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Working Memory and Organizational Skills Problems in ADHD

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Abstract

Background—The current study tested model-driven predictions regarding working memory's role in the organizational problems associated with ADHD.

Method—Children ages 8–13 (*M*=10.33, *SD*=1.42) with and without ADHD (*N*=103; 39 girls; 73% Caucasian/Non-Hispanic) were assessed on multiple, counterbalanced working memory tasks. Parents and teachers completed norm-referenced measures of organizational problems (*Children's Organizational Skills Scale;* COSS).

Results—Results confirmed large magnitude working memory deficits (*d*=1.24) and organizational problems in ADHD (*d*=0.85). Bias-corrected, bootstrapped conditional effects models linked impaired working memory with greater parent- and teacher-reported inattention, hyperactivity/impulsivity, and organizational problems. Working memory predicted organization problems across all parent and teacher COSS subscales (R^2=.19–.23). Approximately 38%-57% of working memory's effect on organization problems was conveyed by working memory's association with inattentive behavior. Unique effects of working memory remained significant for both parent- and teacher-reported task planning, as well as for teacher-reported memory/materials management and overall organization problems. Attention problems uniquely predicted worse organizational skills. Hyperactivity was unrelated to parent-reported organizational skills, but predicted *better* teacher-reported task planning.

Conclusions—Children with ADHD exhibit multi-setting, broad-based organizational impairment. These impaired organizational skills are attributable in part to performance deficits secondary to working memory dysfunction, both directly and indirectly via working memory's role in regulating attention. Impaired working memory in ADHD renders it extraordinarily difficult for these children to consistently anticipate, plan, enact, and maintain goal-directed actions.

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Supporting Information
Additional Supporting Information may be found in the online version of this article:

Keywords

ADHD; working memory; organization; executive functions; functional impairments

Organizational problems are a critical yet understudied area of impairment for children with ADHD (Abikoff et al., 2013). Organization is a multifaceted construct, and children with ADHD frequently show organizational impairments related to planning tasks, tracking assignments, recalling due dates, and managing supplies (Abikoff & Gallagher, 2009; Langberg, Epstein et al., 2011). As a result, these children frequently misplace materials, come to class unprepared (Pelham et al., 2005), and have messy and disorganized lockers, backpacks, and desks (Atkins et al., 1989; Zentall et al., 1993). The centrality of organization problems to ADHD is reflected in DSM-5 diagnostic criteria, which includes several symptoms related to disorganization (e.g., difficulty organizing tasks, failing to finish things; APA, 2013). Interestingly, children with ADHD do not report organizational difficulties (Langberg et al., 2013), but parents, teachers, and objective observers are highly consistent in documenting large-magnitude impairments in this important area of functioning (Langberg et al., 2012).

Identifying the mechanisms and processes that underlie organization problems is imperative given their chronic, worsening course and adverse outcomes. Organizational problems begin in elementary school for many children with ADHD, and increase in severity as they progress in school (Booster et al., 2012; Langberg, Molina et al., 2011), experience higher workloads (Evans et al., 2005), and experience increased expectations for personal responsibility from teachers and parents (Meyer et al., 2004). These organization problems continue into adulthood (Bikic et al., 2017), and portend academic underachievement (Kent et al., 2011) and lower school grades both concurrently (Langberg, Epstein et al., 2011) and longitudinally into high school (Langberg, Molina et al., 2011) – even for intellectually gifted children with ADHD (Leroux & Levitt-Perlman, 2000). Psychostimulant medication appears to improve but not normalize these impairments (Abikoff et al., 2009). Thus, it is not surprising that organizational skills have become a frequent target of behavioral interventions (Abikoff et al., 2013; Langberg et al., 2012).

Despite clear evidence of organizational deficits and promising efficacy of organizational interventions in ADHD, little is known about the underlying mechanisms responsible for these deficits. Recent conceptualizations highlight the role of executive dysfunction in ADHD-related organizational problems (Bikic et al., 2017); however, to our knowledge no study has examined this link directly. In particular, ‘glitches’ in executive functions such as working memory have been proposed as causal mechanisms that are expressed phenotypically as problems with task planning, managing deadlines, and misplacing materials (Abikoff et al., 2013). In this view, executive dysfunction contributes to organizational problems by interfering with opportunities to learn and practice age-expected task planning and materials/project management (Abikoff et al., 2013). In addition, explicit instruction would be less effective in the context of underdeveloped working memory that constrains the encoding, processing, and integration of skill-based instruction with existing knowledge (Baddeley, 2007). Alternatively, core ADHD behavioral symptoms may limit exposure to appropriate scaffolding of organizational skills, either independently or in their role as a phenotypic sequelae of executive dysfunction (Rapport et al., 2008).

Of the primary executive functions (Snyder et al., 2015), working memory is an appealing candidate for explaining organizational problems in ADHD. It serves a critical role in guiding everyday behavior, shows strong convergence with laboratory-based planning tests, and regulates the forethought and planning necessary to coordinate *in vivo* data and metadata (e.g., integrating the current step into the bigger picture/end goal; Baddeley, 2007). Working memory refers to the active, top-down manipulation of information held in short-term memory, and includes interrelated functions of the mid-lateral prefrontal cortex that guide behavior via the updating, processing, and temporal/sequential manipulation of internally-held information (Nee et al., 2013; Wager & Smith, 2003). Relevant to pediatric ADHD, working memory serves as an interface between the environment and long-term memory (Baddeley, 2007) and underlies myriad learning skills, including note-taking (McIntyre, 1992), listening comprehension (McInnes et al., 2003), and following directions (Jaroslawska et al., 2016). Working memory abilities also support behavioral outcomes affected by ADHD, including impulse control (Raiker et al., 2012), cooperating with others (Milinski & Wedekind, 1998), dynamic social decoding (Phillips et al., 2007), and delay tolerance (Patros et al., 2015).

Working memory deficits are present in a substantial portion of children with ADHD (Kasper et al., 2012), and importantly cannot be attributable to low motivation (Dovis et al., 2012, 2013), visual inattention during testing (Kofler et al., 2010), disinhibition (Alderson et al., 2010), or inconsistent responding (Kofler et al., 2014). Experimental studies suggest a potential causal role of working memory dysfunction for evoking ADHD-related inattentive and hyperactive behavior (Kofler et al., 2010; Rapport et al., 2009). Converging evidence also links ADHD-related working memory impairments with ecologically valid, functional outcomes including peer (Bunford et al., 2014; Tseng & Gau, 2013) and parent-child relational problems (Kofler et al., 2016). In addition, working memory strongly predicts math (Swanson & Kim, 2007) and ADHD-related reading deficits (Friedman et al., 2016).

To our knowledge, no study has investigated neurocognitive mechanisms associated with organizational problems in ADHD. Following conceptual models suggesting neurocognitive dysfunction as a plausible causal mechanism of the ADHD phenotype (for review, see Kofler et al., 2016), we predicted direct effects of working memory on ecologically-valid measures of organizational behavior (Figure 1, path c). We further predicted indirect effects (Figure 1, path a*b) based on evidence that working memory deficits evoke ADHD-related inattentive (Kofler et al., 2010) and hyperactive behaviors (Rapport et al., 2009), which in turn predicts ADHD-related organizational problems (Langberg et al., 2012; McBurnett et al., 2014). In contrast, our predictions would be falsified by finding that ADHD symptoms, but not working memory abilities, show strong convergence with organizational problems (Tseng et al., 2014).

Method

Participants

The sample comprised 103 children aged 8–13 years (*M*=10.33, *SD*=1.42; 39 girls) from the Southeastern U.S., consecutively recruited by or referred to a university-based Children's Learning Clinic (CLC) through community resources (e.g., pediatricians, community mental health clinics, school system personnel, self-referral) between 2013 and 2017. The 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. Psychoeducational evaluations were provided to caregivers. All parents/children gave informed consent/assent; IRB approval was obtained. Child race/ethnicity was 73% Caucasian/Non-Hispanic, 13% Hispanic/English-speaking, 5% African American, 4% Asian, and 5% multiracial.

Group Assignment

All children and caregivers completed an identical evaluation, regardless of group assignment, that included detailed, semi-structured clinical interviewing (K-SADS; Kaufman et al., 1997). The K-SADS (2013 Update) assesses developmental history as well as onset, course, and impairment of DSM-5 (APA, 2013) disorders in children and adolescents. Parent and teacher ADHD ratings were obtained from the Behavior Assessment System for Children (BASC-2; Reynolds & Kamphaus, 2004) and Child Symptom Inventory (CSI-IV; Gadow & Sprafkin, 2002).

The ADHD group (*N*=68, 37% girls) required: (1) DSM-5 diagnosis of ADHD Combined (*n*=37, 34% girls), Inattentive (*n*=27, 44% girls), or Hyperactive/Impulsive Presentation (*n*=4, 25% girls) by the directing clinical psychologist based on K-SADS; (2) Borderline/clinical elevations on at least one parent and one teacher ADHD rating scale. The "AND" criteria required children to meet symptom thresholds based on both parent and teacher report (Willcutt et al., 2012), and was used for both ADHD diagnosis and the current presentation specifier. All children had current impairment (K-SADS). Psychostimulants ($N_{prescribed}$=28) were withheld ≥24-hours for testing. Comorbidities reflect clinical consensus best estimates, and include anxiety (18%), depressive (12%), oppositional defiant (10%), and autism spectrum disorders (3%).[1]

The Non-ADHD group comprised 35 consecutive case-control referrals who did not meet ADHD criteria, and included both neurotypical children and children with psychiatric disorders other than ADHD. Neurotypical children (62%) had normal developmental histories and nonclinical parent/teacher ratings. Non-ADHD disorders in this group include anxiety (20%), oppositional-defiant (3%), autism spectrum (6%), depressive (6%), and

[1]The pattern and interpretation of results was unchanged when excluding children with autism spectrum disorder. As recommended in the K-SADS, oppositional defiant disorder was diagnosed clinically only with evidence of multi-informant/multi-setting symptoms. ODD comorbidity was 39% in the ADHD group and 11% in the Non-ADHD group based on parent-reported symptom counts.

obsessive-compulsive disorders (3%).[1] Non-ADHD disorders were included to control for comorbidities in the ADHD group. Importantly, the ADHD and Non-ADHD groups did not differ proportionally in clinical disorders other than ADHD overall ($\chi^2[1]=0.29$, $p=.59$, *ns*), or across diagnostic categories ($\chi^2[5]=5.11$, $p=.40$, *ns*).

Learning disabilities were suspected in 28% of ADHD and 6% of Non-ADHD cases based on score(s) >1 *SD* below age-norms on one or more Kaufman (KTEA-3; 2014) subtests. Children were excluded for gross neurological, sensory, or motor impairment; seizure disorder, psychosis, or intellectual disability; or non-stimulant medications that could not be withheld for testing.

Procedures

Testing occurred during a larger battery of two, 3-hour sessions. Tasks were counterbalanced within/across sessions to minimize order/fatigue effects. Children received brief breaks after each task, and preset longer breaks every 2–3 tasks to minimize fatigue.

Working Memory

The Rapport et al. (2009) computerized working memory tests differentiate ADHD and non-ADHD groups (Kasper et al., 2012), and predict hyperactivity (Rapport et al., 2009), inattention (Kofler et al., 2010), and impulsivity (Raiker et al., 2012). Reliability and validity evidence includes internal consistency ($\alpha=.82–.97$), 1–3-week test-retest reliability (.76–.90; Sarver et al., 2015), and expected relations with criterion working memory complex span ($r=.69$) and updating tasks ($r=.61$)(MASKED FOR REVIEW). Six trials per set size were administered in randomized/unpredictable order (3–6 stimuli/trial; 1 stimuli/second) as recommended (Kofler et al., 2016). Five practice trials were administered before each task (80% correct required). Task duration was approximately 5 (visuospatial) to 7 (phonological) minutes. The phonological and visuospatial tasks were completed on separate, counterbalanced testing days.

Phonological working memory—Children were presented a series of jumbled numbers and a letter (1 stimuli/second). The letter was never presented first or last to minimize primacy/recency effects, and was counterbalanced to appear equally in the other serial positions. Children reordered and recalled the numbers from least to greatest, and said the letter last (e.g., 4H62 is correctly recalled as 246H). Two trained research assistants, shielded from child view, independently recorded oral responses (interrater reliability kappa=1.0).

Visuospatial working memory—Children were shown nine squares arranged in three offset vertical columns. A series of 2.5 cm dots 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 never appeared first or last to minimize primacy/recency effects. Children reordered the dot locations (black dots in serial order, red dot last) and responded on a modified keyboard.

Dependent variable—We controlled for task impurity (Conway et al., 2005) by selecting tasks that differed on short-term memory modality (phonological vs. visuospatial), administering them on different days, and computing a weighted average based on the intercorrelations among scores at each set size (i.e., factor score). This weighted average provides a more accurate estimate of construct stability than confirmatory approaches (Willoughby et al., 2015). Conceptually, this process improves construct specificity by removing variance from non-executive task demands, time-on-task effects (via inclusion of 4 blocks/task), short-term memory modality, and other non-shared task parameters (e.g., orthographic-to-phonological conversion; Alderson et al., 2016). Thus, the 8 working memory performance variables (4 blocks each for PHWM, VSWM) were reduced to a single working memory indicator (62.40% of variance explained; loadings=.76–.82). The participant (103) to factor (1) ratio was acceptable (Hogarty et al., 2005). Higher scores reflect better working memory.

Global Intellectual Functioning (IQ)

IQ was estimated using the WISC-V (*n*=65), WASI-II (*n*=36), or WISC-IV (*n*=2)(Wechsler, 2003, 2011, 2014).

Socioeconomic Status (SES)

Hollingshead (1975) SES was estimated based on caregiver(s)' education and occupation.

Organizational Problems

The Children's Organization Skills Scale (COSS; Abikoff & Gallagher, 2009) contains 66 (parent) and 42 (teacher) items that assess organizational problems in children ages 8–13 (2–3-week test-retest=.88–.99; α=.89–.98). It provides a total score and 3 subscales reflecting *Task Planning* (skill at meeting deadlines, organizing tasks into steps), *Organized Actions* (use of organizational aids and routines like planners, lists), and *Memory/Materials Management* (skill at tracking assignments, recalling due dates, and managing related supplies). Informants were asked to consider behavior off medication. Higher T-scores reflect more organizational difficulty.

Data Analysis Overview

Between-group differences in organizational problems were examined initially (Tier 1). Tier 2 used bias-corrected, bootstrapped conditional effects modeling to examine working memory's associations with ADHD symptoms and COSS Total Organizational Problems. Exploratory analyses were conducted in Tier 3 by repeating the Tier 2 analyses, separately for each COSS subscale, to probe whether Tier 2's significant findings were attributable to specific organizational skills.

Bias-corrected, bootstrapped conditional effects modeling was preferred because it allows shared variance among predictors to be parsed according to theory and previous research. Using PROCESS (Hayes, 2013) and 10,000 bootstrapped samples, the model included working memory (predictor), ADHD inattentive and hyperactive/impulsive symptoms (mediators), and organizational problems (outcome). We modeled working memory to predict ADHD symptoms, rather than vice versa, based on prior theoretical work and experimental evidence that increasing working memory demands evokes inattentive and hyperactive behavior (Kofler et al., 2010; Rapport et al., 2009), whereas working memory deficits remain large when covarying attentive behavior during testing (Kofler et al., 2010). Notably, the cross-sectional design precluded testing competing models regarding directional effects of working memory and ADHD symptoms (i.e., reversing arrows does not distinguish plausible models; Thoemmes, 2015).

Inattention and hyperactivity/impulsivity were included separately based on evidence that they differentially predict relations between working memory and other ADHD-related impairments (Bunford et al., 2014). To remove mono-informant bias, parent-reported ADHD symptoms were modeled to predict teacher-reported organizational problems, and vice versa. Importantly, the BASC-2 Attention Problems and Hyperactivity subscales were considered appropriate predictors because they do not contain any items that explicitly assess organizational skills (Reynolds & Kamphaus, 2004).

Results

Power Analysis

Large-medium effects were predicted based on large working memory/ADHD symptom ($d \geq 2.0$; Kasper et al., 2012) and medium organizational problems/ADHD symptom relations (r=.21–.30; McBurnett et al., 2014). Our N=103 exceeds the N=54 required for bias-corrected bootstrapping to detect expected effects of this magnitude for α=.05, power=.80 (Fritz & MacKinnon, 2007).

Preliminary Analyses

No univariate/multivariate outliers were identified. Parent COSS data were missing for N=7 due to experimenter error (N=96 for parent-COSS models).

Tier 1 Between-Group Differences

The ADHD group showed large working memory deficits (d=−1.24) and Total Organizational Problems (d=0.85; Table 1). Between-group differences were significant for all COSS parent/teacher subscales (d=0.58–0.87).

In contrast, the ADHD/Non-ADHD groups did not differ in age (d=−0.14), FSIQ (d=−0.25), or SES (d= −0.02)(p_{all}>.24); therefore, no covariates were included in Tiers 2–3.

Tier 2 Conditional Effects Models: Parent- and Teacher-Reported Organizational Problems

Results are shown in Table 2 based on Figure 1's conceptual model; intercorrelations are shown in Supplementary Table S1. Results were highly consistent across parent and teacher models, and are therefore reported together for parsimony. Working memory and other-informant ADHD symptoms explained 19%–23% of children's organizational problems (R^2=.19–.23, p<.05).

Direct effects—Less-developed working memory predicted greater attention problems (a_1 pathway), hyperactivity/impulsivity (a_2 pathway), and organizational problems (c pathway) for both parent and teacher models ($p \leq .01$; Table 2). After accounting for working memory, attention problems (b_1 pathway) predicted parent- and teacher-reported organizational problems (p<.01). Hyperactivity/impulsivity (b_2 pathway) failed to predict organizational problems (p≥.22).

Indirect effects—Working memory indirectly affected organizational problems via inattention (ab_1 pathway) in both models (95% CIs exclude 0.0, indicating p<.05). Effect ratios indicated that 38%–57% of working memory's association with organizational problems is conveyed via working memory's influence on ADHD-related attention problems. In other words, impaired working memory portends greater attention problems, which in turn predict greater organization problems. After accounting for these effects, working memory continued to predict teacher-reported (p<.01) but not parent-reported (p=.26) organizational problems. In other words, working memory's impact on teacher-reported organizational problems is both direct and indirect, whereas its impact on parent-reported organizational problems is primarily indirect through its influence on inattentive symptoms.

Tier 3 Exploratory Conditional Effects Models: COSS Subscales

Results were highly consistent with Tier 2 (Supplementary Tables S2–S3), but must be considered exploratory in light of strong intercorrelations among some COSS subscales that question the findings' statistical independence (Table S1). Working memory showed strong convergence with parent- and teacher-reported task planning, organized actions, memory/materials management, inattention, and hyperactivity/impulsivity (p<.05). In addition, working memory indirectly predicted task planning and organized actions (both informants), and memory/materials management (parent model only), via its influence on attention. Accounting for its indirect effects via ADHD symptoms, working memory continued to directly predict parent- and teacher-reported task planning and teacher-reported memory/materials management (p_{all}<.05).

Indirect effects of working memory via hyperactivity/impulsivity were significant only for teacher-reported task planning, in the opposite direction of the working memory→attention problems→task planning relation. Hyperactivity/impulsivity independently predicted task planning in this model, again in the opposite direction of inattention's association. In other words, teachers rated children as better task planners when they displayed fewer attention problems, but *greater* hyperactivity/impulsivity. The indirect effect indicated that *better* working memory portended *better* task planning given *greater* hyperactivity symptoms but *fewer* attention problems.

Discussion

The current study was the first to examine working memory's association with multi-informant organizational problems in a large sample of children with and without ADHD. As expected, ADHD predicted large-magnitude organizational problems (d=0.85). This finding is consistent with conceptual models that highlight organizational skills deficits (Abikoff et al., 2013), and provides additional data confirming broad-based organizational problems in ADHD (Langberg et al., 2012). Further, children with ADHD exhibited very large working memory deficits (d=1.24), which was expected based on meta-analysis (Kasper et al., 2012) and extends this literature by demonstrating that ADHD-related working memory deficits persist when controlling for comorbidity.

Of primary interest was whether working memory deficits underlie organizational problems, a key area of impairment in ADHD. Identifying the neurocognitive mechanisms that underlie ADHD-related functional impairments has the potential to improve long-term outcomes in ADHD via neuropsychologically-informed intervention and accommodation development (Chacko et al., 2013). This line of research has shown promise in recent years as refined tests of executive functioning (Snyder et al., 2015) and working memory (Rapport et al., 2013) have shown robust associations with ADHD behavioral symptoms and functional impairments. For example, working memory deficits show strong continuity with ADHD inattentive, hyperactive, and impulsive symptoms measured objectively (Kofler et al., 2010; Raiker et al., 2012; Rapport et al., 2009) and by parent/teacher report (Kofler et al., 2011). The current study's working memory tests also show strong convergence with ecologically-valid, ADHD-related impairments in peer functioning (Kofler et al., 2011), reading comprehension (Friedman et al., 2017), parent-child relationship quality, academic success/productivity (Kofler et al., 2016), and organizational skills (current study). That these brief, laboratory-based tasks with minimal face valid social, academic, or organizational demands show this robust continuity is fascinating, and speaks to the strong association between children's working memory and how successfully they navigate their social and academic worlds.

The current study adds to this growing body of evidence, and indicates that children's working memory covaries with adult perceptions of children's skill at meeting deadlines and planning tasks, using planners, and tracking assignment due dates. These findings support conceptualizations of ADHD organization problems as performance- rather than knowledge-based, which is consistent with clinical trials showing that skills training and performance-based reinforcement produced highly similar organizational outcomes (Abikoff et al., 2013). This interpretation also parallels recent conceptualizations of *social* problems in ADHD as reflecting performance rather knowledge deficits (de Boo & Prins, 2007). In other words, organizational and social problems in ADHD may not reflect a lack of knowledge, but rather difficulty implementing their knowledge in the moment. Importantly, however, we did not assess organizational knowledge, and the role of explicit memory-related processes cannot be ruled out because our tests required children to retain information for a briefer duration than typically required for long-term goals and actions.

After accounting for working memory's association with ADHD symptoms, working memory continued to predict parent- and teacher-reported task planning, as well as teacher-reported memory/materials management and overall organizational problems. The subtle differences between the parent and teacher models may reflect differences in informant perception, and/or our use of cross-informant paths that controlled for mono-informant bias but may underestimate unique contextual factors present in children's behavior (De Los Reyes & Kazdin, 2005). Alternatively, these findings may suggest different expectations for organizational behavior at home vs. school, but should be interpreted in light of evidence that teachers may be better reporters of functional impairments than parents (Langberg et al., 2013).

Overall, the current findings are consistent with model-driven predictions (Rapport et al., 2008), and suggest that organizational problems reflect, to a large extent, an outcome of impaired working memory processes that in turn negatively impact children's ability to sustain attention and maintain consistent task engagement (McBurnett et al., 2014). This hypothesis is consistent with the strong covariation between treatment-related improvements (but not normalization) in ADHD symptoms and organizational behavior (Abikoff et al., 2009), as well as observations of children with ADHD at school; they often come to class unprepared, have disorganized desks/lockers, misplace materials, and require accommodations to manage deadlines and submit completed homework (Abikoff et al., 2012; Langberg et al., 2011; Power et al., 2006). Working memory deficits would make it extraordinarily difficult to engage in the forethought and planning necessary to organize materials, anticipate deadlines, inhibit irrelevant internal and external stimuli, and simultaneously coordinate relevant, *in vivo* data with project goals and prior knowledge. Impaired working memory would create a world in which children with ADHD must act quickly and without forethought to compensate for the inception of new and rapidly accumulating thoughts that interfere with the maintenance of task-oriented thoughts (Oberauer et al., 2016).

Interestingly, children showed *better* teacher-reported task planning given *greater* parent-reported hyperactivity symptoms. Whereas attention problems were perceived as detrimental to task planning, hyperactivity appears to be viewed as facilitative, both directly and within the context of better-developed working memory. At first glance, these findings appeared counterintuitive. However, this finding is consistent with meta-analytic evidence that hyperactive behavior increases as executive function demands increase (Kofler et al., 2016), as well as studies showing positive relations between hyperactivity and cognitive test performance in children with ADHD (Hartanto et al., 2016; Sarver et al., 2015). The current study adds to this literature, and suggests that hyperactive behavior – despite being characterized as intrusive and detrimental (APA, 2013) – may be functional in at least some cases. In the context of better-developed working memory, this behavior may serve a compensatory function to aid in task planning and organizational behavior (Rapport et al., 2009).

It remains unclear, however, whether this facilitation is attributable to increased gross motor movement and/or the verbally intrusive behaviors that comprise the Hyperactivity/Impulsivity cluster. We speculate that both sub-clusters warrant scrutiny. For example, Rapport et al. (2008) hypothesizes a compensatory, dopaminergic mechanism whereby increased motor movement aids cognitive processing by increasing physiological arousal in the context of task engagement. Similarly, Patrick and Ames (2015) offer a metabolic explanation whereby motor movement indirectly facilitates transport of pre-serotonin metabolites across the blood-brain barrier, which in the context of Omega-3 DHA/EDA sufficiency (Hawkey & Nigg, 2014) directly regulate executive functioning, impulse control, delay aversion, and prosocial behavior.

Alternatively, at least 4 of 9 DSM-5 'hyperactivity' items refer to verbally intrusive behavior (APA, 2013). We speculate that external vocalizations may be viewed as intrusive to others (Winsler, 1998), despite being helpful to the child (e.g., self-talk/external private speech, talking through steps out loud, blurting out answers before they are forgotten; Diaz et al., 1992; Berk & Potts, 1991). That is, overt vocalizations decrease working memory demands by externalizing thoughts and re-engaging sensory encoding and storage buffers (Baddeley, 2007). At the same time, auditory information gains automatic access to the phonological loop (Baddeley, 2007); this mechanism may prove fruitful to the child but disadvantageous to those around her by interfering with the information other children are trying to process (i.e., the child's vocalizations gain automatic access to *other children's* phonological loop as well).

Limitations

The current study was the first to investigate working memory processes, ADHD behavioral symptoms, and organizational problems in a large, well-defined sample. Several caveats merit consideration. Our reliance on subjective organizational ratings introduced error (e.g., negative halo, rater expectation), but also improved ecological validity relative to analog measures. Nevertheless, cross-sectional, subjective ratings disallow causal attributions, and effect sizes may be blunted by measuring cognitive abilities and organizational skills in different settings. Longitudinal and experimental studies are clearly warranted. Approximately 42% of our ADHD sample was prescribed stimulant medication, which was broadly consistent with epidemiological estimates (39% to 69%; Froelich et al., 2007; Visser et al., 2014) but may have dampened association magnitudes when juxtaposing neurocognitive performance obtained off medication with parent/teacher perceptions that may be influenced by medication.

Clinical and Research Implications

Organization problems are a major source of functional impairment in ADHD (Langberg et al., 2012). Our finding support conceptualizations of organization problems as *in situ* performance deficits that are secondary to working memory 'glitches' (Abikoff et al., 2013). Parent and teacher perceptions of children's organizational problems are predicated, to a large extent, on children's ability to efficiently process information in the moment. This finding may explain why behavioral interventions that reinforce organizational performance (e.g., turning in completed homework) without explicit skills training show similar, positive effects relative to programs that explicitly train organizational skills (Abikoff et al., 2013). We hypothesize that these organizational interventions may work, in part, by using behavioral techniques that circumvent working memory. For example, using written lists, breaking down multi-step instructions, and explicit reminders/redirection all inadvertently reduce the dual-processing demands involved in retaining relevant information in working memory while concurrently processing that and related information (Gathercole & Alloway, 2008). As such, organizational interventions – like medical and behavioral interventions targeting core ADHD symptoms (Sonuga-Barke et al., 2013) – likely need to remain in place to retain maximal efficacy over time.

At first glance, this hypothesis appears incongruent with Abikoff et al.'s (2013) report that organizational skills remained improved after the end of active treatment, except to the extent that parents continued to implement key intervention components and/or that the interventions remediated knowledge-based impairments. In this view, the significant reduction in gains detected between post-treatment and follow-up (Abikoff et al., 2013) could reflect discontinuation of active components that address performance-based impairments by circumventing working memory, whereas the continued improvement relative to pre-treatment (Abikoff et al., 2013) could reflect successful remediation of underdeveloped organizational knowledge. Notably, this hypothesis remains highly speculative, and the limited available evidence suggests that behavioral interventions do not significantly improve working memory for children with ADHD (Hannesdottir et al., 2014; Steeger et al., 2016). Nonetheless, these results add to a growing body of literature implicating working memory dysfunction in most if not all of the key behavioral symptoms and functional impairments associated with ADHD.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Key Points

- Children with ADHD exhibit large magnitude deficits in working memory and broad-based organizational skills
- Underdeveloped working memory predicts ecologically-valid, multi-informant organizational problems
- Working memory shows strong convergence with organizational problems both directly and indirectly via its influence on ADHD inattentive behavior

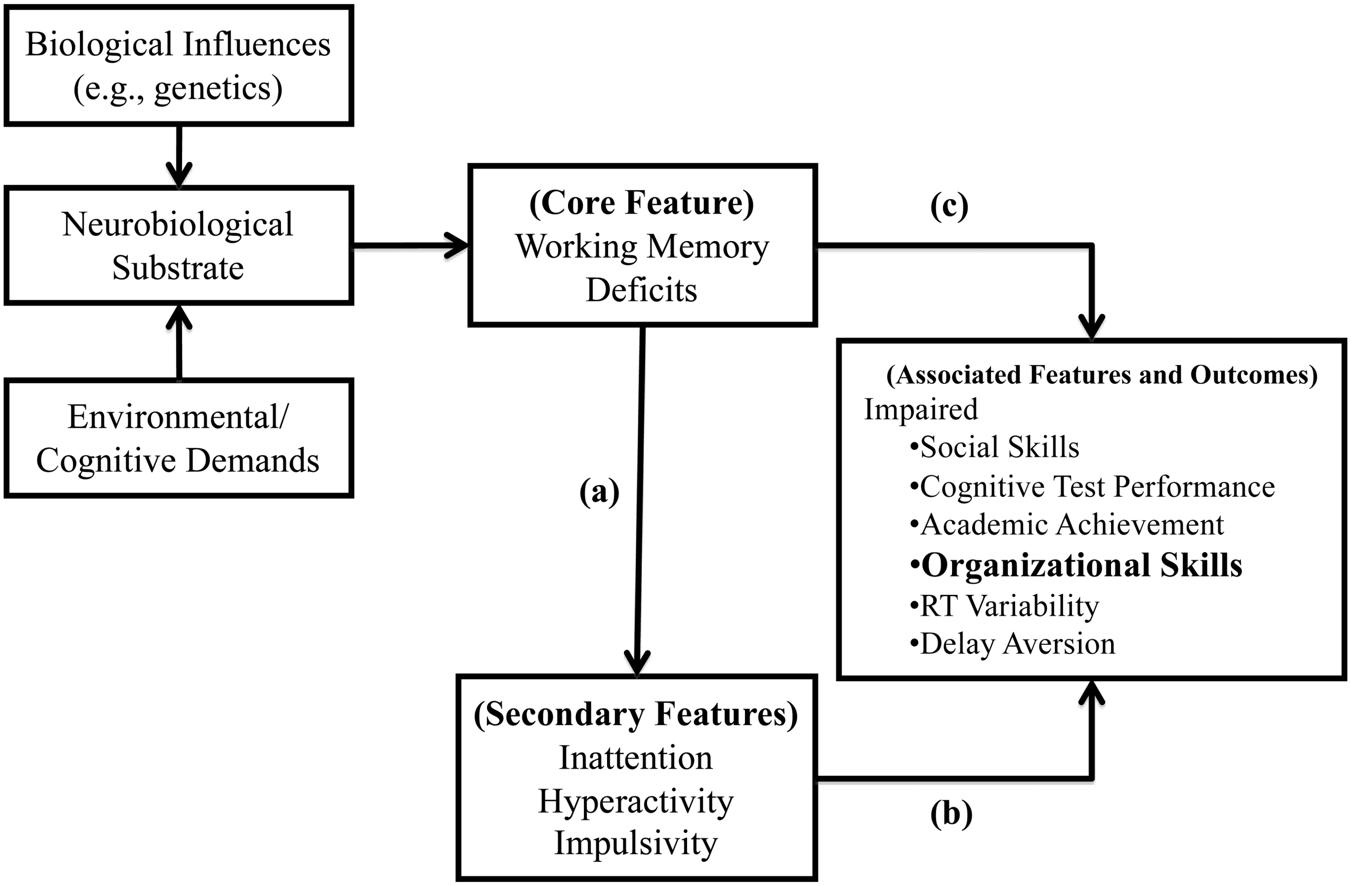

Figure 1.
The Rapport et al. (2001/2008) functional working memory model of ADHD. Working memory deficits are hypothesized to impact organization skills directly (path c) and/or in directly through the impact of working memory on the primary behavioral symptoms of the disorder (path a*b). Figure adapted from Kofler et al. (2011).

Table 1

Sample and Demographic Variables

Variable	ADHD		Non-ADHD		Cohen's *d*	*p*
	M	*SD*	*M*	*SD*		
N (Boys/Girls)	68 (43/25)		35 (21/14)		--	.75, *ns*
Age	10.29	1.42	10.50	1.50	-0.14	.49, *ns*
SES	49.26	11.30	49.46	12.65	-0.02	.94, *ns*
FSIQ	104.25	15.55	107.72	10.95	-0.25	.24, *ns*
BASC-2 Attention Problems (T-score)						
Parent	67.07	7.35	57.60	10.88	1.09	***
Teacher	63.70	8.29	52.46	10.16	1.26	***
BASC-2 Hyperactivity (T-score)						
Parent	70.46	13.60	54.60	11.53	1.23	***
Teacher	61.93	14.85	52.20	12.47	0.69	***
Children's Organizational Skills Scale (COSS) (T-score)						
Teacher						
Total Organization	64.95	12.16	54.63	12.00	0.85	***
Task Planning	62.64	13.93	54.57	14.05	0.58	**
Organized Actions	62.63	8.20	55.00	10.64	0.84	***
Memory/Materials Mgmt	64.91	14.34	53.34	12.45	0.84	***
Parent						
Total Organization	63.92	10.11	54.37	13.07	0.85	***
Task Planning	63.23	10.70	53.51	13.15	0.84	***
Organized Actions	59.55	7.17	53.51	10.05	0.73	***
Memory/Materials Mgmt	62.97	11.75	52.57	12.27	0.87	***
Working Memory Performance Data (Stimuli Correct/Trial)						
PH 3	2.86	0.22	2.83	0.23	0.14	.52, *ns*
PH 4	3.32	0.62	3.65	0.33	-0.61	**
PH 5	3.47	1.02	4.25	0.70	-0.84	***
PH 6	2.91	1.34	4.23	1.15	-1.04	***
VS 3	2.10	0.62	2.48	0.41	-0.68	**
VS 4	2.44	0.91	3.31	0.58	-1.07	***
VS 5	2.45	1.10	3.33	1.00	-0.82	***
VS 6	2.13	1.14	3.41	1.22	-1.10	***
Working Memory Composite (Z-scores)						
Working Memory	-0.36	0.93	0.71	0.73	-1.24	***

Note. Non-significant between-group comparisons are shown in grey font. BASC-2 = Behavior Assessment System for Children (T-scores); FSIQ = Full Scale Intelligence Quotient (Standard Scores); PH = Phonological Working Memory (Stimuli Correct/Trial); VS = Visuospatial Working Memory (Stimuli Correct/Trial).

* $p < .05$,

** $p \leq .01$,

*** $p \leq .001$

Table 2

Impact of Working Memory and ADHD Symptoms on Total Organization Problems

Path		COSS Total Organization Problems					
		Teacher Report			Parent Report		
	Total Effect	*B*	*SE*	*p*	*B*	*SE*	*p*
c	Working Memory → Organization Problems	-4.82	1.27	**	-3.10	1.21	**
	Direct Effects						
a_1	Working Memory → Attention Problems	-3.28	0.97	**	-3.99	1.04	**
a_2	Working Memory → Hyperactivity	-4.74	1.48	**	-4.22	1.51	**
b_1	Attention Problems → Organization Problems	0.56	0.17	**	0.44	0.13	**
b_2	Hyperactivity → Organization Problems	-0.14	0.11	.22	-0.02	0.09	.86
c'	Working Memory → Organization Problems	-3.64	1.28	**	-1.39	1.23	.26
	Indirect Effects (through mediator)						
ab_1	WM → Attention Pxs → Organization Problems	-1.84	0.76	*	-1.77	0.73	*
	95% CI of Bootstrap	(-3.70, -0.65)		*	(-3.69, -0.63)		*
	Effect Ratio (95% CI)	.38 (.13, .97)		*	.57 (.18, 2.03)		*
ab_2	WM → Hyperactivity → Organization Problems	0.66	0.63	*ns*	0.07	0.41	*ns*
	95% CI of Bootstrap	(-0.26, 2.29)		*ns*	(-0.73, 0.94)		*ns*
	Effect Ratio (95% CI)	-.14 (-.66, .05)		*ns*	-.02 (-.42, .29)		*ns*
	Model Summary	R^2		*p*	R^2		*p*
		.23		**	.19		**

Note: Bias-corrected bootstrapping was used for all analyses. Non-significant pathways are shown in grey font (95% CI includes 0.0). Parent-reported ADHD symptoms were tested as mediators of teacher-reported organizational problems, and vice versa. Paths labels reflect standard nomenclature (cf. Fritz & MacKinnon, 2007) and are depicted in Figure 1; c and c' reflect the total and direct effect of WM on organization problems before and after accounting for ADHD symptoms, respectively; Attn Px = Attention Problems, CE = Central Executive, Hyperact = Hyperactivity; WM = working memory;

† $p < .08$,

* $p \leq .05$,

** $p \leq .01$

[1] N = 73 due to skipped items on one teacher COSS.