using all modules of the Kiddie Schedule for Affective Disorders and Schizophrenia for School-Aged Children (K-SADS). The K-SADS assesses onset, course, duration, severity, and impairment of current and past episodes of psychopathology in children and adolescents based on DSM-5 criteria. Its psychometric properties are well established, including interrater agreement of 0.93 to 1.00, test–retest reliability of 0.63 to 1.00, and concurrent (criterion) validity between the K-SADS and psychometrically established parent rating scales (Kaufman et al., 1997; Nishiyama et al., 2020).

Fifteen boys meeting the following criteria were included in the ADHD-combined presentation group: (1) an independent diagnosis by the directing clinical psychologist using DSM-5 criteria for ADHD-combined presentation based on K-SADS interview with parent and child; (2) parent ratings of at least 2 SDs above the mean on the Attention-Deficit/Hyperactivity Problems DSM-Oriented scale of the Child Behavior Checklist (CBCL; Achenbach et al., 2001), or exceeding the criterion score for the parent version of the ADHD-combined subtype subscale of the Child Symptom Inventory-4: Parent Checklist (CSI-P; Gadow et al., 2004); and (3) teacher ratings of at least 2 SDs above the mean on the Attention-Deficit/Hyperactivity Problems DSM Oriented scale of the Teacher Report Form (TRF; Achenbach et al., 2001), or exceeding the criterion score for the teacher version of the ADHD-combined subtype subscale of the Child Symptom Inventory-4: Teacher Checklist (CSI-T; Gadow et al., 2004). The CBCL, TRF, and CSI are among

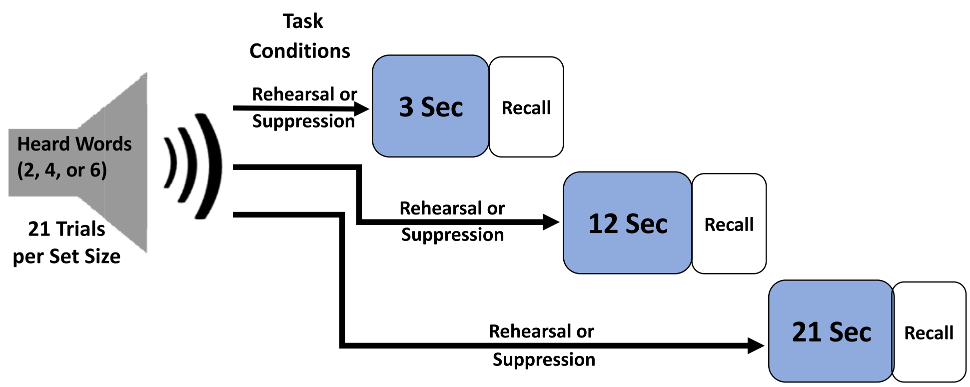

Fig. 1 Visual schematic of the experimental paradigm. Each unique word list length (2, 4, 6 words) was administered for 21 trials under each of the three (3, 12, 21 s delay) *recall only* and three (3, 12, 21 s delay) *suppression/recall* conditions in a counterbalanced order. During the *recall* condition, children verbally state remembered words at the conclusion of the imposed time interval; during the *suppression/recall condition,* children repeat "la" once per second throughout the delay interval and state remembered words at the conclusion of the imposed time interval

the most widely used behavior rating scales for assessing psychopathology in children, and their psychometric properties are well established (Rapport et al., 2008a, b). Six of the children (40%) also met diagnostic criteria for Oppositional Defiant Disorder (ODD). Five of the children with ADHD were receiving medication (a psychostimulant regimen) at the time of the study—parents withheld medication (with physician approval) for a minimum of 24 h prior to each week's assessment session.

Eighteen boys met the following criteria and were included in the Typically Developing group (TD): (1) no evidence of any clinical disorder based on parent and child K-SADS interview; (2) normal developmental history by parental report; (3) ratings within 1.5 SDs of the mean on all CBCL and TRF scales; and (4) parent and teacher ratings within the nonclinical range on all CSI subscales.

Measures

Phonological Memory Tasks Phonological memory (PH) tasks were created for the present study to assess verbal short-term memory for words based on Baddeley's model (2007; 2018). Children were instructed to recall lists of monosyllabic words selected from a second-grade reading list and reviewed by the clinic's research team. Words with strong emotional content (e.g., death, hate), homonyms (e.g., eight, ate), and proper nouns (e.g., Matt) were excluded from the list. Words from the final list were assigned randomly (without replacement) to 18 distinct word lists, each comprised of 21 trials. Each word list contained unique stimuli used exclusively within that list as described below.

All words were recorded using the AT&T Natural Voices ® Text-to-Speech synthesis system and presented auditorily at 1 s intervals for all experimental conditions. Word list presentation and response instructions were identical across all conditions to rule out phonological input (auditory) and output (spoken) mechanisms as potential explanations for changes in performance across conditions. An auditory presentation was used because verbal information gains automatic access to the phonological storage/rehearsal system (Baddeley, 2007) without requiring orthographic conversion of read words to sounds. Spoken output was selected to avoid confounding due to possible motor output deficits (e.g., Klein et al., 2006) given that spoken (left prefrontal) and motor output (right premotor) rely on neuroanatomically distinct cortical regions (Baddeley, 2007).

Nine of the 18 word lists were created for the *recall only* conditions. The lists were constructed to include stimuli presentations of either 2, 4, or 6 words per trial as follows: three distinct lists contained 2 unique words, three distinct lists contained 4 unique words, and three distinct lists contained 6 unique words. One distinct list at each set size (2, 4, and 6 words) was administered once under the 3 s, 12 s, and 21 s delay conditions during which time children could rehearse the words throughout the delay interval imposed. To recapitulate, each child was presented with and recalled one distinct, 21-trial list of 2 words, 4 words, and 6 words, on three separate occasions under the 3 s delay condition, and again under the 12 s and 21 s delay conditions. The remaining nine, word lists were constructed and administered in an identical manner for the *suppression/recall* conditions (see below) to render a total of 18 unique word list administrations in the study. A visual schematic of the experimental protocol is depicted in Fig. 1.

For the *suppression/recall* conditions, children were instructed to verbalize the word 'la' repeatedly for the duration of the entire delay interval. A low but discernable auditory 'click' sound was programmed to emanate from the monitor's speakers once per second throughout the delay interval separating the onset of the red and green light, which depended on the imposed delay interval in force. The click served as an auditory reminder to children to continue repeating the sound "la" once every second until the green light appeared on the monitor, and to assist them with enunciation timing. As discussed earlier, the suppression condition was designed to actively interfere with children's ability to rehearse words during the imposed delay interval.

A red light, indicating *do not respond*, appeared after the presentation of each trial and displayed for 3 s, 12 s, or 21 s to correspond with the recall delay condition implemented. A green light appeared on the monitor at the conclusion of the imposed time delay indicating the onset of the response period. Children were instructed to recall as many words as they could remember in any order from the presented list following the onset of the green light (i.e., free recall). A bell chimed (soft 'ding') after the response phase (10 s), indicating that a new set of words—from the same set size list consisting of 21 distinct trials—was to be presented.

All children completed all word set size *recall only* and *suppression/recall* conditions under each of the three recall delay parameters used in the study (3 s, 12 s, 21 s). The 3 s delay condition was used to minimize the reliance on echoic memory (180–200 ms sensory registry for holding acoustic information; Huggins, 1975) and the opportunity for covert rehearsal of a word list. The two extended delay conditions—12 s and 21 s—were selected to equate the delay interval between adjacent conditions (i.e., 9 s between the 3 s and 12 s, and between the 12 s and 21 s delay conditions), and allow sufficient time to challenge the articulatory (subvocal) rehearsal mechanism based on earlier findings demonstrating that children are able to maintain words by means of covert rehearsal up to 30 s (Bauer, 1977; Bolden et al., 2012).

Two, trained research assistants, shielded from the participant's view and blind to diagnostic status, recorded oral responses independently. Interrater reliability (95%) was computed for all children across the experimental conditions. External validity for the phonological memory task used in the study was evidenced by its expected magnitude relationship with an established, verbally presented measure of short-term memory (i.e., WISC-IV Digit Span standard score: $r = 0.66$), coupled with the expected declining pattern of correlations with increasing time delay (i.e., $r = 0.56$ and 0.52 for the 12 s and 21 s delay conditions, respectively); all p values ≤ 0.005.

Procedure

The Phonological Memory tasks were programmed using Superlab Pro 2.0 (2002). All children participated in four consecutive Saturday assessment sessions. The tasks were administered as part of a larger battery of neurocognitive tasks that require the child's presence for approximately 2.5 h per session. Children completed all tasks while seated alone in an assessment room. 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 the potential influence of examiner demand characteristics (Gomez & Sanson, 1994; Power, 1992). All children received brief (2–3 min) breaks following every task, and preset longer (10–15 min) breaks after every two to three tasks to minimize fatigue. A minimal interval of 30 min was used to separate administration of the word list recall tasks on each of the four assessment days. Performance across the delay conditions was analyzed using a percent correct metric due to individual differences in the number of words presented per trial.

Children were seated in a caster-wheel swivel chair approximately 0.66 m from the computer monitor for all tasks, and were administered a practice block consisting of two stimuli per trial immediately prior to the phonological memory conditions until achieving a minimum of 80% correct to ensure instructional understanding. Similar practice blocks were used to demonstrate and ensure children understood how to perform under the suppression condition (i.e., repeating *la, la, la* throughout the delay interval concomitant with the click emitted from a speaker).

Phonological STM Capacity The Weschler Individual Scale for Children (WISC) digit span subtest consists of two components (digit span forward, digit span backward) and was used to estimate each child's phonological STM capacity. Children are instructed to recall increasingly longer strings of numbers in the same (digit span forward) or reverse (digit span backward) order as presented aloud by the examiner. Raw scores were converted to standard scores via published WISC-IV manual age norms (Wechsler, 2003).

Data Analytic Plan

All statistical analyses were performed using SPSS Version 26 (2019). Preliminary analyses involved screening for multivariate outliers, investigating demographic characteristics for potential between group differences (see Table 1), and conducting a priori power analyses. Consistent with best practice recommendations, stimuli correct per trial were considered (Conway et al., 2005; Kasper et al., 2012; Wells et al., 2018), and separate scores at each word set size condition were derived. Primary analyses involved select three-way mixed model analyses of variance (ANOVAs) examining between (diagnostic group) and within (suppression condition, word list length, recall delay interval) group effects, with each model directly testing study hypotheses. This approach

Table 1 Demographic Variables

Variables	ADHD		TD		
	M	SD	M	SD	t
Age	8.73	1.16	9.61	1.38	1.95
FSIQ	101.13	13.42	110.61	11.67	2.17*
FSIQres	0.085	1.11	0.071	0.887	0.45
SES	46.50	12.83	49.81	10.61	0.81
CBCL ADHD Parent rating	71.20	7.67	55.83	8.16	-5.54***
TRF ADHD Teacher rating	64.53	8.67	56.24	6.82	-3.03***
CSI ADHD Parent rating	76.00	12.17	52.72	12.45	-5.41***
CSI ADHD Teacher Rating	63.60	11.38	52.00	9.15	-3.20***
WISC Digit Span Standard Score	10.00	2.95	10.72	2.96	0.70

ADHD Attention-Deficit/Hyperactivity Disorder, *CBCL ADHD* Child Behavior Checklist scale parent T-score, *CSI ADHD* Parent rating Child Symptom Inventory ADHD scale parent T-score, *CSI ADHD* Teaching rating Child Symptom Inventory ADHD scale teacher T-score, *FSIQ* Full Scale Intelligence Quotient, *FSIQres* Full Scale Intelligence Quotient with working memory factor regressed, *SES* Socioeconomic Status, *TD* Typically Developing Children, *TRF* Teacher Report Form ADHD scale, *WISC STM* Weschler Intelligence Scale for Children digit span forward

*$p \leq 0.05$; **$p \leq 0.01$; ***$p \leq 0.001$

was adopted to balance concerns regarding the sample size required to detect a 4-way ANOVA while also minimizing the effects of family-wise error. Further, post-hoc analyses were limited to those that probed study hypotheses, and the Benjamini–Hochberg False Discovery Rate (FDR) was applied within domain to reduce the likelihood of Type 1 error. The FDR is superior to other post-hoc analyses and is associated with lower rates of familywise error relative to other approaches (e.g., Bonferroni correction).

A Priori Power Analysis

A power analysis performed using G*Power (Faul et al., 2007) indicated that 31 participants were needed to detect between-subject effects for each of the three mixed model repeated measures ANOVAs with three task conditions (2-, 4-, 6 words), three recall intervals (3 s, 12 s, 21 s), 2 groups (ADHD, TD), 0.80 power (1-beta), alpha = 0.05, an estimated effect size of $d = 0.79$, and correlation of $r = 0.74$ between measures based on the delayed word recall investigation results reported by Bolden et al. (2012). Thirty-three children participated in the present study.

Results

Preliminary Analyses

All independent and dependent variables were screened for multivariate outliers using Mahalanobis distance tests ($p < 0.001$); none were identified. Demographic variables were examined to determine whether any needed to be included as covariates in the ensuing focused analyses. These included participant age, socioeconomic status (Hollingshead, 1975), and short-term memory capacity (WISC digit span standard score)—no significant between group differences were detected. Full Scale IQ (FSIQ) was not included as a covariate consistent with best practice recommendations (Dennis et al., 2009; Miller & Chapman, 2001). Briefly, FSIQ shares significant variance ($r = 0.68$ to 0.79) with its working memory factor, and removal of variance attributable to FSIQ would remove important variance in memory—the independent variable in the study. Consistent with past studies (Friedman et al., 2017; Kofler et al., 2016; Rapport et al., 2008a, b), we removed reliable variance associated with working memory (see WISC STM capacity, above) from FSIQ, and examined between group differences without its influence (i.e., FSIQ residual [res]). Results revealed non-significant between-group differences in FSIQres ($p = 0.655$). Children with ADHD received significantly higher scores on all parent and teacher rating scales as expected (see Table 1). Age ($p = 0.06$), SES ($p = 0.42$), and digit span ($p = 0.49$) were not significantly different between the two groups. Therefore, simple model results without demographic or STM covariates are presented.

Results

A 3-tier data analytic approach was used to address the study's hypotheses. The initial tier expanded on the findings reported in the Bolden et al. (2012) investigation by examining whether children with ADHD recalled fewer words for the three set size conditions (2-, 4-, 6-words) relative to TD children, and whether these effects differed as a function of recall time intervals (3 s, 12 s, 21 s). The second tier examined the extent to which suppressing children's use of articulatory rehearsal to maintain to-be-remembered words in phonological short-term memory (STM) affected their recall performance during the progressively longer recall intervals, and whether the suppression manipulation affected the two groups differently. A final set of analyses addressed the foremost question of the study—whether children with ADHD experience rehearsal deficits relative to TD children that reduce their ability to maintain and recall information (words) over time. Subtest scores are reported in the Supplementary Table S1, and all pairwise comparisons are presented within Supplementary Tables S2, S3 and S4.

Word Set Size and Recall Time Effects

For the recall condition, a 2 (Group: ADHD, TD) × 3 (Word Set Size: 2-, 4-, 6-words) × 3 (Delay Time: 3 s, 12 s, 21 s) mixed model ANOVA revealed a nonsignificant three-way interaction. This finding indicates that the magnitude of *between group* differences in recall performance did not change significantly as a function of having to recall a greater number of words and undergo longer time time intervals. Significant two-way interactions emerged for Group by Word Set Size F (2, 32) = 7.63, $p = 0.001$ and Group by Delay Time F (2, 32) = 5.06, $p = 0.01$, wherein TD children performed significantly better than children with ADHD under all word set size and recall time delay conditions during the recall task (all FDR corrected ps < 0.001). A significant two-way Word Set Size by Delay Time interaction effect F (4, 32) = 5.55, $p < 0.001$ also emerged (see Supplementary Table S3), indicating that all children's performance decreased in a linear fashion as the number of to-be-remembered words and recall time delay increased (all ps < 0.001). Finally, significant main effects emerged for Group F (1, 32) = 33.04, $p < 0.001$, Word Set Size F (2, 32) = 272.01, $p < 0.001$, and Delay Time F (2, 32) = 82.29, $p < 0.001$, indicating that ADHD diagnostic status, having to maintain/recall a greater number of words, and prolonged recall times were associated with inferior recall of to-be-remembered words ($p < 0.001$ for all FDR corrected pairwise comparisons).

Effects of Articulatory Suppression

For the articulatory suppression condition, a 2 (Group: ADHD, TD) × 3 (Word Set Size: 2-, 4-, 6-words) × 3 (Time Delay: 3 s, 12 s, 21 s) mixed model ANOVA revealed a significant three-way interaction involving Group, Word Set Size, and Time Delay, F (4, 32) = 4.77, $p = 0.001$, wherein children with ADHD performed worse than TD children as the number of words to be remembered and recall time increased (all FDR corrected ps < 0.009)**.** A significant two-way interaction effect for Group and Time Delay F (2, 32) = 3.90, $p = 0.03$ also emerged, such that TD children performed significantly better than children with ADHD under all three (3 s, 12 s, 21 s) recall intervals (all ps < 0.001). The two-way interaction effect for Word Set Size by Time Delay F (4, 32) = 7.58, $p < 0.001$ was also significant, wherein diminished performance for all children occurred as a function of longer word lists and recall time intervals (all ps < 0.001). In contrast, the nonsignificant Group by Word Set Size interaction effect F (2, 32) = 1.93, $p = 0.15$, indicates that increasing the number of to-be-remembered words diminished the recall performance of both groups in a similar manner. Finally, significant main effects were found for Group F (1, 32) = 36.97, $p < 0.001$, Word Set Size F (2, 32) = 244.96, $p < 0.001$, and Time Delay F (2, 32) = 185.62, $p < 0.001$, wherein ADHD diagnostic status, increasing the number of words to-be-remembered, and longer recall time intervals were associated with lower recall performance ($p < 0.001$ for all FDR corrected pairwise comparisons).

Suppression Relative to Non-suppression On Children's Recall Performance

The foregoing analyses revealed a significant three-way interaction involving group, word set size, and time delay; however, supplemental analyses revealed that the grouping variable interacted only with recall time as a significant two-way effect. Consequently, select analyses were conducted to explicate which recall time delay conditions contributed to the group recall differences, and whether they remained significant when contrasting the recall only and suppression conditions.

For the 2-word condition, a 2 (Group: ADHD, TD) × 2 (Recall Condition: recall only vs suppression) × 3 (Time Delay: 3 s, 12 s, 21 s) mixed model ANOVA revealed a significant main effect of Group F (1, 32) = 34.44, $p < 0.001$, Recall Condition F (1, 32) = 34.57, $p < 0.001$, and Time Delay F (2, 32) = 126.59, $p < 0.001$ such that ADHD diagnostic status, recall condition, and greater time delay were associated with lower word recall performance ($p < 0.001$ for all FDR corrected pairwise comparisons). A Recall Condition by Time Delay interaction effect F (2, 32) = 6.54, $p = 0.003$ was also observed, and follow-up pair-wise comparisons indicated greater articulatory suppression effects occurred as a function of longer recall delay times (all ps < 0.03). The Group by Time Delay interaction F (2, 32) = 14.15, $p < 0.001$ was also significant; however, the lack of any additional significant two- and three-way interactions involving the grouping variable indicate that children with ADHD are not more susceptible to articulatory suppression relative to TD children when tasked with remembering two words.

For the 4-word condition, a 2 (Group: ADHD, TD) × 2 (Recall Condition: recall only vs suppression) × 3 (Time Delay: 3 s, 12 s, 21 s) mixed model ANOVA revealed a significant main effect of Group F (1, 32) = 32.95, $p < 0.001$, Recall Condition F (1, 32) = 47.06, $p < 0.001$, and Time Delay F (2, 32) = 95.06, $p < 0.001$ such that ADHD diagnostic status, recall condition (suppression), and longer recall time delay were associated with poorer performance ($p < 0.001$ for all FDR corrected pairwise comparisons). The two-way interaction for Recall Condition and Time Delay was also significant F (2, 32) = 7.37, $p = 0.001$, and follow up pair-wise comparisons indicated greater articulatory suppression effects for all children as a function of prolonging the recall interval for maintaining words in short-term memory. The remaining two-way and three-way interactions involving the grouping variable were nonsignificant (all p values > 0.05), however, and indicate that children with ADHD are not more susceptible to articulatory suppression relative to TD children when tasked with remembering four words.

The 2 (Group: ADHD, TD) × 2 (Recall Condition: recall only vs suppression) × 3 (Time Delay: 3 s, 12 s, 21 s) mixed model ANOVA for the 6-word condition revealed a significant main effect for Group F (1, 32) = 33.73, $p < 0.001$, Recall Condition F (1, 32) = 54.18, $p < 0.001$, and Time Delay F (2, 32) = 77.79, $p < 0.001$, wherein ADHD diagnostic status, suppression (vs recall only), and greater recall time delay were associated with lower word recall performance ($p < 0.01$ for all FDR corrected pairwise comparisons). The two-way interaction involving Recall Condition and Time Delay F (2, 32) = 10.63, $p < 0.001$ was also significant, and follow up pair-wise contrasts revealed greater articulatory suppression effects as a function of increasing recall time (all FDR corrected pairwise comparisons $p < 0.001$). Finally, none of the 2- or 3-way interactions involving the grouping variable were significant, and indicate that children with ADHD are not more susceptible to articulatory suppression when tasked with remembering six words.

Collectively, the results revealed that (a) all children recall fewer words as a function of longer word lists, prolonged recall time intervals, and a reduced ability to refresh to-be-remembered words using articulatory rehearsal; (b) children with ADHD forget more words relative to TD children when word lists contain more items and recall intervals are prolonged; and (c) the diminished recall performance exhibited by children with ADHD relative to TD children does not appear to be attributable to articulatory rehearsal deficiencies.

Discussion

The abilities to hold (storage) and temporarily preserve (maintenance) a limited amount of verbal information in a readily accessible state are considered vital functions of phonological (PH) short-term memory (STM), and required in myriad activities throughout life. The two functions interact recurrently, with the maintenance function bearing the more active role of revitalizing information via attentional refreshing or overt/covert articulatory rehearsal to minimize the forgetfulness of memoranda (Baddeley, 2007; 2018).

PH STM storage deficiencies in children with ADHD have been substantiated reliably in meta-analytic reviews, based conventionally on digit recall performance using increasingly longer strings of single numbers (Kaspar et al., 2012; Martinussen et al., 2005; Willcutt et al., 2005). These findings were extended to *word* recall performance and expanded to demonstrate deficits in both primary functions (storage and maintenance) over extended time intervals using a single length word lists (Bolden et al., 2012). The present study, conducted concurrently with the Bolden et al. study and with the same participants, examined the extent to which children with ADHD were able to maintain multiple length word lists (2, 4, and 6 words) in PH STM for prolonged time intervals (12-s and 21-s) relative to typically developing (TD) children. More crucially, it is the first to utilize a classical suppression paradigm to ascertain whether higher rates of forgetfulness reflect deficient articulatory rehearsal processes in ADHD, a primary mechanism used by children to maintain information in an accessible state.

Our initial analyses revealed that children with ADHD and typically developing (TD) children experienced significant performance declines related to recalling longer relative to shorter word lists, and maintaining to-be-remembered words over longer relative to shorter time intervals. This was an expected set of findings given the well-documented loss of information exhibited by children and adolescents for retaining higher verbal information loads over extended recall intervals (Ferreira et al., 2015; Lewandowsky & Oberauer, 2015; Vergauwe et al., 2014). Robust between-group differences in forgetting also emerged. Children with ADHD recalled significantly fewer words under the longer word list length and prolonged recall time interval conditions relative to TD children, and these differences remained after controlling for potential differences in PH STM capacity. Collectively, these findings corroborate and expand those of previous studies (Bolden et al., 2012) by demonstrating that children with ADHD are more susceptible to forgetting verbal information (relative to TD children) when tasked with maintaining longer word lists for extended time intervals.

The ensuing analyses examined the effects of introducing an articulatory suppression paradigm, and revealed that the recall of children in both groups diminished significantly relative to their performance in the otherwise identical word list length and delayed recall only conditions. The finding is consistent with previous reported negative effects of suppression on word recall in non-ADHD children of various ages (AuBuchon et al., 2018; Norris et al., 2018; Tianxiao et al., 2014), and supports the veridicality of the experimental manipulation. A follow-up analysis, however, revealed that the imposition of articulatory suppression diminished the recall performance of children in both groups to a similar degree relative to their performance under the recall only (non-suppression) conditions. This finding suggests that inadequate use of overt/covert rehearsal to refresh/maintain verbal memoranda in PH STM is an unlikely explanation for the higher rates of forgetting in children with ADHD relative to TD children, and warrants consideration of other influences.

Two plausible factors that may have contributed to the accelerated loss of verbal information by children with ADHD relative to TD children are grounded in extant theoretical memory models. The first is *time decay*, wherein information is lost relative to the amount of time elapsed and hypothesized to represent the expected neural degeneration of orally presented words (Ricker et al., 2016). Although devalued as an explanation of forgetting in favor of interference-based models (Lewandowsky et al., 2004; Oberauer et al. (2012) more recent critical reviews propose that time-based forgetting may occur for reasons other than interference (Ricker & Cowan, 2010; Ricker et al., 2016). For example, children in the two groups may have adopted different rehearsal strategies to maintain the word lists in PH STM (McNamara & Scott, 2001; Turley-Ames, 2003). Evidence supporting this explanation is derived from developmental studies demonstrating that rehearsal strategies are amended as children grow older to accommodate more complex rehearsal mechanisms (e.g., attentional refreshing and elaborative rehearsal) that are less dependent on techniques such as articulatory rehearsal (cf. Oberauer, 2019, for a review). Given the developmental delay in the frontal/prefrontal cortex evidenced by many children with ADHD (Shaw et al., 2007; 2018), it may be that the development of these more complex rehearsal mechanisms is also delayed, resulting in basic short-term memory maintenance deficits.

An alternative and perhaps more viable explanation for the accelerated loss of verbal information over time by children with ADHD stems from predictions drawn from the *interference model* of short-term memory, wherein task irrelevant information competes for space in the limited capacity short-term store, causing task relevant information to be lost (Lewandowsky et al., 2004; Ricker et al., 2016). If correct, between-group differences would indicate that children with ADHD experience a greater susceptibility to irrelevant information during active maintenance operations relative to TD children. External interference effects, such as ambient noise, were minimized throughout the study; however, procedures were not initiated to assess children's internally generated covert speech or thoughts.[2]

Despite our well phenotyped sample and dedicated experimental controls, potential limitations of the investigation warrant consideration. The inclusion of only boys in the study reflects well-documented gender differences in neurocognitive functioning (Bálint et al., 2009), neural structure (Baving et al., 1999; Dirlikov et al., 2015; Gershon & Gershon, 2002; Mahone & Wodka, 2008), and ADHD symptom presentation (Gaub & Carlson, 1997), as well as recent evidence demonstrating distinct patterns of impaired cognitive control among boys and girls with the disorder (DeRonda et al., 2021). The study also excluded children meeting diagnostic criteria for ADHD-inattention presentation subtype based on extant evidence that they differ on several key neurocognitive dimensions such as executive functioning and motor skills (Dovis et al., 2015) and perform worse on speeded processing tasks (Rostami et al., 2020). While utilizing a narrow yet rigorously defined inclusion criteria has the benefit of strengthening internal validity, it also limits generalization to other populations. Future studies are needed to examine the presence of increased forgetfulness among females with ADHD, other ADHD presentation subtypes, and children with clinical disorders and/or learning disabilities that are thought to exhibit forgetfulness to examine the generalization of the current findings to these populations.

Finally, although our study investigates the differential effects of disruption to the rehearsal system within the PH STM, it remains unknown whether the higher rate of forgetting words evidenced by the ADHD group occurs due to a greater susceptibility to interference effects, or other factors such as the adoption of a more advanced rehearsal strategies by same age TD children. The inclusion of additional experimental controls to explicate self-directed speech and/or other mechanisms that help account for ADHD-related deficits in their ability to maintain information in the PH STM may prove beneficial.

From a clinical perspective, addressing the potential consequences for increased forgetting are noteworthy and may become particularly pronounced in educational or other settings that require active listening, maintaining verbal information for brief time intervals, and following directions to learn and complete daily activities. Clinical/educational practice implications gravitate toward incorporating a compensatory approach to help mitigate the adverse effects of forgetfulness by children with ADHD (Elliott et al., 2010). This might involve refashioning aspects of school-based curricula such as instantiating the word (Horst, 2013), providing external cues to promote recall, and establishing focused and brief learning intervals (Vlach & Sandhofer, 2012). Alternatively, training individuals to become more resistant to interference effects using meditation training techniques have shown encouraging results; however, these efforts are limited to high functioning adults thus far (Greenberg et al., 2019).

[2] In future studies, requiring children to initiate a noninterfering motor response whenever they engage in irrelevant thoughts during the task might address this conceptual question.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s10862-022-09979-3.

Acknowledgements The authors wish to express their grateful appreciate to the parents and children who participated in the study, and to the UCF Children's Learning Clinic's research team members who assisted with the conduct of the study.

Author Contributions All authors contributed significantly to the preparation of the manuscript and have consented to being included as co-authors on the manuscript. The determination of authorship ordering adhered to the APA's published guidelines for determining authorship in research publications.

Funding The authors did not receive support from any organization for the submitted work. All authors certify that they have no affiliations with or involvement in any organization or entity with any financial interest or non-financial interest in the subject matter or materials discussed in this manuscript.

Declarations

Ethical Approval All procedures performed in the study were in accordance with the ethical standards of the University of Central Florida's IRB committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. Preparation and submission of this manuscript was compliant with APA ethical standards and University of Central Florida's Institutional Review Board (IRB) approval was obtained prior to and maintained throughout data collection. The legal guardian (parent) and participants (children) provided full written consent/assent to participating in the study.

Consent for Publication The manuscript is not under review elsewhere, has not been published previously, and adheres to APA style recommendations (Publication Manual, 7th edition).

References

American Psychiatric Association. (2013). *Diagnostic and statistical manual of mental disorders* (5th ed.). https://doi.org/10.1176/appi.books.9780890425596

Achenbach, T. M., Dumenci, L., & Rescorla, L. A. (2001). Ratings of relations between DSM-IV diagnostic categories and items of the CBCL/6-18. In V. T. Burlington (Ed.), *TRF, and YSR* (pp. 1–9). University of Vermont.

Arora, S., Lawrence, M. A., Klein, R. M (2020). The attention network test database: ADHD and cross-cultural applications. *Frontiers in Psychology, 11*. https://doi.org/10.3389/fpsyg.2020.00388

AuBuchon, A. M., McGill, C. I., & Elliott, E. M. (2018). Auditory distraction does more than disrupt rehearsal processes in children's serial recall. *Memory & Cognition, 47*(4), 738–748. https://doi.org/10.3758/s13421-018-0879-4

Awh, E., Jonides, J., Smith, E. E., Schumacher, E. H., Koeppe, R. A., & Katz, S. (1996). Dissociation of storage and rehearsal in verbal working memory: Evidence from positron emission tomography. *Psychological Science, 7*(1), 25–31.

Baddeley, A. D. (2007). *Working memory, thought, and action* (Vol. 45). Oxford University Press.

Baddeley, A. D. (2018). *Exploring working memory: Selected works of Alan Baddeley*. Routledge.

Baddeley, A., Gathercole, S., & Papagno, C. (1998). The phonological loop as a language learning device. *Psychological Review, 105*(1), 158–173.

Bálint, S., Czobor, P., Komlósi, S., Meszaros, A., Simon, V., & Bitter, I. (2009). Attention deficit hyperactivity disorder (ADHD): Gender-and age-related differences in neurocognition. *Psychological Medicine, 39*(8), 1337–1345.

Barkley, R. A. (2015). Psychological assessment of ADHD. In R. Barkley (Ed.), *Attention Deficit Hyperactivity Disorder* (4th ed., pp. 455–474). Guildford Press.

Bauer, R. H. (1977). Memory processes in children with learning disabilities: Evidence for deficient rehearsal. *Journal of Experimental Child Psychology, 24*(3), 415–430. https://doi.org/10.1016/0022-0965(77)90088-1

Baving, L., Laucht, M., & Schmidt, M. H. (1999). Atypical frontal brain activation in ADHD: Preschool and elementary school boys and girls. *Journal of the American Academy of Child & Adolescent Psychiatry, 38*(11), 1363–1371. https://doi.org/10.1097/00004583-199911000-00010

Bolden, J., Rapport, M. D., Raiker, J. S., Sarver, D. E., & Kofler, M. J. (2012). Understanding phonological memory deficits in boys with attention-deficit/hyperactivity disorder (ADHD): Dissociation of short-term storage and articulatory rehearsal processes. *Journal of Abnormal Child Psychology, 40*(6), 999–1011. https://doi.org/10.1007/s10802-012-9619-6

Brown, J. (1958). Some tests of the decay theory of immediate memory. *Quarterly Journal of Experimental Psychology, 10*(1), 12–21.

Calub, C. A., Rapport, M. D., Friedman, L. M., & Eckrich, S. J. (2019). IQ and academic achievement in children with ADHD: The differential effects of specific cognitive functions. *Journal of Psychopathology and Behavioral Assessment, 41*(4), 639–651. https://doi.org/10.1007/s10862-019-09728-z

Cherkasova, M. V., Roy, A., Molina, B. S. G., Scott, G., Weiss, G., Barkley, R. A., Biederman, J., Uchida, M., Hinshaw, S. P., Owens, E. B., & Hechtman, L. (2021). Review: Adult outcome as seen through controlled prospective follow-up studies of children with attention-deficit/hyperactivity disorder followed into adulthood. *Journal of the American Academy of Child & Adolescent Psychiatry*. https://doi.org/10.1016/j.jaac.2021.05.019

Conway, A. R., Kane, M. J., Bunting, M. F., Hambrick, D. Z., Wilhelm, O., & Engle, R. W. (2005). Working memory span tasks: A methodological review and user's guide. *Psychonomic Bulletin & Review, 12*(5), 769–786. https://doi.org/10.3758/bf03196772

Dekkers, T. J., Rapport, M. D., Calub, C. A., Eckrich, S. J., & Irurita, C. (2020). ADHD and hyperactivity: The influence of cognitive processing demands on gross motor activity level in children. *Child Neuropsychology, 27*(1), 63–82. https://doi.org/10.1080/09297049.2020.1793924

Dennis, M., Francis, D. J., Cirino, P. T., Schachar, R., Barnes, M. A., & Fletcher, J. M. (2009). Why IQ is not a covariate in cognitive studies of neurodevelopmental disorders. *Journal of the International Neuropsychological Society, 15*(3), 331–343.

DeRonda, A., Zhao, Y., Seymour, K. E., Mostofsky, S. H., & Rosch, K. S. (2021). Distinct patterns of impaired cognitive control among boys and girls with ADHD across development. *Research on Child and Adolescent Psychopathology, 49*(7), 835–848.

Dirlikov, B., Rosch, K. S., Crocetti, D., Denckla, M. B., Mahone, E. M., & Mostofsky, S. H. (2015). Distinct frontal lobe morphology in girls and boys with ADHD. *Neuroimage: Clinical, 7*, 222–229.

Döpfner, M., Mandler, J., Breuer, D., Schürmann, S., Dose, C., Walter, D., & von Wirth, E. (2020). Children with attention-deficit/hyperactivity disorder grown up: An 18-year follow-up after multimodal treatment. *Journal of Attention Disorders, 25*(13), 1801–1817. https://doi.org/10.1177/1087054720948133

Dovis, S., Van der Oord, S., Wiers, R. W., & Prins, P. J. (2015). Improving executive functioning in children with ADHD: training

multiple executive functions within the context of a computer game. A randomized double-blind placebo controlled trial. *PloS One, 10*(4):e0121651.
DuPaul, G. J., Morgan, P. L., Farkas, G., Hillemeier, M. M., & Maczuga, S. (2016). Academic and social functioning associated with attention-deficit/hyperactivity disorder: Latent class analyses of trajectories from kindergarten to fifth grade. *Journal of Abnormal Child Psychology, 44*(7), 1425–1438. https://doi.org/10.1007/s10802-016-0126-z
Ebbinghaus, H. (1885). *Über das gedächtnis: Untersuchungen zur experimentellen psychologie*. Duncker & Humblot.
Eckrich, S. J., Rapport, M. D., Calub, C. A., & Friedman, L. M. (2019). Written expression in boys with ADHD: The mediating roles of working memory and oral expression. *Child Neuropsychology, 25*(6), 772–794.
Elliott, J. G., Gathercole, S. E., Alloway, T. P., Holmes, J., & Kirkwood, H. (2010). An evaluation of a classroom-based intervention to help overcome working memory difficulties and improve long-term academic achievement. *Journal of Cognitive Education and Psychology, 9*(3), 227–250. https://doi.org/10.1891/1945-8959.9.3.227
Erskine, H. E., Norman, R. E., Ferrari, A. J., Chan, G. C., Copeland, W. E., Whiteford, H. A., & Scott, J. G. (2016). Long-term outcomes of attention-deficit/hyperactivity disorder and conduct disorder: A systematic review and meta-analysis. *Journal of the American Academy of Child & Adolescent Psychiatry, 55*(10), 841–850. https://doi.org/10.1016/j.jaac.2016.06.016
Faul, F., Erdfelder, E., Lang, A., & Buchner, A. (2007). G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods, 39*(2), 175–191. https://doi.org/10.3758/bf03193146
Ferreira, T. D., Brites, C., Azoni, A. S., & C., & Maria Ciasca, S. (2015). Evaluation of working memory in children with attention deficit/hyperactivity disorder. *Psychology, 06*(13), 1581–1588. https://doi.org/10.4236/psych.2015.613155
Fosco, W. D., Kofler, M. J., Groves, N. B., Chan, E. S., & Raiker, J. S. (2020). Which 'working' components of working memory aren't working in youth with ADHD? *Journal of Abnormal Child Psychology, 48*(5), 647–660. https://doi.org/10.1007/s10802-020-00621-y
Friedman, L. M., Rapport, M. D., Orban, S. A., Eckrich, S. J., & Calub, C. A. (2017). Applied problem solving in children with ADHD: The Mediating roles of working memory and mathematical calculation. *Journal of Abnormal Child Psychology, 46*(3), 491–504. https://doi.org/10.1007/s10802-017-0312-7
Friedman, L. M., Rapport, M. D., Raiker, J. S., Orban, S. A., & Eckrich, S. J. (2016). Reading comprehension in boys with ADHD: The Mediating roles of working memory and orthographic conversion. *Journal of Abnormal Child Psychology, 45*(2), 273–287. https://doi.org/10.1007/s10802-016-0171-7
Gadow, K. D., Sprafkin, J., Salisbury, H., Schneider, J., & Loney, J. (2004). Further validity evidence for the teacher version of the child symptom lnventory-4. *School Psychology Quarterly, 19*(1), 50–71. https://doi.org/10.1521/scpq.19.1.50.29408
Gathercole, S. E., & Baddeley, A. D. (2014). *Working memory and language*. Psychology Press.
Gaub, M., & Carlson, C. L. (1997). Gender differences in ADHD: A meta-analysis and critical review. *Journal of the American Academy of Child & Adolescent Psychiatry, 36*(8), 1036–1045.
Gershon, J., & Gershon, J. (2002). A meta-analytic review of gender differences in ADHD. *Journal of Attention Disorders, 5*(3), 143–154. https://doi.org/10.1177/108705470200500302
Goh, P. K., Martel, M. M., & Barkley, R. A. (2020). Clarifying ADHD and sluggish cognitive tempo item relations with impairment: A network analysis. *Journal of Abnormal Child Psychology, 48*, 1047–1061.
Gomez, R., & Sanson, A. V. (1994). Effects of experimenter and mother presence on the attentional performance and activity of hyperactive boys. *Journal of Abnormal Child Psychology, 22*(5), 517–529. https://doi.org/10.1007/bf02168935
Greenberg, J., Romero, V. L., Elkin-Frankston, S., Bezdek, M. A., Schumacher, E. H., & Lazar, S. W. (2019). Reduced interference in working memory following mindfulness training is associated with increases in hippocampal volume. *Brain Imaging and Behavior, 13*(2), 366–376. https://doi.org/10.1007/s11682-018-9858-4
Hollingshead, A. B. (1975). Four factor index of social status. Hollingshead, A. (1975). *Four factor index of social status*. New Haven, CT: Yale University, Department of Sociology.
Horst, J. S. (2013). Context and repetition in word learning. *Frontiers in Psychology, 4*, 149.
Huggins, A. W. F. (1975). Temporally segmented speech. *Perception & Psychophysics, 18*(2), 149–157.
Irwin, L.N., Soto, E.F., Chan, E.S., Miller, C.E., Carrington-Forde, S., Groves, N.B., & Kofler, M.J. (2021) Activities of daily living and working memory in pediatric attention-deficit/hyperactivity disorder (ADHD), Child Neuropsychology, 27:4, 468-490, https://doi.org/10.1080/09297049.2020.1866521
Jangmo, A., Stålhandske, A., Chang, Z., Chen, Q., Almqvist, C., Feldman, I., Bulik, C. M., Lichtenstein, P., D'Onofrio, B., Kuja-Halkola, R., & Larsson, H. (2019). Attention-deficit/hyperactivity disorder, school performance, and effect of medication. *Journal of the American Academy of Child & Adolescent Psychiatry, 58*(4), 423–432. https://doi.org/10.1016/j.jaac.2018.11.014
Jonides, J., Schumacher, E. H., Smith, E. E., Koeppe, R. A., Awh, E., Reuter-Lorenz, P. A., & Willis, C. R. (1998). The role of parietal cortex in verbal working memory. *Journal of Neuroscience, 18*(13), 5026–5034.
Kail, R. V., & Ferrer, E. (2007). Processing speed in childhood and adolescence: Longitudinal models for examining developmental change. *Child Development, 78*(6), 1760–1770.
Kasper, L. J., Alderson, R. M., & Hudec, K. L. (2012). Moderators of working memory deficits in children with attention-deficit/hyperactivity disorder (ADHD): A meta-analytic review. *Clinical Psychology Review, 32*(7), 605–617. https://doi.org/10.1016/j.cpr.2012.07.001
Kaufman, J., Birmaher, B., Brent, D., Rao, U. M. A., Flynn, C., Moreci, P., & Ryan, N. (1997). Schedule for Affective disorders and Schizophrenia for School-Age Children-Present and Lifetime Version (K-SADS-PL): Initial reliability and validity data. *Journal of the American Academy of Child & Adolescent Psychiatry, 36*(7), 980–988. https://doi.org/10.1097/00004583-199707000-00021
Klein, R. G., Mannuzza, S., Olazagasti, M. A., Roizen, E., Hutchison, J. A., Lashua, E. C., & ; Castellanos, F. X. (2012). Clinical and functional outcome of childhood attention-deficit/hyperactivity disorder 33 years later. *Archives of General Psychiatry, 69*(12), 1295. https://doi.org/10.1001/archgenpsychiatry.2012.271
Klein, C., Wendling, K., Huettner, P., Ruder, H., & Peper, M. (2006). Intra-subject variability in attention-deficit hyperactivity disorder. *Biological Psychiatry, 60*(10), 1088–1097. https://doi.org/10.1016/j.biopsych.2006.04.003
Kofler, M. J., Irwin, L. N., Soto, E. F., Groves, N. B., Harmon, S. L., & Sarver, D. E. (2018). Executive functioning heterogeneity in pediatric ADHD. *Journal of Abnormal Child Psychology, 47*(2), 273–286. https://doi.org/10.1007/s10802-018-0438-2
Kofler, M. J., Raiker, J. S., Sarver, D. E., Wells, E. L., & Soto, E. F. (2016). Is hyperactivity ubiquitous in ADHD or dependent on environmental demands? Evidence from meta-analysis. *Clinical Psychology Review, 46*, 12–24. https://doi.org/10.1016/j.cpr.2016.04.004
Kofler, M. J., Rapport, M. D., Bolden, J., Sarver, D. E., & Raiker, J. S. (2010). ADHD and working memory: The impact of central executive deficits and exceeding storage/rehearsal capacity on observed Inattentive behavior. *Journal of Abnormal Child Psychology, 38*(2), 149–161. https://doi.org/10.1007/s10802-009-9357-6

Kofler, M. J., Rapport, M. D., Bolden, J., Sarver, D. E., Raiker, J. S., & Alderson, R. M. (2011). Working memory deficits and social problems in children with ADHD. *Journal of Abnormal Child Psychology, 39*(6), 805–817. https://doi.org/10.1007/s10802-011-9492-8

Lewandowsky, S., & Oberauer, K. (2015). Rehearsal in serial recall: An unworkable solution to the nonexistent problem of decay. Psychological Review, 122(4), 674-699. https://doi.org/10.1037/a0039684

Lewandowsky, S., Duncan, M., & Brown, G. D. (2004). Time does not cause forgetting in short-term serial recall. *Psychonomic Bulletin & Review, 11*(5), 771–790. https://doi.org/10.3758/bf03196705

Loe, I. M., & Feldman, H. M. (2007). Academic and educational outcomes of children with ADHD. *Journal of Pediatric Psychology, 32*(6), 643–654. https://doi.org/10.1093/jpepsy/jsl054

Mahone, E. M., & Wodka, E. L. (2008). The neurobiological profile of girls with ADHD. *Developmental Disabilities Research Reviews, 14*(4), 276–284. https://doi.org/10.1002/ddrr.41

Martinussen, R., Hayden, J., Hogg-Johnson, S., & Tannock, R. (2005). A meta-analysis of working memory impairments in children with attention-deficit/hyperactivity disorder. *Journal of the American Academy of Child & Adolescent Psychiatry, 44*(4), 377–384. https://doi.org/10.1097/01.chi.0000153228.72591.73

McNamara, D. S., & Scott, J. L. (2001). Working memory capacity and strategy use. *Memory & Cognition, 29*(1), 10–17. https://doi.org/10.3758/bf03195736

Miller, G. A., & Chapman, J. P. (2001). Misunderstanding analysis of covariance. *Journal of Abnormal Psychology, 110*(1), 40.

Nishiyama, T., Sumi, S., Watanabe, H., Suzuki, F., Kuru, Y., Shiino, T., & Hirai, K. (2020). The Kiddie schedule for affective disorders and schizophrenia present and lifetime version (K-SADS-PL) for DSM-5: A validation for neurodevelopmental disorders in Japanese outpatients. *Comprehensive Psychiatry, 96*, 152148.

Norris, D., Butterfield, S., Hall, J., & Page, M. P. (2018). Phonological recoding under articulatory suppression. *Memory & Cognition, 46*(2), 173–180. https://doi.org/10.3758/s13421-017-0754-8

Oberauer, K. (2019). Is rehearsal an effective maintenance strategy for working memory? *Trends in Cognitive Sciences, 23*(9), 798–809. https://doi.org/10.1016/j.tics.2019.06.002

Oberauer, K., Lewandowsky, S., Farrell, S., Jarrold, C., & Greaves, M. (2012). Modeling working memory: An interference model of complex span. *Psychonomic Bulletin & Review, 19*(5), 779–819.

Paulesu, E., Frith, C. D., & Frackowiak, R. S. (1993). The neural correlates of the verbal component of working memory. *Nature, 362*(6418), 342–345.

Peterson, L., & Peterson, M. J. (1959). Short-term retention of individual verbal items. *Journal of Experimental Psychology, 58*(3), 193.

Polanczyk, G. V., Willcutt, E. G., Salum, G. A., Kieling, C., & Rohde, L. A. (2014). ADHD prevalence estimates across three decades: An Updated systematic review and meta-regression analysis. *International Journal of Epidemiology, 43*(2), 434–442. https://doi.org/10.1093/ije/dyt261

Power, T. J. (1992). Contextual factors in vigilance testing of children with ADHD. *Journal of Abnormal Child Psychology, 20*(6), 579–593. https://doi.org/10.1007/bf00911242

Rapport, M. D., Alderson, R. M., Kofler, M. J., Sarver, D. E., Bolden, J., & Sims, V. (2008a). Working memory deficits in boys with attention-deficit/hyperactivity disorder (ADHD): The contribution of central executive and subsystem processes. *Journal of Abnormal Child Psychology, 36*(6), 825–837. https://doi.org/10.1007/s10802-008-9215-y

Rapport, M. D., Bolden, J., Kofler, M. J., Sarver, D. E., Raiker, J. S., & Alderson, R. M. (2008b). Hyperactivity in boys with attention-deficit/hyperactivity disorder (ADHD): A ubiquitous core symptom or manifestation of working memory deficits? *Journal of Abnormal Child Psychology, 37*(4), 521–534. https://doi.org/10.1007/s10802-008-9287-8

Ricker, T. J., & Cowan, N. (2010). Loss of visual working memory within seconds: The combined use of refreshable and non-refreshable features. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 36*(6), 1355–1368. https://doi.org/10.1037/a0020356

Ricker, T. J., Vergauwe, E., & Cowan, N. (2016). Decay theory of immediate memory: From Brown (1958) to today (2014). *Quarterly Journal of Experimental Psychology, 69*(10), 1969–1995. https://doi.org/10.1080/17470218.2014.914546

Rostami, M., Khosrowabadi, R., Albrecht, B., Pouretemad, H., & Rothenberger, A. (2020). ADHD subtypes: Do they hold beyond core symptoms? A multilevel testing of an additive model. *Applied Neuropsychology: Child,* 1–11. https://doi.org/10.1080/21622965.2020.1806067

Shaw, P., Eckstrand, K., Sharp, W., Blumenthal, J., Lerch, J. P., Greenstein, D., & Rapoport, J. L. (2007). Attention-deficit/hyperactivity disorder is characterized by a delay in cortical maturation. *Proceedings of the National Academy of Sciences, 104*(49), 19649–19654. https://doi.org/10.1073/pnas.0707741104

Shaw, P., Ishii-Takahashi, A., Park, M. T., Devenyi, G. A., Zibman, C., Kasparek, S., Sudre, G., Mangalmurti, A., Hoogman, M., Tiemeier, H., von Polier, G., Shook, D., Muetzel, R., Chakravarty, M. M., Konrad, K., Durston, S., & White, T. (2018). A multicohort, longitudinal study of cerebellar development in attention deficit hyperactivity disorder. *Journal of Child Psychology and Psychiatry, 59*(10), 1114–1123. https://doi.org/10.1111/jcpp.12920

Smith, E. E., & Jonides, J. (1999). Storage and executive processes in the frontal lobes. *Science, 283*(5408), 1657–1661.

Swanson, H. L., & Fung, W. (2016). Working memory components and problem-solving accuracy: Are there multiple pathways? *Journal of Educational Psychology, 108*(8), 1153.

Tamm, L., Loren, R. E., Peugh, J., & Ciesielski, H. A. (2021). The association of executive functioning with academic, behavior, and social performance ratings in children with ADHD. *Journal of Learning Disabilities, 54*(2), 124–138.

Tianxiao Yang, T., Gathercole, S.E., & Allen, R.J. (2014). Benefit of enactment over oral repetition of verbal instruction does not require additional working memory during encodingPsychonomic Bulletin Review, 21, 186–192.

Tillman, C., Eninger, L., Forssman, L., & Bohlin, G. (2011). The relation between working memory components and ADHD symptoms from a developmental perspective. *Developmental Neuropsychology, 36*(2), 181–198. https://doi.org/10.1080/87565641.2010.549981

Turley-Ames, K. (2003). Strategy training and working memory task performance. *Journal of Memory and Language, 49*(4), 446–468. https://doi.org/10.1016/s0749-596x(03)00095-0

Vlach, H., & Sandhofer, C. M. (2012). Fast mapping across time: Memory processes support children's retention of learned words. *Frontiers in Psychology, 3*, 46.

Vergauwe, E., Camos, V., & Barrouillet, P. (2014). The impact of storage on processing: How is information maintained in working memory? *Journal of Experimental Psychology: Learning, Memory, and Cognition, 40*(4), 1072.

Wechsler, D. (2003). Wechsler Intelligence Scale for Children, Fourth edition. *PsycTESTS Dataset*. https://doi.org/10.1037/t15174-000

Wells, E. L., Kofler, M. J., Soto, E. F., Schaefer, H. S., & Sarver, D. E. (2018). Assessing working memory in children with ADHD: Minor administration and scoring changes may improve digit span backward's construct validity. *Research in Developmental Disabilities, 72*, 166–178.

Willcutt, E. G., Doyle, A. E., Nigg, J. T., Faraone, S. V., & Pennington, B. F. (2005). Validity of the executive function theory of attention-deficit/hyperactivity disorder: A meta-analytic review. *Biological Psychiatry, 57*(11), 1336–1346. https://doi.org/10.1016/j.biopsych.2005.02.006

Yang, T., Gathercole, S. E., & Allen, R. J. (2014). Benefit of enactment over oral repetition of verbal instruction does not require additional working memory during encoding. *Psychonomic Bulletin & Review, 21*(1), 186–192. https://doi.org/10.3758/s13423-013-0471-7

SuperLab Pro (Version 2) [Computer program]. (2002). San Pedro, California. (http://www.cedrus.com): Cedrus Corporation.

IBM Corp. (2019). IBM SPSS Statistics for Mac, Version 26.0. Armonk, NY: IBM Corp.

Kofler, M. J., Rapport, M. D., Bolden, J., Sarver, D. E., Raiker, J. S., & Alderson, R. M. (2011). Working memory deficits and social problems in children with ADHD. *Journal of Abnormal Child Psychology, 39*(6), 805–817. https://doi.org/10.1007/s10802-011-9492-8