Executive functions and ADHD: The interplay between basic and translational research

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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)
1st line, Primary Treatments for children with ADHD:
[The enigma between near- and long-term outcome results following 50 years
of treatment]

- **Psychostimulants alone or combined with intensive packaged behavioral
treatment (parent training + classroom contingency management)**
  - Associated with large magnitude ES changes in core symptoms
  - ES range = 1.53 to 1.89 for attention and hyperactivity/impulsivity
  - Molina et al. [2009] MTA study; Rapport et al. [1994]

- **Psychosocial treatment alone**
  - Associated with more moderate ES benefits (ES range = .31 to .87)
  - Abikoff et al. [2004]; Lee et al. [2012]; van der Oord et al. [2008]

- **No significant gains relative to community-based ADHD treatment-as-
usual control children, and significantly worse relative to local normative
comparison children across a wide range of clinical, educational, and
interpersonal outcome measures** (Jensen et al., 2007; Molina et al., 2009).
Psychostimulants were discovered serendipitously by an astute physician noting improved concentration and reduced motor activity in children administered Benzedrine who suffered postpneumoencephalography headaches.

Pneumoencephalography is an obsolete medical procedure used during the early 20th century that involved draining most of the cerebrospinal fluid from around the brain and replacing it with air, oxygen, or helium to enhance x-ray imaging.

Contemporary parent and classroom contingency management (behavioral) therapies, in contrast, were appropriated from the widespread application of operant conditioning principles used to improve the functioning of individuals with moderate to profound developmental and/or intellectual disabilities beginning in the 1960s (for a historical review, see Bijou, 1966).
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

FIG. 2. The estimated three-factor model. Single-headed arrows have standardized factor loadings next to them. The loadings, all significant at the .05 level, are equivalent to standardized regression coefficients (beta weights) estimated with maximum likelihood estimation. The numbers at the ends of the smaller arrows are error terms. Squaring these terms gives an estimate of the variance for each task that is not accounted for by the latent construct. The curved, double-headed arrows have correlation coefficients next to them and indicate significant correlations between the latent variables.
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.
ADHD and working memory: Evaluating translational research from the trenches

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Empirical findings related to WM deficits in children with ADHD and their functional relationship with inattention, hyperactivity/impulsivity

Examining the extent to which current WM/Cognitive Treatments target these deficit areas (based on meta-analysis)
What is Working Memory?

- Working memory is a limited capacity system that enables individuals to store briefly and process information (Baddeley, 2007).

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
Alloway and Gathercole, 2008 (Nature)
Alan Baddeley’s (2007) WM Model

Shared Variance

Auditory Input
  → Phonological Analysis
  ↓
  → Phonological STS
  ↓
  → Phonological output buffer
  ↓
  → Spoken Output

Visual Input
  → Visual analysis & STS
  ↓
  → Orthographic to phonological recoding
  ↓
  → Visuospatial output buffer
  ↓
  → Motor Output

Central Executive

Visuospatial task
  → Visuospatial input process
  ↓
  → Visuospatial output buffer/rehearsal loop

Visuospatial task
  → Visuospatial input process
  ↓
  → Visuospatial output buffer/rehearsal loop

Visuospatial STS
  → Visuospatial STS
  ↓
  → Visuospatial output buffer

Inferior parietal lobe

Phonological output buffer
  → Broca’s area-premotor cortex

Phonological task
  → Phonological input process
  ↓
  → Phonological output buffer/rehearsal loop

Phonological analysis

Domain General:
Internal Focus of Attention
Divided Attn/set shifting
Interaction with LTM

Shared Variance

Input Process

Interaction with LTM

Central Executive

Input Process

Rehearsal Process

Interaction with LTM

Domain General:
Internal Focus of Attention
Divided Attn/set shifting
Interaction with LTM

Shared Variance

Input Process
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>
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<tr>
<td>- Writing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Bridge playing</td>
<td></td>
<td></td>
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<tr>
<td>- Chess playing</td>
<td></td>
<td></td>
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<tr>
<td>- Learning to program computers</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Verbal achievement</td>
<td>- Verbal achievement</td>
<td>- Math achievement</td>
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<tr>
<td>- Math achievement</td>
<td>- Math achievement</td>
<td></td>
</tr>
<tr>
<td>- Lexical-semantic abilities</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Orthographic abilities</td>
<td>- Phonological/ syntactic abilities</td>
<td></td>
</tr>
<tr>
<td>- Complex learning</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Motor activity</td>
<td>- Attentive behavior</td>
<td>- Attentive behavior</td>
</tr>
<tr>
<td>- Attentive behavior</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Example illustrating the differences between short-term (STM) and working memory (WM)
Short-term Memory

Remember the following 6 digits:

4 3 7 5 8 6
Mentally calculate the sum of the three digit number series below:

\[
\begin{array}{ccc}
4 & 3 & 7 \\
\underline{+} & 5 & 8 & 6 \\
1 & 0 & 2 & 3
\end{array}
\]
# Working memory impairments in children with ADHD

<table>
<thead>
<tr>
<th>WM Systems</th>
<th>WM Components</th>
<th>CE</th>
</tr>
</thead>
<tbody>
<tr>
<td>VS Working Memory</td>
<td>PH Working Memory</td>
<td>VS Storage/Rehearsal</td>
</tr>
<tr>
<td><strong>Meta-analyses</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Martinussen et al. (2005)</td>
<td>--</td>
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</tr>
<tr>
<td>Willcutt et al. (2005)</td>
<td>0.63</td>
<td>0.55</td>
</tr>
<tr>
<td>Brocki et al. (2008)</td>
<td>0.60</td>
<td>0.85</td>
</tr>
<tr>
<td>Martinussen &amp; Tannock, (2006)</td>
<td>--</td>
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</tr>
<tr>
<td>Marzocchi et al. (2008)</td>
<td>1.00</td>
<td>--</td>
</tr>
</tbody>
</table>

**Trends:**
(a) Deficits in both systems/all three subcomponents
(b) Deficits in CE > VS > PH
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
- 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
Development of Working Memory in Children: Peak Developmental Periods

Phonological (PH) WM Task

Children are instructed to recall the numbers in order from smallest to largest, and say the letter last.

Phonological Task

6 2 M 5

Verbal Response: 2, 5, 6, M

Correct Response Sequence

3, 4, 5, 6 stimuli sequences

Watch the following series of numbers and letter and re-arrange the stimuli based on these instructions
Visuospatial (VS) WM Task

Children are instructed to indicate the serial position of black dots in the order presented by pressing the corresponding squares on a computer keyboard, and indicate the position of the red dot last.

Visible spatial Task

<table>
<thead>
<tr>
<th>Black Dot 1</th>
<th>Black Dot 2</th>
<th>Red Dot</th>
<th>Black Dot 3</th>
<th>Correct Response Sequence</th>
</tr>
</thead>
</table>
| 3, 4, 5, 6 stimuli sequences
Participants and Inclusion Criteria

- **Diagnostic Procedures**
  - Detailed developmental 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], including onset, course, continuity of symptoms.

- **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)
Participants and Inclusion Criteria

- Other Child Measures and Inclusion/Exclusion Criteria
  - WISC-IV Full Scale Intellectual Evaluation
  - Kaufmann Test of Educational Achievement – 2nd Edition
  - Children’s Depression Inventory (CDI)
  - Revised Children’s Manifest Anxiety Scale (RCMAS)
  - For ADHD: onset prior to 7 years of age; moderate to severe impairment across multiple settings; not better accounted for by other Dx or illness.
  - Comorbidity allowed for ODD
A Child Assessment requires the following:

- Detailed developmental history (includes pre/pari/postnatal, medical, social, education, family psychiatric & medical histories) 1-1.5 hr Parent
- K-SADS semi-structured interview with parent and child 3 hr Parent
- WISC-IV (full IQ battery) with child 4 hr Child
- KTEA (full achievement battery) with child 3 hr Child
- CBCL, CSI-P (Child Symptom Inventory), Barkley HSQ 1 hr Parent
- TRF and CSI-T 1 hr Teacher
- Additional Clinical Scales (CDI, Manifest Anxiety Scale, Behavioral/physical Complaints Scale) 1 hr Child
- 4, 3-hour assessment sessions, once per week x 4 consecutive weeks (Saturdays) – requires 6 adults 72 hr CLC
- Protocol scoring and data input 4 hr CLC
- Noldus Observer observations (per child) 24 hr CLC
- Case conceptualization and written report 8 hr CLC
- Parent debriefing 1.5 hr CLC 124 hours total per child

n = 30-40 require 3720 to 4960 total hours
[excluding the r/o participants who fail to meet dx criteria]
Phonological and Visuospatial WM Deficits in boys with ADHD

*J of Abnormal Child Psychology, 36*, 825-837.
CE Performance Composite Score

PH, VS, and CE Performance Composite Scores

PH Storage/Rehearsal Performance Composite Score

**Central Executive ES = 2.76**

VS Storage/Rehearsal Performance Composite Score

2.76 CE ES indicates an .89 to .93 probability that you could guess which group the child was from

PH ES = .55 [1.89 w/CE]

VS ES = .89 [2.31 w/CE]
The Development of Phonological Working Memory Processes in Children with ADHD [223] and TD [223]

[Shaw, NIMH Study Group, 2007]
To what extent do WM related phonological (PH) deficits reflect short-term storage as opposed to articulatory (covert) rehearsal deficiencies?

Contribution of Phonological Processing to other abilities

- 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)

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
Phonological Memory Task

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

Storage/Rehearsal
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 1
Phonological output buffer
Broca’s area-premotor cortex
Spoken Output
Stimuli Recalled Correctly

Each child is performing at their established memory span

3 set size conditions at 3-s recall

Stimuli (words)

Stimuli Recalled Correctly

% Correct

Seconds

Short-term storage capacity ES = 1.15 to 1.98
Articulatory rehearsal ES = .47 to 1.02

~ 57% storage capacity deficit

~ 30% of words learned or .5 SD per 9-s

TD
ADHD

Each child is performing at their established memory span

TD
ADHD

**
ns
**

ns

**

~ 57% storage capacity deficit

~ 30% of words learned or .5 SD per 9-s

TDs lose ~ 10% of words learned
ADHDs lose ~ 30% of words learned
Are components of working memory functionally related to inattention?

Phonological (PH) WM Task

Children are instructed to recall the numbers in order from smallest to largest, and say the letter last.

3, 4, 5, 6 stimuli sequences

Watch the following series of numbers and letter and re-arrange the stimuli based on these instructions.
Tier I: Attentive behavior and phonological 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
  - TDC: Pre = Post > 3 = 4 > 5 > 6
  - Pre = Post ($p \geq .18$)
  - Hedges’ $g = 1.55$ (SE = 0.42)
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>Fiumesi &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>
</tr>
<tr>
<td>Self &amp; Self (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>
</tr>
<tr>
<td>Campbell et al. (1978)</td>
<td>10.7 (15.1)</td>
<td>12.4 (10.8)</td>
<td>25.8</td>
<td>0.32 (0.15)</td>
</tr>
<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>
</tr>
<tr>
<td>Klein &amp; Young (1979)</td>
<td>39.8 (9.0)</td>
<td>26.5 (5.0)</td>
<td>33.1</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>
</tr>
<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>
</tr>
<tr>
<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>
</tr>
<tr>
<td>Atkins et al. (1985)</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>0.59 (0.30)</td>
</tr>
<tr>
<td>Boek &amp; Skren (1987)</td>
<td>5.11 (4.82)</td>
<td>0.78 (1.47)</td>
<td>84.7</td>
<td>1.21 (0.17)</td>
</tr>
<tr>
<td>Cunningham &amp; Siegel (1987)</td>
<td>33.0 (NR)</td>
<td>26.4 (NR)</td>
<td>39.9</td>
<td>0.31 (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>Lenn &amp; Kamphuis (1997)</td>
<td>18.3 (16.5)</td>
<td>12.7 (12.7)</td>
<td>30.6</td>
<td>0.36 (0.29)</td>
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<tr>
<td>Nolan &amp; Gadou (1997)</td>
<td>30.5 (15.9)</td>
<td>13.3 (8.3)</td>
<td>56.4</td>
<td>1.34 (0.27)</td>
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<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>Skoogaard &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>
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<td>Solanto et al. (2001)</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>0.58 (0.19)</td>
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<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)
Magnitude of Working Memory Deficits in ADHD

PH WM (Rapport et al., 2008)
PH WM After Accounting for Inattentive Behavior
VS WM (Rapport et al., 2008)
VS WM After Accounting for Inattentive Behavior

Hedges' g ES

PH WM

1.9
1.1

VS WM

2.3
1.5
Magnitude of Attention Deficits in ADHD

- **PH Attn**
  - Attention During PH Tasks: 1.6
  - Attention During PH Tasks After Accounting for WM Deficits: 0.0

- **VS Attn**
  - Attention During VS WM Tasks: 1.5
  - Attention During VS Tasks After Accounting for WM Deficits: 0.0
Are components of working memory functionally related to hyperactivity?

Mean Weekday Hourly Activity Scores

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

- Controls  $n = 12$
- Hyperactives  $n = 12$
- $p < .05$

Mean Activity Counts Per Hour

Hour

Mean Activity Counts Per Hour

1 5 10 15 20 24
Is Movement Functional in Animals?
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
Activity Level Assessed During the PH and Control Conditions

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).

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.
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.
WORKING MEMORY  MODEL OF ADHD

Biological Influences, e.g., genetics

NEUROBIOLOGICAL SUBSTRATE

CORE FEATURES: INATTENTION HYPERACTIVITY IMPULSIVITY

ENVIRONMENTAL/COGNITIVE DEMANDS

SECONDARY FEATURES

Rapport et al., 2001
**Biological Influences** (e.g., genetics)

**Neurobiological Substrate**

**Environmental/Cognitive Demands**

**Core Feature**

**Working Memory Deficits**

**Secondary Features**

Inattentiveness
Hyperactivity
Impulsivity

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

**Far Transfer Effects?**

**Far Transfer Effects?**
To what extent have experimental research findings translated into the development of WM cognitive Interventions for children with ADHD?

A Meta-Analytic Review
Cognitive training meta-analysis

• 3-tier literature search
  – **Tier I**: PsycInfo, PsycArticles, PsycBooks, ERIC, Medline, Dissertation Abstracts International, and Social Science Citation Index
  – **Tier II**: Backwards search
    • Studies cited by included studies
  – **Tier III**: Forward search
    • Newer studies citing included studies
Cognitive training meta-analysis

• **Inclusion criteria**
  – English language
  – Children with ADHD or low working memory
  – At least one cognitive training intervention, with or without one or more control conditions
  – Sufficient data from which effect sizes could be computed, or author responses to queries for data
    • \( K = 8 \) studies whose authors responded with data

• **Exclusion criteria**
  – Participants with gross neurological, sensory, or motor impairment, history of a seizure disorder, or psychosis
  – Children with estimated IQ below 80
  – Cognitive interventions that focused on instructions/strategies rather than training specific CE or subsystem related abilities
Cognitive training meta-analysis

- $K = 26$ studies
- Random effects models (Hunter & Schmidt, 2004) corrected for publication bias (Duval & Tweedie, 2000)
- Hedges’ $g$ effect sizes
  - Cohen’s $d$ effect sizes corrected for the upward bias of small N studies

<table>
<thead>
<tr>
<th>Effect size magnitude</th>
<th>Label</th>
<th>Interpretation (Cohen, 1988)</th>
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<tbody>
<tr>
<td>0.2</td>
<td>Small</td>
<td>Detectable only with statistics</td>
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<tr>
<td>0.5</td>
<td>Medium</td>
<td>Detectable to a careful observer</td>
</tr>
<tr>
<td>0.8</td>
<td>Large</td>
<td>Obvious to any observer</td>
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</table>
Cognitive training meta-analysis

- **Primary analyses**: Comprehensive Meta-Analysis (v2.2) software
- **Moderator analyses**: Lipsey & Wilson (2001) meta-analysis macros for SPSS using random/mixed effects
  - Random effects models with inverse variance weighting
<table>
<thead>
<tr>
<th>Author</th>
<th>Year</th>
<th>Program</th>
<th>Areas Targeted</th>
<th>Control Type</th>
<th>n</th>
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<tr>
<td>Beck et al.</td>
<td>2010</td>
<td>CogMed</td>
<td>STM</td>
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<td>Captain’s Log</td>
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<td>2012</td>
<td>Other</td>
<td>Mixed EF</td>
<td>None</td>
<td>24</td>
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</tbody>
</table>
Desirable Effects associated with Cognitive Training

[Near and Far Transfer; Immediate and Long-term]

**Near Transfer:** increased performance on tasks that are highly similar to the tasks used during training (e.g., training on verbal STM tasks such as digits transfer to being able to recall lists of verbally mediated information such as instructions or strings of numbers).

**Far Transfer:** increased performance on tasks that share or are dependent upon an underlying processing component (e.g., memory updating, task switching) that are not of the same nature or appearance as those used during training (improved performance on fluid IQ measures or improved math/reading achievement & reduced inattentiveness and hyperactivity following WM training).
Meta Analytic Results \([k = 26]\)

**Near Transfer Effects**

- \(k = 18\)
- \([\text{Pre-post ES} = .81]\)
- \(k = 4\)
- Pre to LT follow-up

**Far Transfer Effects**

- \(k = 26\)
- \(k = 11\)
- Pre to LT follow-up

Post Rx ES

- \(k = 5\) \(\cdot .45^*\)
- \(k = 10\) \(\cdot .40^*\)
- \(k = 10\) \(\cdot .45^*\)

3-6 month post ES

- \(ns\)
- \(\cdot .69^*\)
- \(ns\)
**Meta Analytic Results**

**Far Transfer Objective Effects**
- $k = 18$
- Post Rx ES: $0.33^*$
- 3-6 month post ES: ns

**Far Transfer Un-blinded Rater Effects**
- $k = 15$
- Pre to LT follow-up:
  - $k = 6$: $0.51^*$
  - ns

**Far Transfer Blinded Rater Effects**
- $k = 9$
- Pre to LT follow-up:
  - $k = 2$: ns

**Subjective Measures**
- $k = 2$
- Pre to LT follow-up: ns
Summary

1. Current cognitive treatments are associated with moderate magnitude ES changes in WM but limited to near transfer domains (i.e., improved STM) – larger magnitude effects are associated with more training (minutes).

2. Small magnitude (unobservable) ES changes are reported for far transfer measures but associated with un-blinded ratings for most studies – the inclusion of appropriate control groups is associated with even smaller magnitude ES changes in far transfer measures.

3. Current cognitive interventions have ignored the findings of basic research by targeting the least impaired aspects of WM deficits in ADHD (i.e., the short-term passive stores).

4. The ‘on-line’ claims of cognitive interventions are unsupported by the meta-analytic review results:
   a. “Cogmed training improves attention, concentration, focus, impulse control, social skills, and complex reasoning skills by substantially and lastingly improving working memory capacity.” (www.cogmed.com/)
Recommendations

1. **Innovative Treatments:**
   a. Focus on improving central executive (CE) processes
   b. Include practice for holding information (covert rehearsal) for successively longer time intervals
   c. Focus on promoting far transfer effects

2. **Experimental:**
   a. Randomized controlled trials are needed that include credible adaptive training placebo control conditions
   b. Include multiple measures of near- and far-transfer that are ecologically meaningful to children’s educational, clinical, and interpersonal function