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Working Memory Profiles in Children with ADHD: Differences Between ADHD-I, ADHD-C, and Typically Developing Children

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ABSTRACT

Attention-Deficit/Hyperactivity Disorder (ADHD) is characterized by significant working memory (WM) deficits. However, cognitive differences between the predominantly inattentive (ADHD-I) and combined (ADHD-C) presentations require further investigation based on Baddeley's multi-component model. This study compared WM profiles in children with ADHD-I, ADHD-C, and typically developing (TD) children to identify subtype-specific cognitive signatures and discuss clinical implications. Participants included 137 children (41 ADHD-I, 45 ADHD-C, 51 TD) aged 7–12 recruited from clinics in Tehran, Iran, using convenience sampling. Diagnosis was confirmed via DSM-5 criteria and the IVA-2 test. WM components were assessed using the Working Memory Test Battery for Children (WMTB-C). Data were analyzed using one-way ANOVA with post-hoc tests. Both ADHD groups showed significant impairments across all WM components compared to TD children. For the phonological loop and visuospatial sketchpad, no significant differences were found between ADHD-I and ADHD-C. However, for the central executive component, the ADHD-C group performed significantly worse than the ADHD-I group ($p < .01$). While WM impairments are widespread in ADHD, the central executive is more severely affected in the combined presentation. These findings suggest distinct cognitive profiles for ADHD subtypes, highlighting the need for tailored interventions targeting executive functions in ADHD-C. However, due to the cross-sectional design and clinic-based sample, causal inferences and generalizability are limited. Future longitudinal and neuroimaging studies are warranted to confirm these findings and inform clinical practice.

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Introduction

Attention-Deficit/Hyperactivity Disorder (ADHD) is one of the most prevalent neurodevelopmental disorders, affecting approximately 5–7% of children and adolescents worldwide (Liu et al., 2025). It is characterized by persistent difficulties in sustaining attention, impulse control, and hyperactivity (Ayano et al., 2020). The disorder not only leads to academic, social, and emotional consequences (Coghill et al., 2023) but also underlies profound deficits in cognitive systems associated with attentional control and information processing (Rubia, 2018). According to the DSM-5 diagnostic framework (APA, 2013), ADHD manifests in three clinical presentations: the predominantly inattentive presentation (ADHD-I), the predominantly hyperactive-impulsive presentation (ADHD-H), and the combined presentation (ADHD-C). The predominantly inattentive presentation is the most common pattern in the general population across age groups, while the combined presentation is more frequently observed in clinic-referred samples and is associated with higher symptom severity and behavioral challenges (Lin et al., 2023). Children with ADHD-I primarily exhibit prominent difficulties in sustained attention, organization, and slower information processing, whereas those with ADHD-C demonstrate these issues along with hyperactive and impulsive behaviors (Nikolas & Nigg, 2013). Evidence suggests that the underlying cognitive and neuropsychological mechanisms of these presentations may not be identical and that each may possess a distinct cognitive profile (Saad et al., 2020; Wu et al., 2022). Therefore, investigating more fundamental cognitive structures, particularly systems crucial for attentional regulation and sequential information processing, can provide deeper insight into the differences between these two presentations and pave the way for developing more targeted interventions.

One of the most significant cognitive components impaired in ADHD is working memory (WM) (Kofler et al., 2020; Kofler et al., 2024; Wells et al., 2018). Deficits in this system not only affect the maintenance, processing, organization, and updating of information but are also critical for learning, problem-solving, and behavioral regulation (Kofler et al., 2020). WM is the ability to hold and manipulate information over a brief period without external guidance (Baddeley et al., 2021), enabling individuals to retain information in the presence of irrelevant stimuli and manipulate it to guide goal-directed behavior (Hasanzadeh & Ahmadi, 2015). Within Baddeley's multi-component model (Baddeley & Hitch, 1974), WM comprises three key subsystems: the phonological loop, responsible for the temporary storage and retrieval of verbal information; the visuospatial sketchpad, which maintains visual and spatial representations; and the central executive, which oversees attentional control, coordinates the subsystems, and actively manipulates information. Examining the performance of each of these components in ADHD can reveal the specific cognitive weaknesses of each clinical presentation and help delineate cognitive differences between ADHD-I and ADHD-C.

From a theoretical standpoint, Baddeley's multi-component model offers a framework for predicting differential WM impairments across ADHD subtypes (Kofler et al., 2020). The central executive, responsible for attentional control and information manipulation, is theoretically more aligned with the regulatory deficits characteristic of ADHD-C, such as impulse control and hyperactivity (Barkley, 1997). In contrast, the phonological loop and visuospatial sketchpad, as passive storage systems, may be more directly related to the primary attentional and organizational difficulties seen in ADHD-I (Martinussen & Tannock, 2006). Therefore, examining these components separately allows for a test of whether the cognitive architecture of ADHD subtypes diverges in a manner consistent with the model's predictions.

Previous research indicates that children and adolescents with ADHD have significant impairments in various WM components. A meta-analytic study found that effect sizes were generally larger for visuospatial storage and visuospatial central executive tasks (storage-plus-processing) compared to phonological storage and phonological central executive tasks

(Martinussen et al., 2005). The central executive component, in particular, appears to be distinctly affected (Kofler et al., 2020). Previous studies in this area have typically controlled for potential confounding variables such as age, gender, full-scale IQ, socioeconomic status, and the presence of comorbid psychiatric conditions (e.g., Martinussen et al., 2005; Nikolas & Nigg, 2013) to isolate the specific relationship between ADHD subtypes and working memory function. Consequently, WM deficit patterns in ADHD are multifaceted, varying in nature and severity depending on the task type (simple storage vs. storage-plus-processing) (Kofler et al., 2020; Martinussen et al., 2005).

However, research findings regarding differences in WM components between the inattentive and combined presentations are inconsistent. Some studies suggest that individuals with ADHD-C perform more poorly on verbal and visual recall tasks compared to those with ADHD-I (Nikolas & Nigg, 2013; Phillips et al., 2022). In contrast, other studies report no significant differences in WM between the two subtypes (Alloway et al., 2010). Conversely, some research indicates that differences are more closely related to the overall severity of the disorder rather than the specific subtype (Nikolas & Nigg, 2013; Wu et al., 2022). Distinguishing WM profiles between ADHD-I and ADHD-C is fundamentally important for several reasons. Theoretically, according to Baddeley's multi-component model, the phonological loop, visuospatial sketchpad, and central executive may be differentially impaired in ADHD subtypes (Marsh et al., 2025). Research suggests that WM deficits in ADHD-I and ADHD-C may reflect more fundamental differences in cognitive architecture and neural networks involved in attentional control and response inhibition. Specifically, the central executive and storage subcomponents are vulnerable in both subtypes, but the severity and pattern of these impairments may differ (Saydam et al., 2015). On a practical and clinical level, distinguishing between WM profiles can have significant implications.

A precise understanding of the weaknesses specific to each subtype allows professionals to design interventions that better align with the actual cognitive needs of children. Research shows that WM deficits, particularly in the central executive component, play a key role in the behavioral and academic problems of children with ADHD, and the severity of these deficits correlates with the severity of inattentive and hyperactive/impulsive symptoms (Kofler et al., 2020). Recent studies emphasize that cognitive interventions are most effective when tailored to the individual cognitive profile and ADHD subtype of each child. For example, children with severe WM deficits benefit more from targeted interventions in this domain, and improvements in WM performance can lead to a reduction in clinical symptoms and enhanced academic and daily functioning (Wexler et al., 2021).

Given the inconsistencies in previous research regarding WM differences between ADHD subtypes and the methodological limitations of prior studies (e.g., small samples, lack of comprehensive WM assessment), the present study aimed to compare WM profiles using a well-validated battery in a reasonably sized clinical sample. Accordingly, this research specifically evaluates the three main components of Baddeley's model: the phonological loop, the visuospatial sketchpad, and the central executive. Using standardized tasks designed to independently assess the performance of each WM subcomponent, this study seeks to determine whether each presentation possesses a distinct cognitive signature. The findings of this study can contribute to a more precise understanding of the heterogeneity within ADHD and facilitate the development of cognition-based assessments and interventions.

Method

Participants

The present study sample consisted of 137 children (41 with ADHD-I, 45 with ADHD-C, and 51 TD) aged 7 to 12 years (mean = 8.09, SD = 1.05) from Tehran, Iran, selected via convenience sampling from psychology clinics (see Table 1). All parents and children provided informed consent prior to participation. It is important to acknowledge that the use of convenience sampling from clinic-referred populations may limit the representativeness of the sample. Additionally, the sample lacks diversity in terms of socioeconomic status, geographic location, and cultural background, which may restrict the generalizability of the findings to broader populations.

Group Assignment

All children diagnosed with ADHD and their parents completed a comprehensive psychoeducational and diagnostic evaluation. This included a semi-structured clinical interview conducted by psychologists or psychiatrists in accordance with DSM-5 criteria (APA, 2013), along with the completion of the Child Behavior Checklist-Parent Version (CBCL-P). The precise subtyping of ADHD was further confirmed based on scores from the Integrated Visual and Auditory Continuous Performance Test version 2 (IVA-2), in which participants must respond to the target stimulus (the number "1") while inhibiting responses to the non-target stimulus (the number "2") (Sandford & Turner, 2000). To enhance the validity of the test results, stimulant medication was discontinued at least 24 hours prior to testing.

Participants in the typically developing (TD) group were recruited from the same clinic population, but specifically among children presenting for routine, non-clinical consultations (e.g., academic counseling, parenting guidance) rather than for psychiatric concerns. To ensure neurotypical status, TD participants were required to meet the following criteria: (1) no parent-reported history of psychiatric, neurological, or learning disorders; (2) school records indicating typical academic and behavioral functioning with no history of individualized educational support; and (3) normal-range scores on all syndrome scales of the Child Behavior Checklist-Parent version (CBCL-P; $T < 60$). Additionally, all TD children underwent the same IVA-2 assessment as the ADHD groups, and only those with scores within the normal range (standard score ≥ 85) were included in the final sample.

Inclusion criteria for all participants required an IQ of 85 or above, assessed using the Stanford-Binet Intelligence Test. Children with neurological disorders or other major psychiatric conditions were excluded from the study. Subsequently, all children were assessed individually using the Working Memory Test Battery for Children (WMTB-C) in a quiet, distraction-free room.

Materials

Working Memory Test Battery for Children (WMTB-C)

This test, based on the model by Baddeley and Hitch (1974), was designed to assess WM in children aged 4.7 to 15 years. The present study utilized the Persian version of the test, which was translated and validated by Arjmandnia (2017). The battery measures three components: the phonological loop, the visuospatial sketchpad, and the central executive, and includes nine subtests: Digit Recall, Word List Matching, Word Recall, Nonword Recall, Block Recall, Mazes Recall, Listening Recall, Counting Recall, and Backward Digit Recall. Test-retest reliability for children aged 4.7 to 15 years has been reported to range from .45 to .83 (Arjmandnia, 2017). Completing this battery takes approximately 45 minutes.

Integrated Visual and Auditory Continuous Performance Test (IVA-2)

The Integrated Visual and Auditory Continuous Performance Test (IVA-2) is a computerized assessment tool. It is used as a screening instrument alongside other diagnostic methods such as parent and teacher behavioral rating scales to evaluate attention, response inhibition, and to screen for Attention-Deficit/Hyperactivity Disorder (ADHD) in individuals aged 6 through adulthood. Administered in approximately 20 minutes, it consists of 500 trials, including practice and warm-up phases. During the test, respondents must respond to the target stimulus (e.g., the number "1") while inhibiting responses to non-targets (e.g., the number "2"). Scores are provided as raw and standardized values (mean = 100, SD = 15). Test-retest reliability coefficients for its subtests range from .75 to .97 (Sandford & Turner, 2000). The IVA-2 has demonstrated high sensitivity (92%) and predictive power (90%) compared to parent-report diagnostic scales (Sandford & Turner, 2000).

Results

The present study employed a cross-sectional design with three groups (ADHD-I, ADHD-C, and TD) to compare working memory profiles. An a priori power analysis using G*Power indicated that a minimum sample of 96 participants was required to detect medium-to-large effects ($f = 0.35$) with 80% power at $\alpha = 0.05$. The final sample of 137 children exceeded this requirement, ensuring adequate statistical power for group comparisons. Table 1 presents the demographic characteristics of the study participants. There were no statistically significant differences in age between the ADHD-I, ADHD-C and TD groups (see Table 1).

Table 1. Description of the Sample

	Groups			F	P
	ADHD-I	ADHD-C	TD		
N	41	45	51		
Male: female	(17:24)	(20:25)	(28:23)		
Age, mean (SD)	8.08 (1.04)	9.09 (1.06)	8.09 (1.05)	.37	.69

To investigate group differences, a one-way ANOVA was conducted on each subtest. All assumptions were met, including normality (assessed via Shapiro-Wilk tests, all $p > .05$) and homogeneity of variance (confirmed by Levene's test, all $p > .05$).

Table 2. ANOVA Results Comparing WM Subtest Scores

Variable	groups ADHD-I	ADHD-C	TD	ANOVA			Tukey results		
	Means (SD)	Means (SD)	Means (SD)	F	p	η^2			
Digit Recall	84.71 (11.09)	81.22 (12.61)	95.96 (7.62)	25.92	<.01	.28	ADHD-I = ADHD-C	ADHD-I < TD	ADHD-C < TD
Word matching Recall	90.02 (11.43)	87.35 (14.27)	98.49 (7.65)	12.78	<.01	.16	ADHD-I = ADHD-C	ADHD-I < TD	ADHD-C < TD
Word Recall	96.58 (10.56)	91.75 (13.43)	107.02 (11.53)	20.61	<.01	.23	ADHD-I = ADHD-C	ADHD-I < TD	ADHD-C < TD
Nonword Recal	92.48 (10.02)	88.96 (9.61)	96.86 (6.63)	9.82	<.01	.13	ADHD-I = ADHD-C	ADHD-I < TD	ADHD-C < TD
Block Recall	90.05 (10.71)	82.53 (14.01)	101 (11.45)	28.12	<.01	.30	ADHD-I > ADHD-C	ADHD-I < TD	ADHD-C < TD
Maze Recall	95.90 (10.21)	91.58 (16.21)	107.23 (9.71)	20.70	<.01	.24	ADHD-I = ADHD-C	ADHD-I < TD	ADHD-C < TD
Listening Recall	91.93 (11.06)	83.82 (14.28)	100.82 (10.98)	23.45	<.01	.26	ADHD-I > ADHD-C	ADHD-I < TD	ADHD-C < TD
Counting Recall	92.59 (10.74)	86.58 (14.95)	106.86 (9.81)	34.85	<.01	.34	ADHD-I = ADHD-C	ADHD-I < TD	ADHD-C < TD
Backward digit Recall	86.04 (11.82)	78.69 (14.06)	101.98 (10.49)	23.75	<.01	.26	ADHD-I = ADHD-C	ADHD-I < TD	ADHD-C < TD

Results of the one-way ANOVA (Table 2) indicated significant differences among the three groups across all WM subtests ($p < .01$).

Regarding the phonological component, post-hoc comparisons revealed that both ADHD-I and ADHD-C groups performed significantly worse than the TD group, with no significant difference between the two ADHD subtypes. Within the visuospatial component, in Block Recall, the ADHD-I group outperformed the ADHD-C group, though both ADHD groups scored significantly lower than the TD group. In Maze Recall, no significant difference was observed between the two ADHD groups, and both performed worse than the TD group. For the central executive-related subtests, post-hoc analysis showed that in Listening Recall, the ADHD-I group performed better than the ADHD-C group. However, in the other central executive subtests, there was no significant difference between the ADHD groups. Across all central executive subtests, both ADHD groups performed significantly worse than the TD group.

Table 3. ANOVA Results Comparing WM Components

Variable	groups ADHD-I	ADHD-C	TD	ANOVA			Tukey		
	Means (SD)	Means (SD)	Means (SD)	F	p	η2			
PL	88.15 (11.32)	83.84 (14)	99.04 (7.62)	23.83	<.01	.26	ADHD-I = ADHD-C	ADHD-I < TD	ADHD-C < TD
VSSP	91.51 (10.28)	86.49 (13.74)	105.22 (10.17)	34.37	<.01	.34	ADHD-I = ADHD-C	ADHD-I < TD	ADHD-C < TD
CE	86.51 (11.82)	78.69 (14.06)	101.98 (10.49)	45.92	<.01	.41	ADHD-I > ADHD-C	ADHD-I < TD	ADHD-C < TD

Note. PL: Phonological Loop; VSSP: Visuospatial Sketchpad; CE: Central Executive

The results presented in Table 3 indicate significant differences among all three groups across the main components of WM. ($p < .01$). For the Phonological Loop, post-hoc tests using Tukey's method indicated that both ADHD groups performed significantly worse than the TD group, with no significant difference between ADHD-I and ADHD-C. The effect size for this component ($\eta^2 = .26$) is large according to Cohen's guidelines, indicating that 26% of the variance in phonological loop performance is explained by group membership.

In the Visuospatial Sketchpad, performance was also significantly lower in both ADHD groups compared to the TD group, and no significant difference emerged between the two ADHD subtypes. The effect size ($\eta^2 = .34$) is large, suggesting that 34% of the variance in visuospatial sketchpad performance is attributable to group differences.

Regarding the Central Executive, a significant and substantial difference was observed among the groups. Post-hoc comparisons revealed that the ADHD-I group performed better than the ADHD-C group, while both ADHD groups scored significantly lower than the TD group. The effect size for this comparison ($\eta^2 = .41$) is considered large, indicating that approximately 41% of the variance in central executive performance is accounted for by group membership. This represents a clinically meaningful distinction between the two ADHD subtypes.

It should be noted that the absence of significant differences between ADHD-I and ADHD-C on several subtests (e.g., Digit Recall, Word Recall, Counting Recall, and Backward Digit Recall) may reflect insufficient statistical power for pairwise subtype comparisons. Although the a priori power analysis confirmed that the total sample was adequately powered for the overall three-group comparisons, the subgroup sizes (41 and 45 participants for ADHD-I and ADHD-C, respectively) were not specifically powered to detect smaller effects between the two clinical groups. Therefore, these non-significant findings should not be interpreted as definitive evidence of equivalence, and replication with larger samples specifically designed for pairwise subtype comparisons is warranted.

Discussion and Conclusion

The findings demonstrate that children with ADHD, regardless of subtype, exhibit impaired performance across all three components of WM—phonological loop, visuospatial sketchpad, and central executive—compared to TD children. This aligns with prior meta-analytic reviews identifying WM as a core cognitive deficit in ADHD (Martinussen et al., 2005; Pievsky & McGrath, 2018).

According to Baddeley's multicomponent model, the phonological loop and visuospatial sketchpad primarily support temporary storage, while the central executive coordinates attention, integrates information across subsystems, and manipulates content (Baddeley, 2000). In ADHD, deficits in sustained attention and executive control may compromise these subsystems, particularly under increased cognitive load (Kofler et al., 2020). A notable finding concerns the distinction between subtypes: although both ADHD groups showed deficits in phonological and visuospatial storage, children with ADHD-C exhibited more pronounced impairment in the central executive relative to those with ADHD-I (Pasini et al., 2007). This pattern is consistent with theoretical frameworks that position the central executive as a supervisory system, with ADHD characterized by greater impairment in this domain compared to storage-related subsystems (Kofler et al., 2020).

Recent meta-analyses further indicate that central executive demands increase with processing load and response inhibition requirements, effects that appear more marked in the combined subtype (Friedman & Robbins, 2022). However, it is important to emphasize that the present study did not include neuroimaging measures; therefore, any interpretations linking behavioral findings to specific neural mechanisms (e.g., Cai et al., 2021) remain speculative and should be viewed as hypotheses to be tested in future research. From a neural perspective, some studies have associated ADHD-C with altered connectivity—particularly increased coupling between executive, salience, and sensory networks—which may contribute to broader deficits in cognitive control and attention regulation (Qian et al., 2019). Structural and functional differences in frontostriatal and prefrontal regions have been suggested to be more prominent in ADHD-C than in ADHD-I (Saad et al., 2020). Nevertheless, because the current study did not collect neuroimaging data, these neurobiological interpretations are offered as hypotheses rather than conclusions drawn from the present findings.

These results are also consistent with the Dual Pathway Model of ADHD, which posits separable but overlapping contributions of WM/executive deficits and inhibitory dysregulation to ADHD symptomatology (Stevens et al., 2018). In ADHD-C, additive impairments across both pathways may exacerbate executive dysfunction, whereas in ADHD-I, deficits may relate more specifically to attentional maintenance. Neuroimaging studies further distinguish subgroups with predominant executive hypofunction in prefrontal-striatal circuits from those with altered reward processing, supporting heterogeneous neural profiles across presentations (Stevens et al., 2018).

The finding that children with ADHD-C exhibit more severe central executive deficits than those with ADHD-I has practical implications. The large effect size ($\eta^2 = .41$) indicates a clinically meaningful distinction, supporting the inclusion of central executive tasks (e.g., listening recall, backward digit span) in routine assessments. For children with ADHD-C, interventions targeting executive functions—such as computerized working memory training, self-regulation strategies, and classroom accommodations—may be particularly beneficial. For those with ADHD-I, interventions might focus on strengthening storage components through mnemonic strategies and external aids. Future research should examine whether matching interventions to cognitive profiles enhances outcomes.

Several limitations should be acknowledged. The cross-sectional design precludes causal inferences, and convenience sampling from clinic-referred populations limits generalizability. The absence of neuroimaging measures means neural interpretations remain speculative, and some WMTB-C subtests demonstrated low reliability, affecting measurement precision. Although the total sample was adequately powered for three-group comparisons, subgroup sizes may have been insufficient to detect smaller effects between ADHD-I and ADHD-C. Finally, potential confounding variables (e.g., comorbidities, medication history) were not fully controlled, highlighting the need for future longitudinal studies with more diverse samples and rigorous methodologies.

This study confirms WM impairments across ADHD presentations, with more severe central executive deficits in the combined subtype. The results align with established cognitive models and neuropsychological evidence, supporting distinct cognitive profiles in ADHD-I and ADHD-C. Comprehensive assessment of executive functions and tailored interventions, particularly for the combined presentation, are warranted. However, given the aforementioned limitations, future longitudinal and neuroscientific studies are needed to further elucidate the mechanisms underlying these subtype differences and to inform evidence-based clinical practice**.**

Declarations

Author Contributions

All authors contributed actively to the conception, design, and execution of the research.

Data Availability Statement

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

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Ethical considerations

All procedures performed in studies involving human participants were in accordance with the ethical standards of University of Tehran research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

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Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this research.

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