Seriousness and pervasiveness of impairments: Educational, Clinical, Interpersonal

- **Poor School Performance (90%+)**
  - More failing grades
  - Reduced productivity (greatest problem)
  - Lower GPA (1.7 vs 2.6)
  - Grade retentions (42% vs 13%)
  - Lower class rankings (69% vs 50%)
  - Higher rate of suspensions (60% vs 19%) and expulsions (14% vs 6%)

- **Low Academic Achievement (10-15 pt. deficit)**

- **Low Average Intelligence (7-10 point deficit)**

- **Learning Disabilities (10 to 70%)**
  - Reading (15-30%; 21% in Barkley, 1990)
  - Spelling (26% in Barkley, 1990)
  - Math (10-60%; 28% in Barkley, 1990)
  - Handwriting (common but % unspecified)

- **Academic Outcomes**
  - 23% to 32% fail to complete high school
  - 22% vs 77% enter college
  - 5% vs 35% complete college

[Barkley et al. 2006 Milwaukee Young Adult Outcome Study]
ADHD Cost of Illness (COI) in USA

**COI =** Educational accommodations
Mental health care
Parental work loss
Juvenile justice system involvement

**COI =** Mean = $14,576 annually per child (Pelham et al., 2007)
Range = $12,005 to $17,458

**COI =** $40.8 billion annually (based on assumed 5% prevalence rate and 2.8 million school age children in the United States (National Center for Education Statistics, 2010, enrollment data)
DSM-IV CLINICAL MODEL OF ADHD

Biological Influences, e.g., genetics

NEUROBIOLOGICAL SUBSTRATE

Behavioral Interventions

ENVIRONMENTAL/COGNITIVE DEMANDS

CORE FEATURES:
- INATTENTION
- HYPERACTIVITY
- IMPULSIVITY

SECONDARY FEATURES:
- Academic Underachievement
- Social Skill Deficits
- Poor Organizational Skills
- Classroom Deportment
- Cognitive Abilities

Pharmacological Treatment
The enigma – why do large magnitude changes in core symptoms not translate into sustainable or generalizable changes in treated children?

- Pharmacodynamic studies reveal DA and NA activation of cortical-subcortical pathways involving the frontal/prefrontal, temporal lobe, and basal ganglia – areas that play a critical role in executive functions (EFs)

- Optimal activation of structures underlying EFs and accompanying arousal is necessary but insufficient to facilitate the development of executive function processes supported by these structures and wide range of behaviors dependent upon these processes
Overview of Executive Functions (EFs)

Executive Function (EF): an umbrella term used to describe a broad range of ‘top-down’ cognitive processes and abilities that enable flexible, goal-directed behavior; and represents the dominant paradigm during the past decade following Dr. Barkley’s (1997) seminal theoretical paper in 1997.

Ensuing debate focused on two alternative models:
1. EF viewed as a unitary construct with interrelated sub-processes.
2. EF viewed as a componential model of dissociable EF processes

Accumulating evidence supports an integration of the two approaches (i.e., interrelated sub-processes governed by a domain general executive or attentional controller (e.g., Miyake et al., 2000) emphasizing 3 primary executive functions:

- **Updating**: the continuous monitoring and quick addition or deletion of contents within one’s working memory
- **Inhibition**: the capacity to supersede responses that are prepotent in a given situation
- **Shifting**: the cognitive flexibility to switch between different tasks or mental states
Miyake et al. (2000): 3-factor model of executive function based on SEM

Lehto et al. (2003): replicated factor structure in 8-13 year old children

Huizinga et al. (2006): WM & set shifting are developmentally contiguous between 7 & 21 years of age
Miyake et al., 2008: Genetic Contribution associated with EFs

Figure 7. Nested factors executive function model with Wechsler Adult Intelligence Scale full-scale IQ (WAIS–IQ). Numbers above the ACEs for the latent variables and WAIS–IQ are the percentages of those variables accounted for by genetic and environmental influences. Numbers occluding the double-headed arrows are correlation coefficients. Correlations for components with zero or near-zero variance were not estimated. Numbers occluding arrows are standardized factor loadings. Numbers under the lower ACEs are estimates for task-specific variances. Boldface type and solid lines indicate $p < .05$. Anti = antisaccade; stop = stop signal; keep = keep track; letter = letter memory; S2ba = spatial 2-back; num = number–letter; col = color–shape; cat = category switch.
Biological Influences
(e.g., genetics)

Neurobiological Substrate

Environmental/Cognitive Demands

(Core Feature)
Working Memory Deficits

(Associated Features & Outcomes: Impaired
- Learning
- Cognitive Test Performance
- Academic Achievement
- Social Skills
- Organizational Skills
- Classroom Deportment
- Delay Aversion

(Secondary Features)
Inattentiveness
Hyperactivity
Impulsivity

What is Working Memory?

– Working memory is a limited capacity system that enables individuals to store briefly and process information (Baddeley, 2007).
Alan Baddeley’s (2007) WM Model

- **Shared Variance**
  - Phonological task
  - Input Process
  - Phonological buffer/rehearsal loop
  - Central Executive
  - Visuospatial task
  - Input Process
  - Visuospatial buffer/rehearsal loop

- **Central Executive**
  - Auditory Input
  - Visual Input

- **Phonological Analysis**
  - Phonological
  - STS
  - Inferior parietal lobe
  - Orthographic to phonological recoding
  - Phonological output buffer
  - Broca’s area-premotor cortex
  - Spoken Output

- **Visuospatial Analysis**
  - Visual analysis & STS
  - Orthographic to phonological recoding
  - Visuospatial output buffer
  - Right premotor cortex
  - Motor Output

- **Domain General**
Central Executive Processes: Past Conceptualization

- Continuous Updating
- Manipulation/Dual Processing
- Serial Reordering

[Baddeley, 2007]
Development of Working Memory in Children: Peak Developmental Periods

Phonological (Verbal) STM

Visuospatial STM

Central Executive (CE)

AGE: 6 7 8 9 10 11 12 13 14 15

Forward and Backward Span Tasks

- Operation span: 0.63
- Reading span: 0.77
- Counting span: 0.80
- Backward span: 0.74
- Forward span (dissimilar): 0.60
- Forward span (similar): 0.70

Working Memory

- Fluid IQ: 0.49
- Short-Term Memory
  - Backward span: 0.67
  - Forward span (dissimilar): 0.80
  - Forward span (similar): 0.71

Forward and backward span tasks load on the same dimension and are both measures of short-term storage (Engle, Tuholski, Laughlin, & Conway, 1999).

References:
- Swanson & Kim, 2007
- Colom, Abad, Rebollo, & Shih, 2005
- Rosen & Engle, 1997
- Swanson, Mink, & Bocian, 1999
- Engle, Tuholski, Laughlin, & Conway, 1999
- Fluid IQ: 0.49
- ns: not significant
Working Memory, Short-Term Memory, and General Fluid Intelligence: A Latent-Variable Approach

ENGLE, TUHOLSKI, LAUGHLIN, AND CONWAY

Figure 2. (a) Path model for two-factor model (A1). All paths are significant at the .05 level. (b) Path model for two-factor model with additional tasks (B2). Paths significant at the .05 level are indicated by solid lines. OSPAN = operation span; RSPAN = reading span; CSPAN = counting span; BSPAN = backward span; FSPAND = forward span, dissimilar; FSPANS = forward span, similar; KTRACK = keeping track; IFRSM = Immediate Free Recall Secondary Memory; CONTOP = continuous opposites; WM = working memory; STM = short-term memory.
Figure 4. Path model for Model D. Significant paths are indicated by an asterisk. OSPAN = operation span; RSPAN = reading span; CSPAN = counting span; BSPAN = backward span; FSPAN  = forward span, dissimilar; FSPANS = forward span, similar; WM = working memory; STM = short-term memory; gF = fluid intelligence.
Higher-order cognitive tasks, skills, and abilities dependent on working memory components

<table>
<thead>
<tr>
<th>Central Executive</th>
<th>Phonological Storage/Rehearsal</th>
<th>Visuospatial Storage/Rehearsal</th>
</tr>
</thead>
<tbody>
<tr>
<td>General fluid intelligence</td>
<td>Verbal reasoning</td>
<td>Visual reasoning</td>
</tr>
<tr>
<td>Verbal and visual reasoning</td>
<td>Vocabulary learning</td>
<td>Speech production</td>
</tr>
<tr>
<td>Vocabulary learning</td>
<td>Word recognition</td>
<td></td>
</tr>
<tr>
<td>Literacy</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Arithmetic</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reading comprehension</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Listening comprehension</td>
<td></td>
<td></td>
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<tr>
<td>Ability to follow directions</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Note taking</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Writing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bridge playing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chess playing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Learning to program computers</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Verbal achievement</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Math achievement</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lexical-semantic abilities</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Orthographic abilities</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Complex learning</td>
<td></td>
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</tr>
<tr>
<td>Motor activity</td>
<td></td>
<td></td>
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<tr>
<td>Attentive behavior</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Verbal achievement</td>
<td>Math achievement</td>
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<tr>
<td></td>
<td>Math achievement</td>
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<tr>
<td></td>
<td>Phonological/ syntactic abilities</td>
<td></td>
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<tr>
<td></td>
<td>Attentive behavior</td>
<td>Attentive behavior</td>
</tr>
<tr>
<td></td>
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</tr>
</tbody>
</table>
WM Capacity

- Academic achievement
- Computer programming
- Reasoning/organizational ability
- Literacy
- Long-term memory retrieval
- Bridge & chess playing
- Writing; Note taking
- Following directions
- Complex learning
- Lexical-semantic abilities
- Reduced proactive interference
- General fluid intelligence
WISC-IV

IQ

$R^2 = .58$

WM

Previous Research

IQ

$R^2 = .22 - .81$

WM

IQ

5 Years

Working Memory

5 Years

Reading

$R^2 = .329$

Math

$R^2 = .453$

Spelling

$R^2 = .419$

Reading

ns

Math

ns

Spelling

Alloway and Gathercole, 2008 (Nature)
# Working memory impairments in children with ADHD

<table>
<thead>
<tr>
<th>WM Systems</th>
<th>WM Components</th>
</tr>
</thead>
<tbody>
<tr>
<td>VS Working Memory</td>
<td>PH Working Memory</td>
</tr>
<tr>
<td><strong>WM Systems</strong></td>
<td><strong>WM Components</strong></td>
</tr>
<tr>
<td><strong>Meta-analyses</strong></td>
<td></td>
</tr>
<tr>
<td>Martinussen et al. (2005)</td>
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<tr>
<td>Willcutt et al. (2005)</td>
<td>0.63</td>
</tr>
<tr>
<td>Brocki et al. (2008)</td>
<td>0.60</td>
</tr>
<tr>
<td>Martinussen &amp; Tannock, (2006)</td>
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<tr>
<td>Marzocchi et al. (2008)</td>
<td>1.00</td>
</tr>
</tbody>
</table>

**Trends:**
(a) Deficits in both systems/all three subcomponents
(b) Deficits in CE > VS > PH
Participants and Inclusion Criteria

- **Diagnostic Procedures**
  - Extensive child histories (pre, pari, post-natal; early developmental; medical; educational; psychiatric; parent/family)
  - K-SADS Semi-Structured Clinical Interview, Lifetime Version [parent and child interviewed separately]

- **Parent Rating Scales [ADHD factor in clinical range; DSM criteria]**
  - Child Symptom Inventory – 4 Parent Form (DSM-IV criteria)
  - Child Behavior Checklist – Parent Form (ADHD factor in clinical range)

- **Teacher Rating Scales [ADHD factor in clinical range; DSM criteria]**
  - Child Symptom Inventory – 4 Teacher Report Form (DSM-IV criteria)
  - Child Behavior Checklist – Teacher Report Form (TRF)
Phonological and Visuospatial
WM Deficits in boys with ADHD

ES = 1.89

(a)

ES = 2.31

(b)

Phonological WM

Visuospatial WM

*J of Abnormal Child Psychology*, 36, 825-837.
PH 3
VS 3

PH 4
VS 4

PH 5
VS 5

PH 6
VS 6

CE ES = 2.76

PH Storage/Rehearsal Performance Composite Score
PH ES = .55
[1.89 w/CE]

VS Storage/Rehearsal Performance Composite Score
VS ES = .89
[2.31 w/CE]

CE Performance Composite Score
[Gathercole & Alloway, 2008]
AGE: 5

ADHD

Central Executive

Articulatory Rehearsal

Spatial Rehearsal

Phonological Storage

Visual Storage

TYPICALLY DEVELOPING CONTROLS

Central Executive

Articulatory Rehearsal

Spatial Rehearsal

Phonological Storage

Visual Storage
To what extent do WM related phonological (PH) deficits reflect short-term storage as opposed to articulatory (covert) rehearsal deficiencies?

Phonological Working Memory

Central Executive

Auditory Input

Phonological Analysis

Phonological output buffer
Broca’s area-premotor cortex

Rehearsal Process

Visual Input

Visual analysis & STS

Orthographic to phonological recoding

Spoken Output

Baddeley, 2007
Contribution of Phonological Processing to other abilities

Auditory Input
- Phonological Analysis
  - Phonological STS
    - Inferior parietal lobe

Rehearsal Process
- Phonological output buffer
  - Broca’s area-premotor cortex

Spoken Output
- Left, temporo-parietal cortex (Jonides et al., 1998)
- Left, prefrontal region (Broca’s area) (Awh et al., 1996; Smith & Jonides, 1999)

Language Processing (Adams & Gathercole, 1995)
Math Achievement (Gathercole, Alloway, Willis, & Adams, 2006)
Reading Decoding and Reading Comprehension (Swanson & Howell, 2001)
Understanding Classroom Instructions (Gathercole & Alloway, 2008)
Phonological Memory Task

**Presentation Phase**
- 2-Words
- 4-Words
- 6-Words
- 21 distinct trials at each list length

**Storage/Rehearsal Phase**
- 3-seconds delay
- 12-seconds delay
- 21-seconds delay
- List length set based on each child’s span

**Recall Phase**

**Central Executive**
- Auditory Input
  - Phonological Analysis
    - Phonological STS
    - Inferior parietal lobe
    - Rehearsal Process
    - Phonological output buffer
    - Broca’s area-premotor cortex
    - Spoken Output
Each child is performing at their established memory span.

3 set size conditions at 3-s recall

- TD
- ADHD

~ 57% storage capacity deficit

**

Short-term storage capacity ES = 1.15 to 1.98
Articulatory rehearsal ES = .47 to 1.02
Are components of working memory functionally related to hyperactivity?

Working Memory Model of ADHD

Biological Influences (e.g., genetics)

Neurobiological Substrate

Environmental/Cognitive Demands

(Core Feature) Working Memory Deficits

(Secondary Features) Hyperactivity Inattentiveness Impulsivity

(Associated Features and Outcomes)
- Impaired
  - Cognitive Test Performance
  - Academic Achievement
  - Social Skills
  - Organizational Skills
  - Classroom Deportment
  - Delay Aversion
Mean Weekday Hourly Activity Scores

Porrino et al. (1983)
Arch Gen Psychiatry, 40, 681-687

Controls  $n = 12$

Hyperactives  $n = 12$

$* p < .05$
“Little evidence was found, however, to support the hypothesis that hyperactivity is simply an artifact of the structure and attentional demands of a given setting.” p.681

“… a substantial ubiquitous increase in simple motor behavior is a clear characteristic of this group.” p. 685

“In a variety of situations with differing degrees of structure and attentional demand, hyperactives showed consistently higher levels of motor movement than did their normal controls.” p. 686

Mean Hourly Activity Scores During the Week

Porrino et al., 1983

Overall Weekly Mean

Lunch/Recess

Reading

Mathematics

Physical Education

Controls

Hyperactives

$^*$ $p < .01$
DEPENDENT MEASURES AND TECHNIQUES

ACTIGRAPHS

- Ambulatory Monitoring, Inc. MicroMini Motionlogger®
- SETTING: Low PIM Mode [intensity of movement] [Proportional Integrating Measure]
- SAMPLING RATE = 16 samples per second collapsed into 1-minute epochs
- Placement: both ankles; non-dominant wrist
Experimental Design

- Phonological WM (21 consecutive trials) at 4 set sizes (3, 4, 5, 6) [programmed using SuperLab 2.0]

- Visuospatial WM (21 consecutive trials) at 4 set sizes (3, 4, 5, 6) [programmed using SuperLab 2.0]

- All tasks administered in counterbalanced order across 4-week Saturday assessment sessions.
Primary Hypothesis

- If activity level is functionally related to PH/VS subsidiary system processes, we would expect movement to vary systematically as greater demands are imposed on the storage/rehearsal systems.

- If activity level is functionally related to Central Executive processes, we would expect movement to increase from control (minimal CE or storage demands) to WM demand conditions, but not vary between set size conditions because no additional demands are placed on the CE when only the number of stimuli increase (i.e., no additional processing demands are imposed).
Activity Level Assessed During the PH and Control Conditions

Total extremity activity level (right foot, left foot, and non-dominant hand) expressed in PIM (Proportional Integrated Measure) units for children with ADHD (triangles) and typically developing children (circles) under control (C1, C2) and four phonological set size (PH 3, 4, 5, 6) working memory task conditions. Vertical bars represent standard error.

Computation of Hedges’ g indicated that the average magnitude difference between children with ADHD and TD children was 1.49 standard deviation units (range: 0.93 to 2.10).
Activity Level Assessed During the VS and Control Conditions

Hedges’ $g$ effect size indicated that the average magnitude difference in activity level between children with ADHD and TD children during visuospatial WM tasks was 1.83 standard deviation units (range=1.47 to 2.67).

Total extremity activity level (right foot, left foot, and non-dominant hand) expressed in PIM (Proportional Integrated Measure) units for children with ADHD (triangles) and typically developing children (circles) under control (C1, C2) and four visuospatial set size (VS 3, 4, 5, 6) working memory task conditions. Vertical bars represent standard error.
STEP 1:
PH, VS, and CE Performance Composite Scores

PH Storage/Rehearsal Performance Composite Score

VS Storage/Rehearsal Performance Composite Score

CE Performance Composite Score
Results indicated that PH functioning was *NOT* a significant contributor to objectively measured activity level (average $R^2 = .10$; values ranged from .06 to .21 and were all non-significant with one exception).

Results indicated that VS functioning was *NOT* a significant contributor to objectively measured activity level (average $R^2 = .07$; values ranged from less than .001 to .14 and were all non-significant).
Results indicated that CE functioning was a significant contributor of objectively measured activity level (average $R^2 = .32$; values ranged from .17 to .61; all $p \leq .04$).

An independent samples t-test on the derived CE-activity level variable indicated a significant between-group difference, $t(21)=7.54$, $p<0.0005$, with children with ADHD evincing higher rates of activity directly associated with CE functioning relative to TD children.

Hedges’ g effect size indicated that the average magnitude difference between children with ADHD and TD children was 3.03 standard deviation units ($SE=0.60$).
Activity Level Assessed During the PH and Control Conditions

Total extremity activity level (right foot, left foot, and non-dominant hand) expressed in PIM (Proportional Integrated Measure) units for children with ADHD (triangles) and typically developing children (circles) under control (C1, C2) and four phonological set size (PH 3, 4, 5, 6) working memory task conditions. Vertical bars represent standard error.
The 2 (group: ADHD, TD) by 2 (condition: C1, C2) Mixed-model ANOVA was non-significant for group, condition, and the group by condition interaction (all \( p \geq .52 \)), indicating that children with ADHD were not ubiquitously more motorically active than typically developing children during the clinical assessment after accounting for task-related WM demands.

Hedges’ \( g \) effect size indicated that the average magnitude difference between children with ADHD and TD children was 0.20 standard deviation units (SE=0.29), with a confidence interval that included 0.0.
Findings Summary

- All children are significantly more active when engage in tasks requiring working memory.

- Children with ADHD are significantly more active than TDs when engaged in tasks requiring WM.

- Children with ADHD are not significantly more active than typically developing children after controlling for the influence of WM [not ubiquitously hyperactive]

- Central Executive functioning (not storage/rehearsal) is functionally related to children’s activity level.

- Differences in children’s activity level during WM task may reflect underlying differences in arousal.
Working Memory Model of ADHD

Biological Influences (e.g., genetics)

Neurobiological Substrate

Environmental/Cognitive Demands

(Core Feature)
Working Memory Deficits

(Secondary Features)
Inattentiveness
Hyperactivity
Impulsivity

(Associated Features and Outcomes)
Impaired
• Cognitive Test Performance
• Academic Achievement
• Social Skills
• Organizational Skills
• Classroom Deportment
• Delay Aversion
Dependent Measures and Techniques

Noldus Observer

- Mutually exclusive Behavioral Codes
  - Oriented to task
    - Head is directed within $45^\circ$ vertically/horizontally of the center of the monitor.

- Observers
  - Two coders per tape
  - Observers pre-trained to exceed 80% agreement
  - Interrater reliability = .94; Kappa = .88
Hypotheses: Inattentiveness may be associated with any of the following deficiencies:

I. Deficient CE processes [internal focus of attention]

II. Exceeding child’s storage capacity [STS]

III. Deficiencies in both the CE and PH/VS storage capacity

IV. Ubiquitous inattentiveness unrelated to WM processes
Tier I: Attentive behavior and phonological memory load

- Group, set size, and group x set size: all $p < 0.0005$
- Post hocs:
  - TDC > ADHD across all conditions (all $p \leq 0.009$)
  - ADHD: Pre = Post > 3 = 4 > 5 = 6
  - TDC: Pre = Post > 3 = 4 = 5 > 6
  - Pre = Post ($p \geq 0.18$)
  - Hedges' $g = 1.55$ (SE = 0.42)

76% [24% off-task]
Table 2. Mean Off-task Rates, Standard Difference Scores, and Effect Sizes in Children with ADHD and Typically Developing Children

<table>
<thead>
<tr>
<th>Study</th>
<th>ADHD % Off-task M (SD)</th>
<th>Control % Off-task M (SD)</th>
<th>Std. Diff. Scores (%)</th>
<th>Hedges’ g Effect Sizes (Std. Error)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Werry &amp; Quay (1969)</td>
<td>46.3 (12.8)</td>
<td>23 (15.4)</td>
<td>50.3</td>
<td>2.09 (0.53)</td>
</tr>
<tr>
<td>Forness &amp; Esveldt (1975)</td>
<td>47.0 (16.5)</td>
<td>34 (12.4)</td>
<td>27.7</td>
<td>0.88 (0.30)</td>
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<tr>
<td>Sheket &amp; Sheket (1976)</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>0.00</td>
</tr>
<tr>
<td>Abikoff et al. (1977)</td>
<td>13.1 (10.0)</td>
<td>2.1 (2.6)</td>
<td>84.2</td>
<td>1.50 (0.21)</td>
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<tr>
<td>Campbell et al. (1978)</td>
<td>16.73 (15.15)</td>
<td>12.41 (10.88)</td>
<td>25.8</td>
<td>0.32 (0.35)</td>
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<tr>
<td>Jacob et al. (1978)</td>
<td>15.8 (NR)</td>
<td>10.5 (NR)</td>
<td>33.3</td>
<td>1.41 (0.53)</td>
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<tr>
<td>Klein &amp; Young (1979)</td>
<td>39.8 (9.0)</td>
<td>26.6 (5.0)</td>
<td>31.1</td>
<td>1.78 (0.40)</td>
</tr>
<tr>
<td>Abikoff et al. (1980)</td>
<td>15.1 (23.4)</td>
<td>4.1 (7.8)</td>
<td>72.8</td>
<td>0.62 (0.19)</td>
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<tr>
<td>Zentall (1980)</td>
<td>15.0 (NR)</td>
<td>7.1 (NR)</td>
<td>52.2</td>
<td>0.45 (0.25)</td>
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<td>Abikoff &amp; Gittelman (1984)</td>
<td>17.4 (12.3)</td>
<td>3.5 (6.6)</td>
<td>79.7</td>
<td>1.39 (0.29)</td>
</tr>
<tr>
<td>Abikoff &amp; Gittelman (1985)</td>
<td>15.7 (10.4)</td>
<td>2.5 (4.6)</td>
<td>84.1</td>
<td>1.71 (0.31)</td>
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<td>Atkins et al. (1985)</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>0.59 (0.30)</td>
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<td>Book &amp; Skee (1987)</td>
<td>5.11 (4.82)</td>
<td>0.78 (1.47)</td>
<td>84.7</td>
<td>1.21 (0.17)</td>
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<tr>
<td>Cunningham &amp; Siegel (1987)</td>
<td>33.0 (NR)</td>
<td>26.4 (NR)</td>
<td>19.9</td>
<td>0.51 (0.26)</td>
</tr>
<tr>
<td>Roberts (1990)</td>
<td>39.5 (18.8)</td>
<td>12.9 (20.9)</td>
<td>67.3</td>
<td>1.31 (0.39)</td>
</tr>
<tr>
<td>DuPaul &amp; Rapport (1993)</td>
<td>44.26 (16.56)</td>
<td>19.72 (11.56)</td>
<td>55.4</td>
<td>1.66 (0.31)</td>
</tr>
<tr>
<td>Lett &amp; Kamphaus (1997)</td>
<td>18.3 (16.5)</td>
<td>12.7 (12.7)</td>
<td>30.6</td>
<td>0.36 (0.29)</td>
</tr>
<tr>
<td>Nolan &amp; Gadow (1997)</td>
<td>30.5 (15.9)</td>
<td>13.3 (8.3)</td>
<td>56.4</td>
<td>1.34 (0.27)</td>
</tr>
<tr>
<td>DuPaul et al. (1998)</td>
<td>33.0 (19.2)</td>
<td>9.5 (11.9)</td>
<td>71.2</td>
<td>1.31 (0.45)</td>
</tr>
<tr>
<td>Skansgaard &amp; Burns (1998)</td>
<td>23.8 (10.3)</td>
<td>4.8 (6.1)</td>
<td>79.8</td>
<td>2.23 (0.60)</td>
</tr>
<tr>
<td>Solanto et al. (2001)</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>0.58 (0.19)</td>
</tr>
<tr>
<td>Abikoff et al. (2002)</td>
<td>10.6 (24.0)</td>
<td>3.3 (13.2)</td>
<td>68.8</td>
<td>0.38 (0.06)</td>
</tr>
<tr>
<td>Lauth &amp; Mackowiak (2004)</td>
<td>83.0 (12.0)</td>
<td>70.0 (13.0)</td>
<td>15.7</td>
<td>1.03 (0.20)</td>
</tr>
</tbody>
</table>

Column M (SD) = 28.15 (18.28) / 14.96 (16.47) / 54.65 (23.71) / 0.71 (0.04)

Best case estimation:
ES = 1.40

Tier I: Attentive behavior and visuospatial memory load

- Group, set size, and group x set size: all $p < .0005$
- Post hocs:
  - TDC > ADHD across all conditions (all $p \leq .009$)
  - ADHD: Pre = Post > 3 > 4 = 5 = 6
  - TDC: Pre = Post = 3 = 4 = 5 > 6
  - Pre = Post ($p \geq .18$)
  - Hedges’ $g = 1.45$ (SE = 0.42)
WM Components and Attentive Behavior
[2 (group) x 3 (conditions) mixed-model ANOVA]

ADHD % Oriented
TD % Oriented

Percent Oriented

ADHD % Oriented
TD % Oriented

CE: CE < CE = CE
(S/R Not Overwhelmed) (S/R Overwhelmed)
Hedges' g ES

Magnitude of Working Memory Deficits in ADHD

<table>
<thead>
<tr>
<th></th>
<th>PH WM (Rapport et al., 2008)</th>
<th>PH WM After Accounting for Inattentive Behavior</th>
<th>VS WM (Rapport et al., 2008)</th>
<th>VS WM After Accounting for Inattentive Behavior</th>
</tr>
</thead>
<tbody>
<tr>
<td>PH WM</td>
<td>1.9</td>
<td>1.1</td>
<td>2.3</td>
<td>1.5</td>
</tr>
<tr>
<td>VS WM</td>
<td></td>
<td></td>
<td>2.3</td>
<td>1.5</td>
</tr>
</tbody>
</table>

Hedges' g ES

PH WM

VS WM
Magnitude of Attention Deficits in ADHD

- Attention During PH Tasks
- Attention During PH Tasks After Accounting for WM Deficits
- Attention During VS WM Tasks
- Attention During VS Tasks After Accounting for WM Deficits
Summary

- Initial inattentiveness in ADHD reflects underlying deficits in CE processes – most likely the internal focus of attention.

- Exceeding WM storage capacity results in similar rates of inattentiveness in children with ADHD and typically developing children.

- WM deficits remain after accounting for between-group differences in inattentiveness.

- Between-group inattentiveness differences are no longer significant after accounting for WM differences.
Deficient WM systems/subsidiary systems & processes

Internal Focus ??
LTM interaction ??
Divided attention no

Central Executive

Auditory Input yes
Visual Input yes

Phonological Analysis

Phonological ES=.55
STS
Inferior parietal lobe

Visual analysis & STS

Orthographic to phonological recoding

Visual Input yes

Visuospatial Analysis ??

Visuospatial ES=.89
STS
Right hemisphere

Rehearsal Process

Phonological output buffer
Broca’s area-premotor cortex

Spoken Output

Rehearsal Process

Visuospatial output buffer
Right premotor cortex

Motor Output

ES=.55

ES=.89

ES=2.76