Attention-deficit/ hyperactivity disorder (ADHD)

Outline:

- ❑ History and Background Information
- ❑ DSM-5 Clinical Model of ADHD – basic assumptions
- ❑ Initial formulation of the functional WM model of ADHD
- ❑ Baddeley's WM model as an experimental paradigm
- ❑ WM components implicated as core deficits in ADHD
- ❑ Hyperactivity and Inattention as secondary features of ADHD

"He who loves practice without theory is like the sailor who boards ship without a rudder and compass and never knows where he may cast" Leonardo da Vinci (1452-1519)

Pre-twentieth Century

493 BC

- Hippocrates described patients with "quickened responses to sensory experience, but also less tenaciousness because the soul moves on quickly to the next impression".
  - Condition attributed to an "overbalance of fire over water".
  - Remedy: "barley rather than wheat bread, fish rather than meat, water drinks, and many natural and diverse physical activities."

Circa 1600

- Shakespeare referred to a "malady of attention" in one of his characters in King Henry VIII.

Mid 1800s

- Heinrich Hoffman, a German physician, penned the poem "Fidgety Phil".
- Figety Phil

1890

- William James, in his Principles of Psychology text (1890), described a normal variant of character which he called the "Explosive Will":
- "… impulses seem to discharge so promptly onto movements that inhibitions get no time to arise. These are the 'dare-devil' and 'mercurial temperaments, overflowing with animation, and fizzling with talk" (p.800).

Twentieth Century

1902

English physician George Still (1902) reported on a group of children in his clinical practice whom he defined as having a deficit in "volitional inhibition" or a "defect in moral control" over their behavior.

- Their behavior was described as aggressive, passionate, lawless, inattentive, impulsive, and overactive.
- An over-representation of male subjects (3:1).
- An aggregation of alcoholism, criminal conduct, and depression among the biological relatives.
- A familial predisposition to the disorder – hereditary.

Minimal Brain Damage/Dysfunction

Interest in children with similar characteristics arose in North America around the time of the encephalitis epidemic of 1917-1918.

- Children surviving these brain infections were noted to have many behavioral problems similar to ADHD.
- These cases and others known to have arisen from birth trauma, head injury, toxin exposure, and infections gave rise to the concept of a brain-injured child syndrome (Strauus & Lehtinen, 1947).

Minimal Brain Damage/ Dysfunction

- The brain-injured child syndrome eventually was applied to children manifesting these same behavior features but without evidence of brain damage or retardation.
- This concept would later evolve into the concept 'minimal brain damage', and eventually 'minimal brain dysfunction' (MBD), owing to the dearth of evidence of brain injury in most cases (Dolphin & Cruickshank, 1951; Strauus & Kephardt, 1955).

Hyperkinetic

- During the 1950's, greater attention was paid to the specific behaviors of hyperactivity and impulsivity resulting in the label "hyperkinetic impulse disorder." The disorder was attributed to poor thalamic filtering of stimuli entering the brain (Laufer, Denhoff, & Solomons, 1957) and eventually termed the "hyperactive child syndrome" (Chess, 1960).
- The influence of psychoanalytic thought at the time held sway when the DSM-II appeared and all childhood disorders were described as "reactions" – the hyperactive child syndrome became "hyperkinetic reaction of childhood" (DSM-II, 1968).

Hyperkinetic Reaction of Childhood DSM-II (1968)

Characterized by overactivity, restlessness, distractibility and short attention span, especially in young children; the behavior usually diminishes in adolescence.

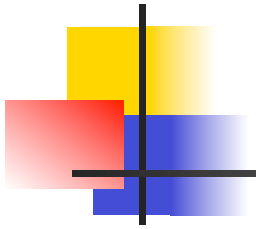
- **Definition included problems of attention and distractibility along with those of hyperactivity/ restlessness.**
- **The condition was assumed to be developmentally benign and not caused by brain damage - resulting in a departure from European thinking.**

Attention

By the 1970s, research emphasizing the importance of problems with sustained attention and impulse control in addition to hyperactivity was emphasized (Douglas, 1972).

Douglas (1980; 1983) theorized that the disorder was comprised of four major deficits:

- **The investment, organization, and maintenance of attention and effort.**
- **The ability to inhibit impulsive behavior.**
- **The ability to modulate arousal levels to meet situational demands.**
- **An unusually strong inclination to seek immediate reinforcement.**



Douglas's work coupled with numerous studies of attention, impulsiveness, and other cognitive sequelae resulted in the DSM-III (1980) moniker, Attention Deficit Disorder (ADD).

- **Psychoanalytic perspective discarded.**
- **Cognitive-developmental nature emphasized.**
- **Symptom lists, cutoff scores recommended.**
- **Polythetic categorization scheme (3 major symptom groupings required for a diagnosis).**
- **Distinction between "with" and "without" hyperactivity.**

Attention-Deficit/Hyperactivity Disorder (DSM-III-R; 1987)

Hyperactivity and impulsivity

Needed to:

- **Differentiate the disorder from other conditions, and**
- **Predict developmental risks (Weiss & Hechtman, 1993).**

Monothetic categorization scheme (14 symptoms - 1 list)

ADD without hyperactivity replaced with undifferentiated Attention Deficit Disorder based on insufficient research.

Attention-Deficit/Hyperactivity Disorder (DSM-IV, 1994)

Three (3) subtypes of ADHD (predominantly inattention; predominantly hyperactivity-impulsive; and combine type).

- **Hyperactivity-Impulsive Type appears to be a developmental precursor to the combined type.**
- **Hyperactive-Impulsive Type was comprised primarily of preschool children (DSM-IV field trials).**
- **Combined Type and Inattentive Type were comprised primarily of school-age children.**

The Hyperactive-Impulsive behavior pattern seems to emerge first in development during the preschool years, whereas symptoms of "inattention" associated with it appear to have their onset several years later (Loeber et al., 1992; Hart et al., 1995).

Attention-Deficit/Hyperactivity Disorder (DSM-IV, 1994)

Research began demonstrating that deficits were not limited to the attentional domain.

- **Problems with motivation and insensitivity to response consequences were emphasized (poor performance under partial reward and extinction - Douglas, 1980s).**
- **Deficient "rule governed" behavior was hypothesized by Barkley (1981; 1989).**
- **Information processing paradigms failed to demonstrate that poor performance was due to attentional difficulties vs motivation and response inhibition (Sergeant, 1988).**
- **Factor analytic studies failed to differentiate hyperactivity and impulsivity domains (loaded together as 1 factor).**

Nomenclature

493 BC	Overbalance of fire over water (Hippocrates)
1890	Explosive Will (James)
1902	Volitional Inhibition
	Deficit in Moral Control (Still)
c. 1918	Brain Injured Child Syndrome (Strauus & Lehtinen)
1940s	Minimal Brain Damage (Dolphin & Cruikshank)
	Minimal Brain Dysfunction (Strauus & Kephardt)
1950s	Hyperkinetic Impulse Disorder (Laufer, Denhoff, & Solomons)
1960	Hyperactive Child Syndrome (Chess)
1968	Hyperkinetic Reaction of Childhood (DSM-II)
1980	Attention Deficit Disorder (DSM-III)
1987	Attention-Deficit/Hyperactivity Disorder (DSM-III-R, DSM-IV, DSM-IV-TR, DSM-5: classified as a neurodevelopmental disorder)

Evolution of the DSM

Laufer & Denhoff (1957)	DSM-III (1980)	DSM-III-R (1987)	DSM-IV(1994)
Hyperkinetic Syndrome	Attention-Deficit Disorder	ADHD	ADHD
Inattention	Inattention	Inattention	Inattention Subtype
Impulsivity	Impulsivity	Impulsivity	H/I Subtype
Hyperactivity	Hyperactivity (W/O)	Hyperactivity	H/I Subtype
Concentration	Concentration	Concentration	Concentration
Variability	Variability	Variability	Variability
Poor Delay	Poor Delay	Poor Delay	Poor Delay
Irritability			
Explosiveness	Explosiveness	Explosiveness	Explosiveness
Academic Probs	Academic Probs	Academic Probs	Academic Probs
	Disorganized	Disorganized	Disorganized
	Negativism		
	Bossiness		Bossiness
	Bullying		
	Mood Lability	Mood Lability	Mood Lability
	Low Self-Esteem	Low Self-Esteem	Low Self-Esteem
	Discipline Probs	Discipline Probs	Discipline Probs
		Peer Difficulties	Peer Difficulties
		Easily Distracted	Easily Distracted
			Dysphoria
			Not Situational
			R/O Other Disorders
	Polythetic Categorization [multiple lists]	Monothetic Categorization [single list]	Polythetic Categorization [multiple lists]

Attention-Deficit/Hyperactivity Disorder (DSM-IV, 1994) continued

- Types of problems with "inattention" seen in the Inattentive Type appear to have their onset even later than those associated with hyperactive-impulsive behavior (Barkley, 1996).
- Implications:
  - Attentional impairment associated with the Predominantly Inattentive Type may be different from those seen in the other two types.
  - Inattentive Type symptoms: daydreaming, spacing out, in a fog, easily confused, staring frequently, lethargic, hypoactive, and passive. [DAMP: developmentally delayed attention, motor and perceptual abilities]
  - Inattentive Type also appears to have deficits in speed of information processing & focused or selective attention (Goodyear & Hynd, 1992; Lahey & Carlson, 1992).
  - Combined Type deficits are characterized as consisting of sustained attention (persistence) and distractibility difficulties.

Attention-Deficit/Hyperactivity Disorder (DSM-IV, 1994) continued

- Implications (Continued):
  - Current clinical view of ADHD may be clustering two qualitatively different disorders into a single set of disorder.
  - Children with ADHD Combined Type who move into the Inattentive Type (owing to developmental reduction in hyperactivity) as they get older are not actually changing types of ADHD; Their attentional problems should still be distinct (poor persistence, distractibility) from those seen in the Inattentive Type.

DSM-5 Criteria: 6 of 9 Inattention Symptoms

- fails to give close attention to details
- difficulty sustaining attention
- does not seem to listen
- does not follow through on instructions
- difficulty organizing tasks or activities
- avoids tasks requiring sustained mental effort
- loses things necessary for tasks
- easily distracted
- forgetful in daily activities

DSM-5 Criteria: 6 of 9 Hyperactive-Impulsive

- fidgets with hands or feet or squirms in seat
- leaves seat in classroom inappropriately
- runs about or climbs excessively
- has difficulty playing quietly
- is “on the go” or “driven by a motor”
- talks excessively
- blurts out answers before questions are completed
- has difficulty awaiting turn
- interrupts or intrudes on others

Other DSM-5 Criteria

- Developmentally Inappropriate Levels
- Duration of 6 Months
- Cross-setting Occurrence of Symptoms
- Impairment in Major Life Activities
- Onset of Symptoms/Impairment by 7
- Exclusions: Severe MR, Psychosis
- Subtyping into Inattentive, Hyperactive, or Combined Types

Unresolved Problems with DSM-5 Criteria

- Symptoms are not developmentally scaled
  - Need more appropriate items for adults
- Cutoffs are not developmentally referenced
  - May have to adjust thresholds if > 16 or < 4 yrs.
- Cutoffs not sex-referenced (lower for girls)
- Duration may be too short for preschoolers
  - Consider adjusting upward to 1 year
- Age of onset of 7 has no validity (childhood)
- Developmental deviance undefined (93%??)
- Implies need for parent-teacher agreement
  - Blend reports and use history of cross setting impairment
- No requirement for corroboration by others (adults)

ADHD - Inattentive Type

- Daydreaming/Spacey/Stares
- Slow Information Processing
- Hypoactive/Lethargic/Sluggish
- Easily Confused, Mentally “Foggy”
- Poor Focused/Selective Attention
- Erratic Retrieval - Long-Term Memory
- Socially Reticent/Uninvolved

ADHD Inattentive Type (2)

- Rarely Aggressive or ODD/CD
- Not Impulsive (By Definition)
- Less Likely to Have a Clinically Impressive Response to Stimulants (65% improve but only 20% show clinical response)
- Possibly Greater Family History of Anxiety Disorders and LD (?)

Inattentive Type is a New Disorder

- Focus on sluggish cognitive tempo
- Will not have same course and risks
- Probably requires different interventions
- Need to distinguish it from:
  - Sub-threshold Combined Type
  - Central Auditory Processing Disorder
  - Situational Stress Events or PTSD
  - Schizophrenic Spectrum Disorders
  - Learning Disabilities
  - Anxiety Disorders or Depression
  - Substance Use/Abuse Disorder

Beck et al. (2016) Sluggish Cognitive Tempo

- Sluggish
- Tired/lethargic
- Slow thinking/processing cognitive set
- Sleepy/drowsy
- Spacey
- In a fog
- Underactive/slow moving
- Daydreams
- Lost in thoughts
- Stares blankly
- Easily confused
- Apathetic / unmotivated
- Easily bored

[items with high factor loadings]

Prevalence (United States)

- Varies by gender, age, social class, & urban-rural (population density)
- 5-73% of children
- 4.7% of adult population (DSM-IV - All Types) (3.4% Combined/Hyper. Types)
- 3:1 males:females (community samples)
  - 5:1 to 9:1 (clinical samples)

Prevalence (Internationally)

- Canada (Montreal): 3.8-9.4% kids (DSM-III-R)
- Australia: 3.4% of kids (DSM-III-R)
- New Zealand: 6.7% kids, 2-3% teens (DSM-III-R)
- Germany: 4.2% children (ICD-9)
- India: 5-29% children (DSM-III)
- China: 6-9% children (DSM-III-R)
- Netherlands: 1.3% teens (DSM-III-R)
- Puerto Rico: 9.5% child & teens (DSM-III)
- Japan: 7.7% children (DSM-III-R ratings)
- Colombia: 2-13% (DSM-IV ratings)
- Brazil: 5.8% of 12-14 year olds (DSM-IV)

Persistence of Disorder

- Evaluated via structured interviews (DSM-based)
  - Symptoms Decrease (graph)
  - Adolescence: (Based on parent reports)
    - 50% persistence to adolescence (1970-80s)
    - 70-80% in modern DSM studies (1990s onward)
  - Young Adulthood (age 20-26) (Barkley et al. in press)
    - Depends on who you ask (self vs. parents)
    - 3-8% Full disorder (self-report using DSM3R)
    - 46% Full disorder (parent reports using DSM3R)
    - 12% - Using 98th percentile (+ 2SDs; self-report)
    - 66% - Using 98th percentile (parent report)
    - Parent reports correlate more highly with various domains of major life activities than do self reports

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Etiologies - Heredity/Genetics

- Family Aggregation of Disorder:
  - 25-35% of siblings - 55-92% of identical twins
  - 15-20% of mothers- 25-30% of fathers
  - If parent is ADHD, 20-54% of offspring
- Twin Studies of Heritability:
  - Heritability = 57-97% (Mean 80%+; 95%+ if DSM)
  - Shared Environment = 0-6% (Not significant)
  - Unique Environment = 15-20%
- Molecular Genetics (DRD4, DAT1, DBH?)

Etiologies: Food Allergies & Miscellaneous Factors

- Sugar (Disproven)
- Hyper/hypoglycemia (No evidence)
- Food Allergies (Largely Disproven)
  - Possibly 5% of ADHD Preschoolers react adversely to high doses of food additives
- Side Effects of Anticonvulsants (10-35%)
  - mainly to phenobarbital and dilantin
- Thyroid abnormalities (unlikely)
  - Rare in children
  - Evidence is conflicting

Comorbid DSM-IV Disorders

As assessed by DSM-based structured interviews (e.g. Kiddie SADS, DISC-P)

- Oppositional Defiant Disorder (40-67%)
- Conduct Disorder (20-56%)
- Delinquent/Antisocial Activities (18-30%)
- Anxiety Disorders (10-40%; partly referral bias!)
  - Related more to poor emotion regulation than to fear
- Major Depression (0-45%; 27% by age 20)
- Bipolar Disorder (0-27%)
  - Not documented in any follow-up studies to date

Childhood Developmental Risks

- Language Disorders (Expressive: 10-54%
  Pragmatic deficits in 60% (Language tests)
- Central Auditory Processing Disorder (45-75%)
  - (Audiological examination and language processing tests)
- Developmental Coordination Disorder (50+%)
  - (Motor development tests, e.g. Lincoln-Oseretsky)
- Reduced Physical Fitness, Strength, & Stamina (Standard physical fitness tests)
- Accident Proneness (parental reports)
  - 1.5 to 4x risk of injuries (non-head) (28 vs. 6% in Worcester 4-6 year olds) (greater in ODD subset)
  - 3x risk for accidental poisonings (23 vs. 7.7% of clinic referrals; 7.3 vs. 2.3% in community)

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

Social-Emotional Impairments

Assessed via parent ratings, peer sociometrics, and videotaped interactions of ADHD children with others

- Increased parent-child conflict & stress
  - especially ODD/CD subgroup
- Peer Relationship Problems (50%+)
  - Less sharing, cooperation, turn-taking
  - More talking, commanding, intrusive, hostile
  - Most serious in ODD/CD subgroup
- Poor Emotional Control
  - More anger, frustration, hostility (ODD/CD)
  - Less self-regulation of emotional states

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)

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Psychiatric Disorders (age 20-26)

- ODD (12%+ by self-report) (Not Significant)
- Conduct Disorder (26%+ by self-report)*^
- Depression (27%)^ (not found in other studies)
- Substance Use/Abuse Disorders (10-24%)^
  - Greater Use of Alcohol, Tobacco, and Marijuana
  - Milwaukee Study: Not different from controls due to elevated drug use among controls
- Personality Disorders:

  - Antisocial (11-21%)*^
  - Passive Aggr. (18%)*^
  - Histrionic (12%)^
  - Borderline (14%)*^
  - *=greater risk if elevated child conduct problems
  - ^=greater risk if CD at adulthood

Educational Outcomes (ages 20-25)

Assessed by self-report and high school transcripts:

- More grade retention (25-45%; MKE: 42 vs. 13)
- More are suspended (40-60%; MKE: 60 vs. 19)
- Greater expulsion rate (10-18%; MKE: 14 vs. 6)
- Higher drop out rate (30-40%; MKE 32 vs 0)
- Lower Class Ranking (MKE: 69% vs. 50%)
- Lower GPA (MKE: 1.7 vs. 2.6)
- Fewer enter college (MKE: 22 vs. 77%)
- Lower college graduate rate (5 vs. 35%)

MKE = Milwaukee Young Adult Outcome Study

Employment Problems

- More likely to be fired
  - (MKE: 55 vs. 23%; Mean 1.1 vs. 0.3 jobs)
- Change jobs more often (MKE: 2.7 vs. 1.3 over 2-8 years since leaving high school)
- More ADHD/ODD symptoms on the job
  - As rated by current supervisors (MKE)
- Lower work performance ratings
  - As reported by current supervisors (MKE)
- Lower social class (SES) (Hollingshead System)
- By 30s, 35% self-employed (NY Study)

Motor Vehicle Driving Risks

Assessed via self-report, driving records, lab testing, driving simulators, and BTW tests (Barkley studies)

- Poorer steering, more false braking, and slower reaction times to significant events
- Rated as using fewer safe driving habits
- More likely to drive before licensing
- More accidents (and more at faults) (2-3 vs. 0-2)
  - % with 2+ crashes: 40 vs. 6
  - % with 3+ crashes: 26 vs 9
- More citations (Speeding - mean 4-5 vs. 1-2)
- Worse accidents ($4200-5000 vs $1600-2200)
  - (% having a crash with injuries: 60 vs 17%)
- More Suspensions/Revocations (Mean 2.2 vs 0.7)
  - (% suspended: 22-24 vs. 4-5%)

Sexual-Reproductive Risks

Assessed via self-reports: (MKE study)

- Begin Sexual Activity Earlier (15 vs 16 yrs.)
- More Sexual Partners (18.6 vs. 6.5)
- Less Time with Each Partner
- Less Likely to Employ Contraception
- Greater Risk of Teen Pregnancy (38 vs. 4%)
- Ratio for Number of Births (42:1)
  - 54% Do Not Have Custody of Offspring
- Higher Risk for STDs (16 vs. 4%)

Etiologies - Heredity/Genetics

- Family Aggregation of Disorder:
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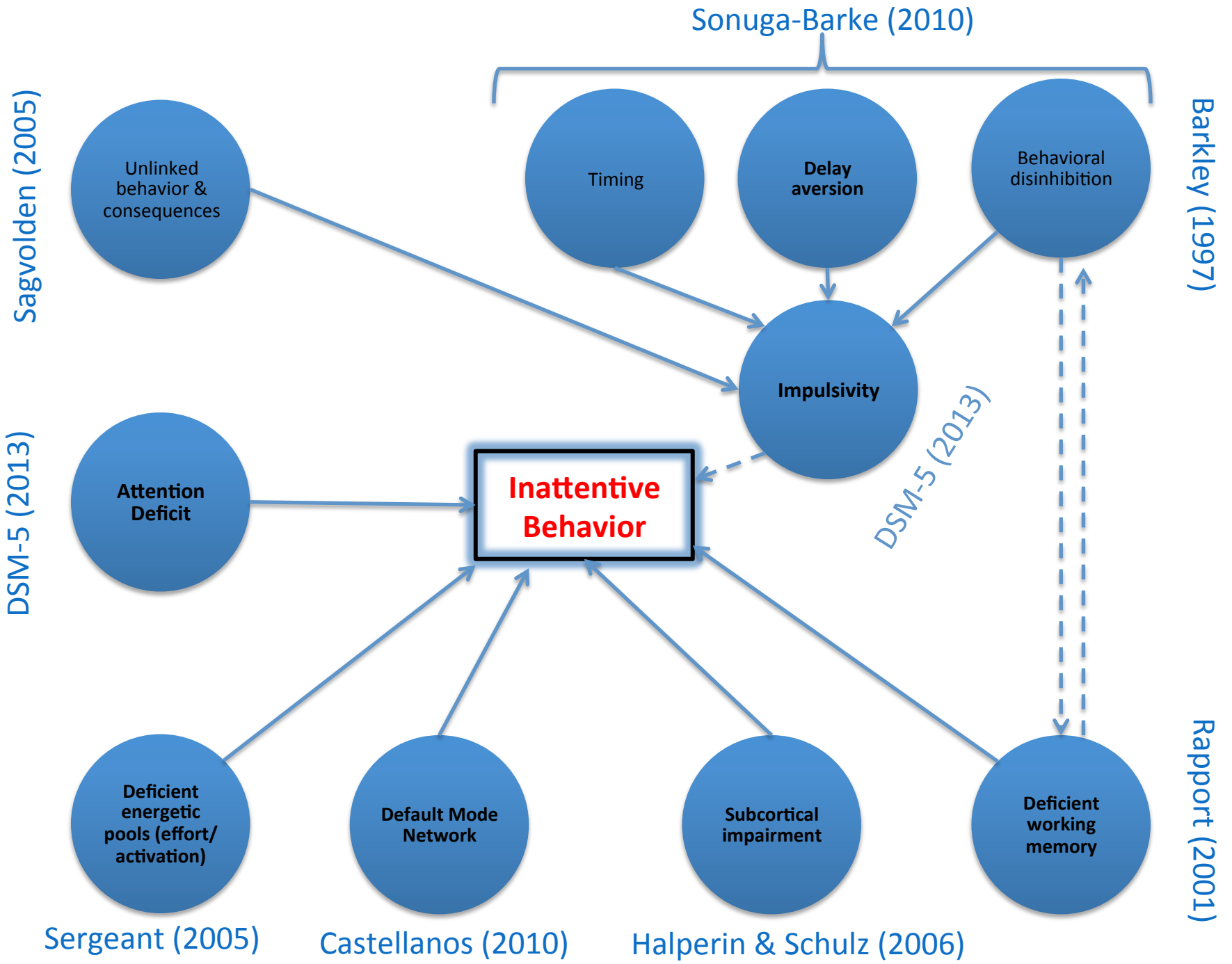
Current Models of ADHD

- Behavioral inhibition deficits (Barkley)
- Cognitive-energetic model (Sergeant)
- Delay aversion (Sonuga-Barke)
- Dynamic developmental model (Sagvolden)
- State-regulation theory (van der Meere)
- Working memory deficits (Rapport)


Sonuga-Barke (2010)
Sagvolden (2005)
Barkley (1997)
Unlinked behavior & consequences
Timing
Delay aversion
Behavioral disinhibition
Impulsivity
DSM-5 (2013)
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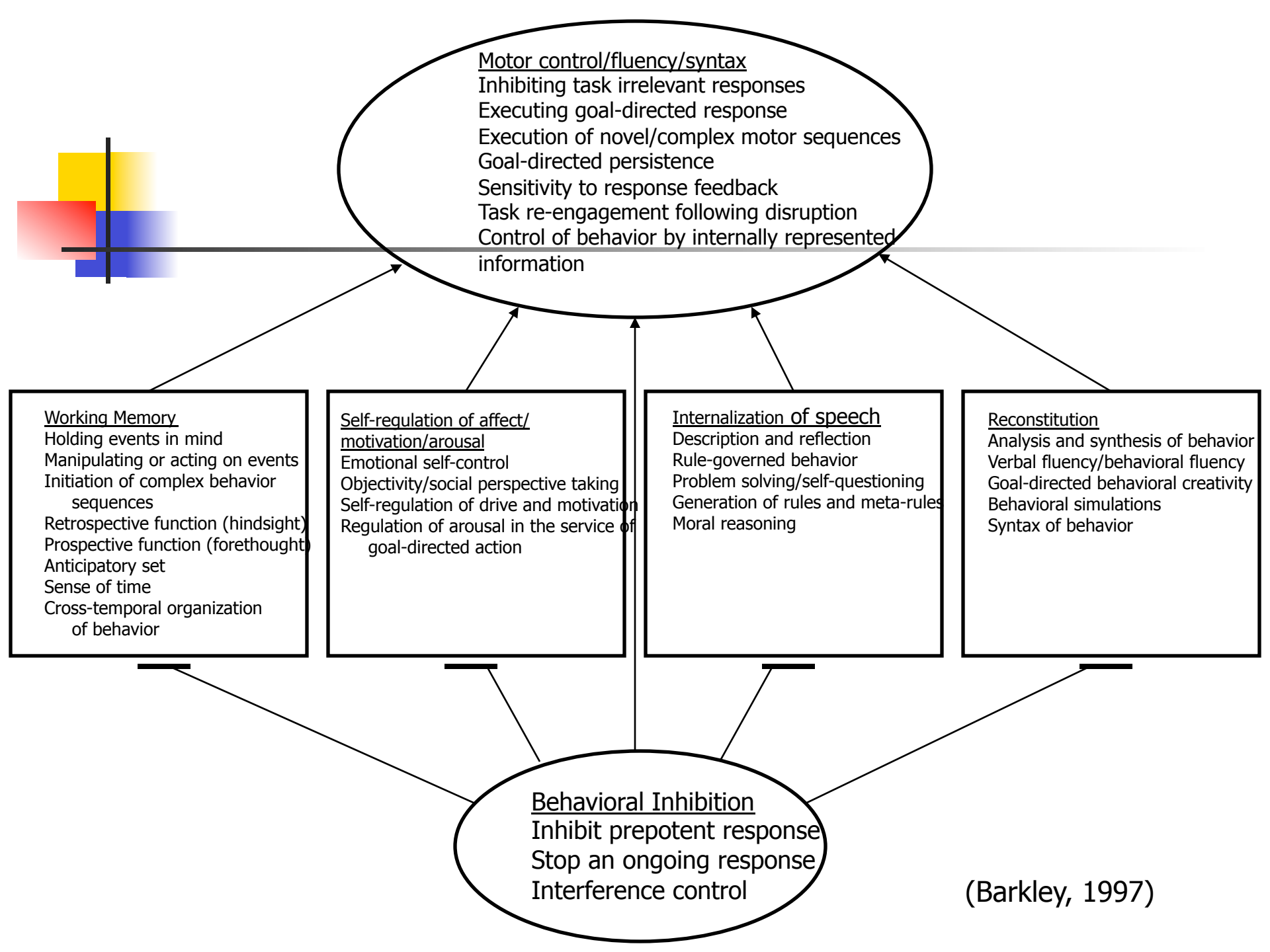
Attention Deficit
Inattentive Behavior
Rapport (2001)
Deficient energetic pools (effort/ activation)
Default Mode Network
Subcortical impairment
Deficient working memory
Sergeant (2005)
Castellanos (2010)
Halperin & Schulz (2006)

Behavioral Inhibition Theory of ADHD

- A deficit in response inhibition
- That disrupts 4 executive functions
  - Sensing to the self (nonverbal working memory)
  - Self-speech (verbal working memory)
  - Self-management of emotion/motivation
  - Self-play – Mental planning-problem solving
- Impairing self-regulation across time to maximize delayed social consequences
- Making ADHD a form of time blindness or myopia to the future – an intention deficit


Motor control/fluency/syntax
Inhibiting task irrelevant responses
Executing goal-directed response
Execution of novel/complex motor sequences
Goal-directed persistence
Sensitivity to response feedback
Task re-engagement following disruption
Control of behavior by internally represented information
Working Memory
Holding events in mind
Manipulating or acting on events
Initiation of complex behavior sequences
Retrospective function (hindsight)
Prospective function (forethought)
Anticipatory set
Sense of time
Cross-temporal organization of behavior
Self-regulation of affect/ motivation/arousal
Emotional self-control
Objectivity/social perspective taking
Self-regulation of drive and motivation
Regulation of arousal in the service of goal-directed action
Internalization of speech
Description and reflection
Rule-governed behavior
Problem solving/self-questioning
Generation of rules and meta-rules
Moral reasoning
Reconstitution
Analysis and synthesis of behavior
Verbal fluency/behavioral fluency
Goal-directed behavioral creativity
Behavioral simulations
Syntax of behavior
Behavioral Inhibition
Inhibit prepotent response
Stop an ongoing response
Interference control
(Barkley, 1997)

Behavioral Inhibition (Barkley, 2007)

- Inhibition of a prepotent response
- Stop an ongoing response
- Interference Control

Evolution of the Stop-Signal Task

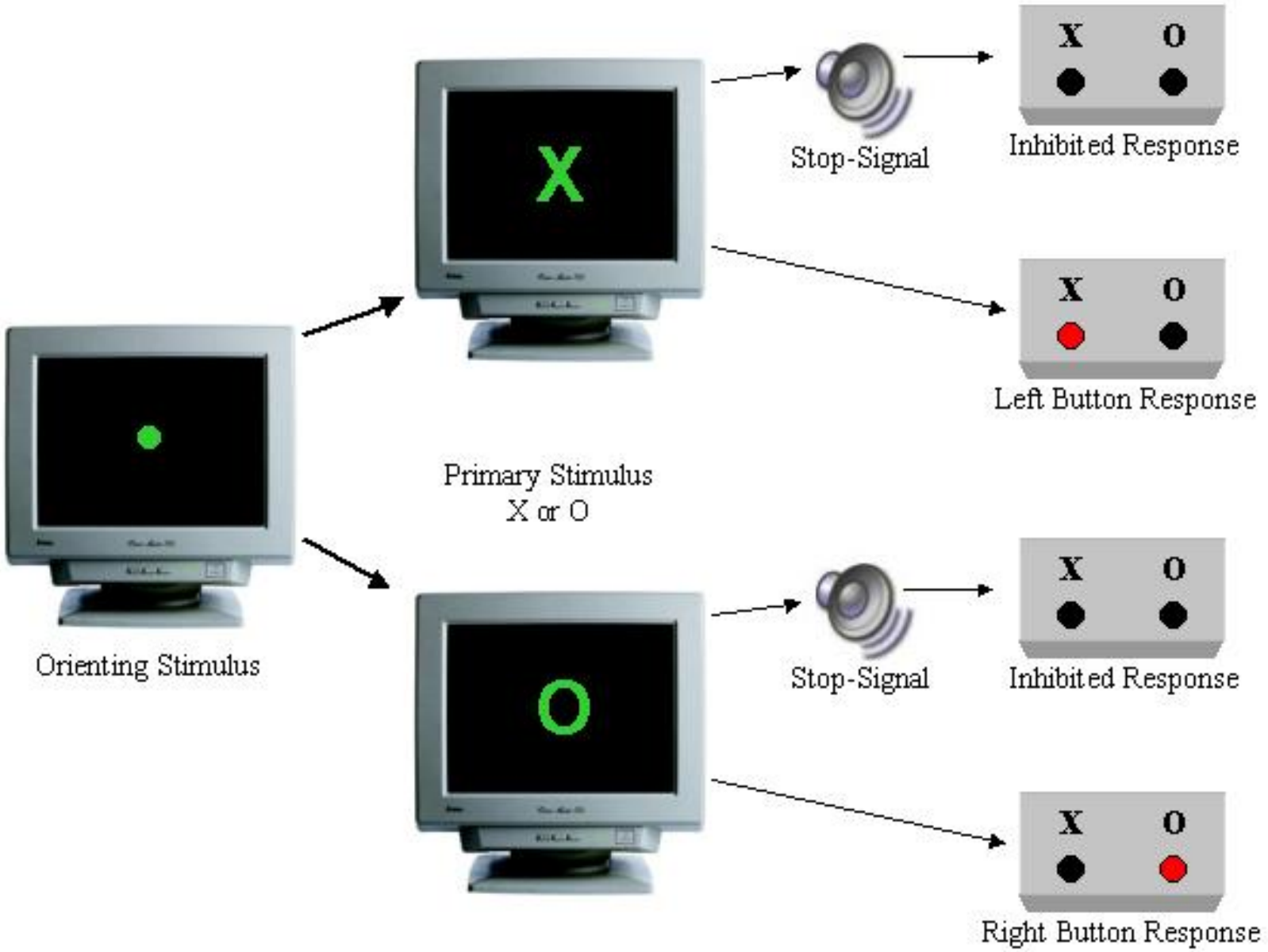
- Logan (1981) developed his model following the work of Lappin and Eriksen (1964, 1966), who were doing similar studies on ***ballistic responses***.
- Logan, 1981, 1982a, 1982b, 1983 initially examined the ballistic responses of typists.
- Logan (1984) became interested in the extent to which ***choice reaction times*** are controlled or ballistic and ultimately developed his *Race Horse Model* of behavioral inhibition.

Continued Evolution of the Stop-Signal Task

- Advantages over simple reaction time tasks, such as the go, no-go paradigm (Tekok-Kilic et al., 2001), include:
  1. A greater demand on cognitive resources relevant to inhibitory processes (Logan, Cowan, & Davis, 1984)
  2. The ability to examine speed-accuracy trade-off processes that reflect children's strategic adjustment in primary task reaction time (Logan, 1981).
- Early version of the Stop-Signal Task relied on fixed stop-signal delays, inhibition slopes, and logarithmic calculations of SSRT.

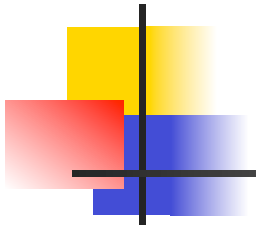
Horse Race Model of Behavioral Inhibition (Logan, Cowan, & Davis, 1984)

- Go and stop processes *race* to the *finish line*
- If go process wins, response is executed
- If stop process wins, response is inhibited


X
O
Stop-Signal
Inhibited Response
Left Button Response
Primary Stimulus
X or O
Orienting Stimulus
Stop-Signal
Inhibited Response
Right Button Response

Stop-Signal Task Variables

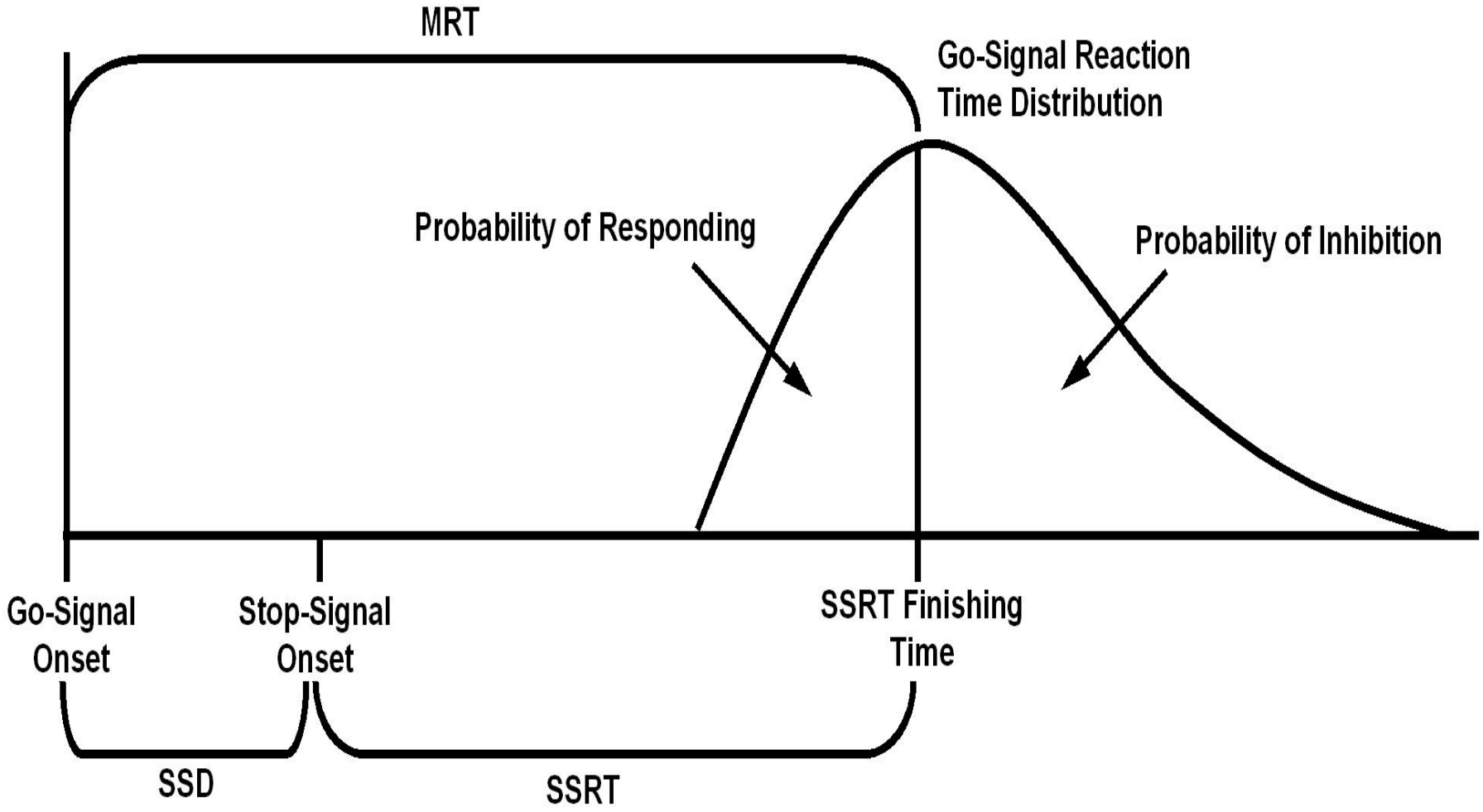
- **Go-Signal** – stimuli (typically X or O) that signals one to respond
- **Stop-Signal** – stimuli (typically an auditory tone) that signals one to withhold or stop a response.
- **Mean Reaction Time (MRT)** – choice reaction time to go-stimulus
- **Stop-Signal Delay (SSD)** – stimulus onset asynchrony between the presentation of the go-stimulus and stop-stimulus
- **Stop-Signal Reaction Time (SSRT)** – reaction time to the stop-stimulus, calculated as MRT-SSD

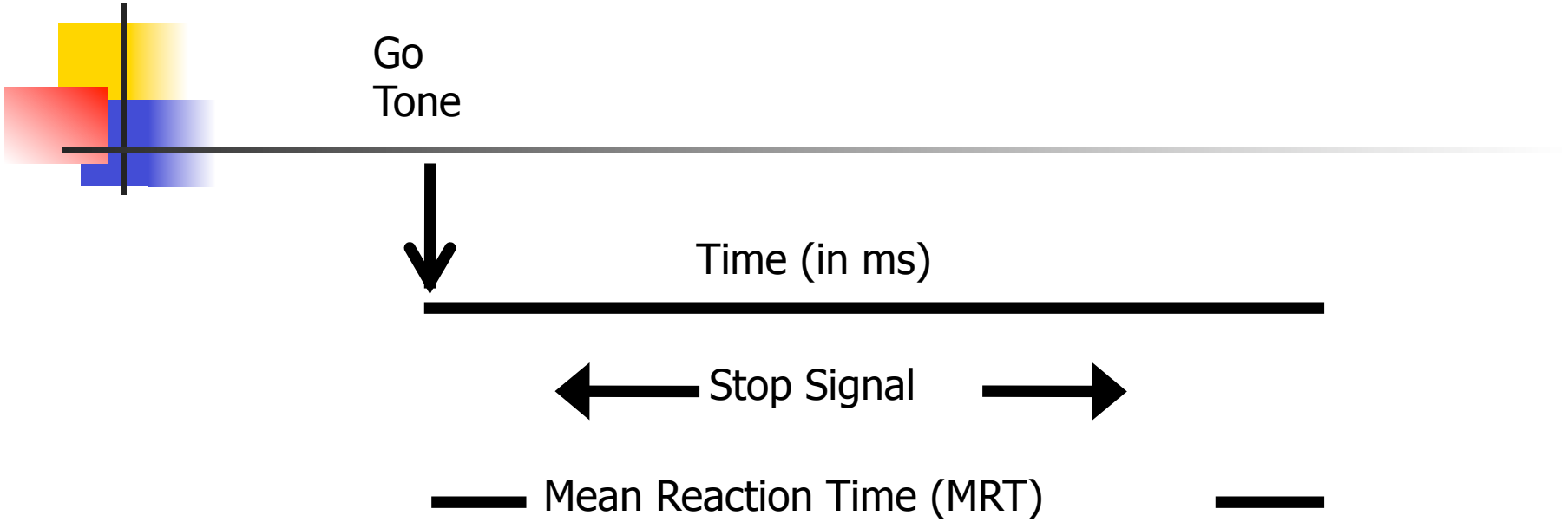


Behavioral Inhibition and the Stop Signal Paradigm

SSRT = MRT – SSD

SSRT = Stop Signal Reaction Time
MRT = Mean Reaction Time
SSD = Stop Signal Delay


MRT
Go-Signal Reaction
Time Distribution
Probability of Responding
Probability of Inhibition
Go-Signal
Onset
Stop-Signal
Onset
SSRT Finishing
Time
SSD
SSRT



Response accuracy varies with tone presentation – easier to stop when stop signal is closer to go-signal

Alderson, Rapport, Sarver & Kofler (2008)

ADHD and Behavioral Inhibition: A Re-examination of the Stop-signal Task.

***Journal of Abnormal Child Psychology*.**

Meta-Analysis of the Stop-Signal Task (Alderson, Rapport, & Kofler, 2007)

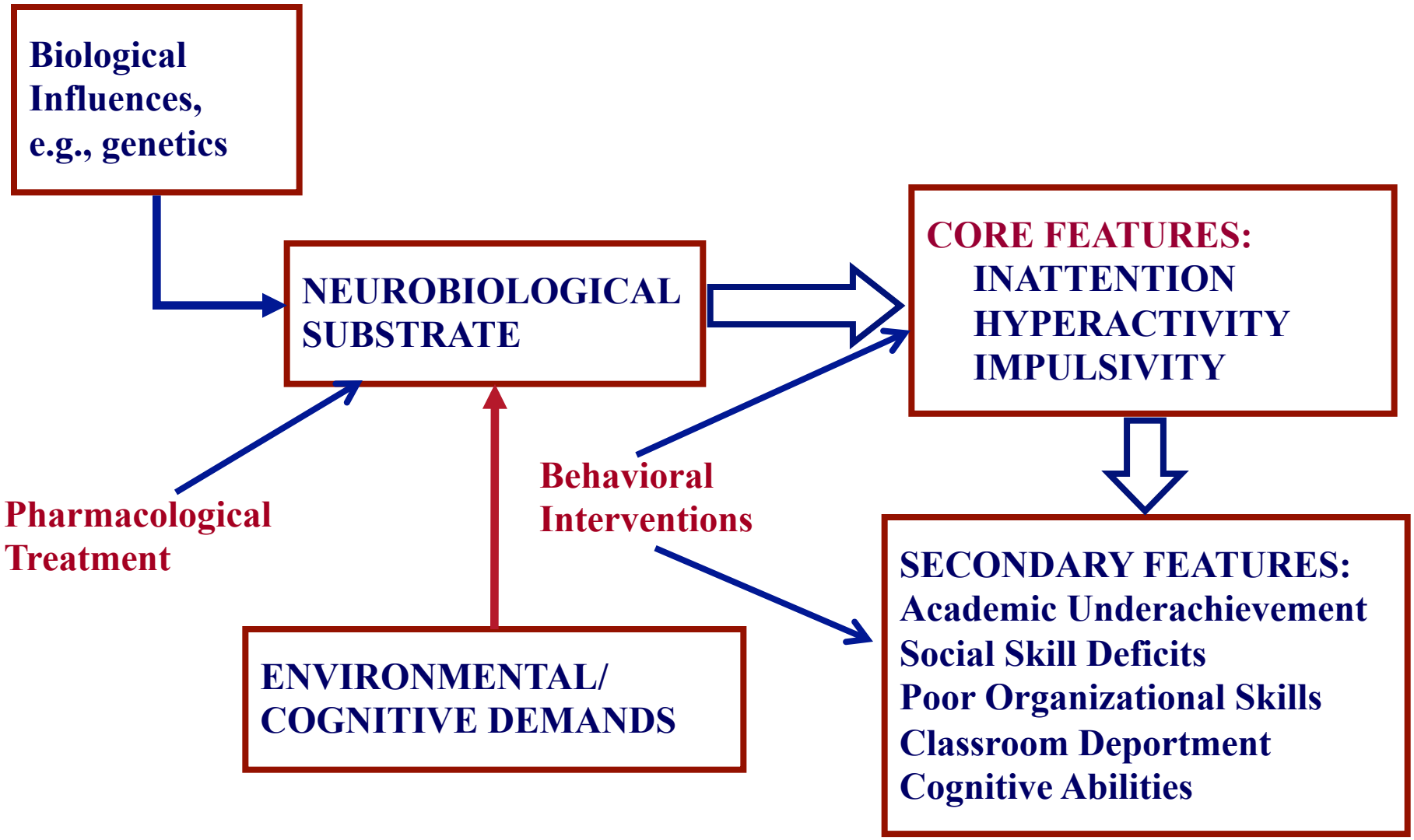
- Compared 23 studies of children with ADHD and typically developing children on the stop-signal task
- Results:
  - MRT: ADHD > NC (ES = 0.45)
  - MRT Variability: ADHD > NC (ES = 0.73)
  - SSRT: ADHD > NC (ES = 0.63)

- Results were highly consistent across meta-analytic reviews:
  - MRT: ESs = 0.49, 0.52, and 0.45
  - MRT Variability: 0.73, 0.72, and 0.72
  - SSRT: 0.64, 0.58, and 0.63

Meta-Analysis of the Stop-Signal Task (Alderson, Rapport, & Kofler, 2007)

- SSD: ADHD = NC (ES = -0.02 unstandardized)
- SSD is direct reflection of inhibitory success.
- SSD was indirectly estimated

DSM-5 CLINICAL MODEL OF ADHD

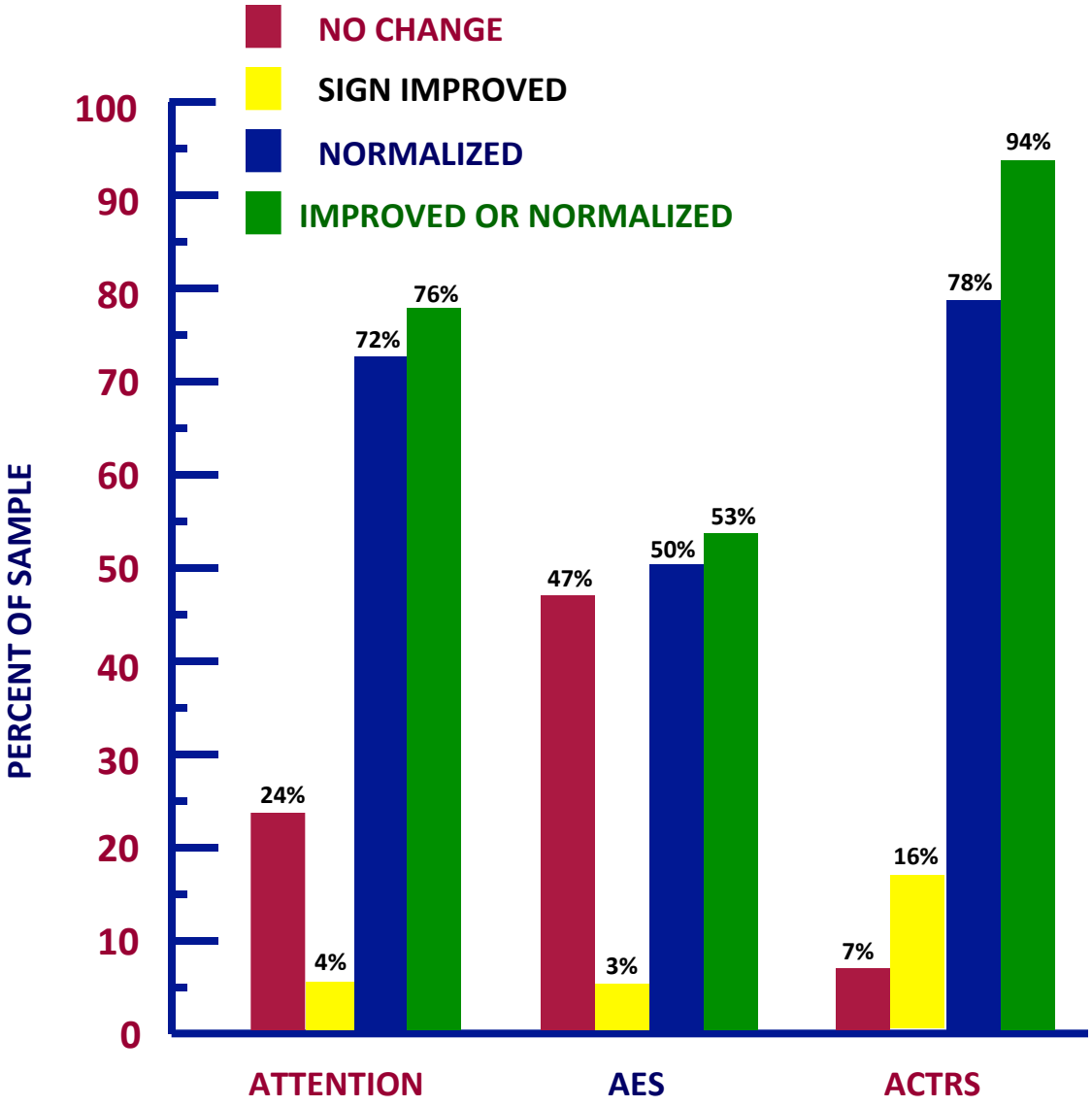


Initial Conceptualization of the Functional Working Memory Model of ADHD

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

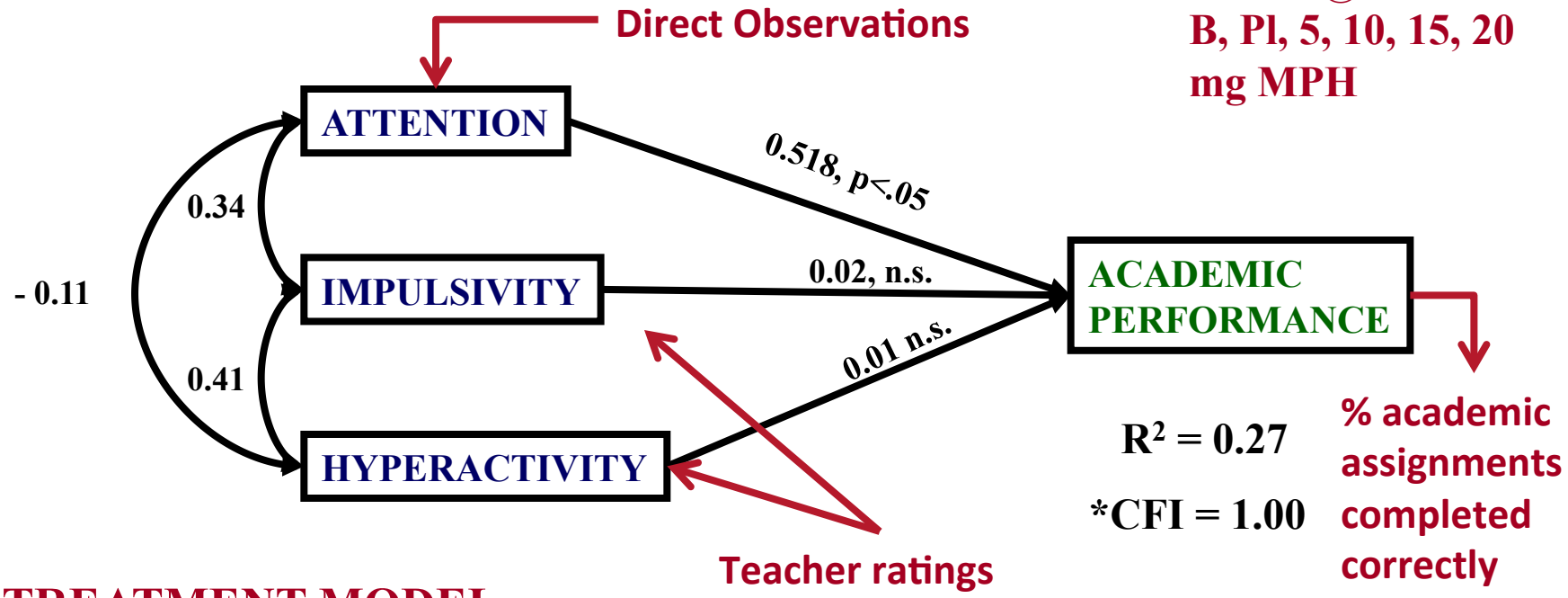


ADHD N = 76
NC N = 25

Rapport, Denney, DuPaul, & Gardner (1994).
J AM. ACAD. CHILD ADOLESC. PSYCHIATRY

BASELINE MODEL

N = 76 @
B, Pl, 5, 10, 15, 20
mg MPH

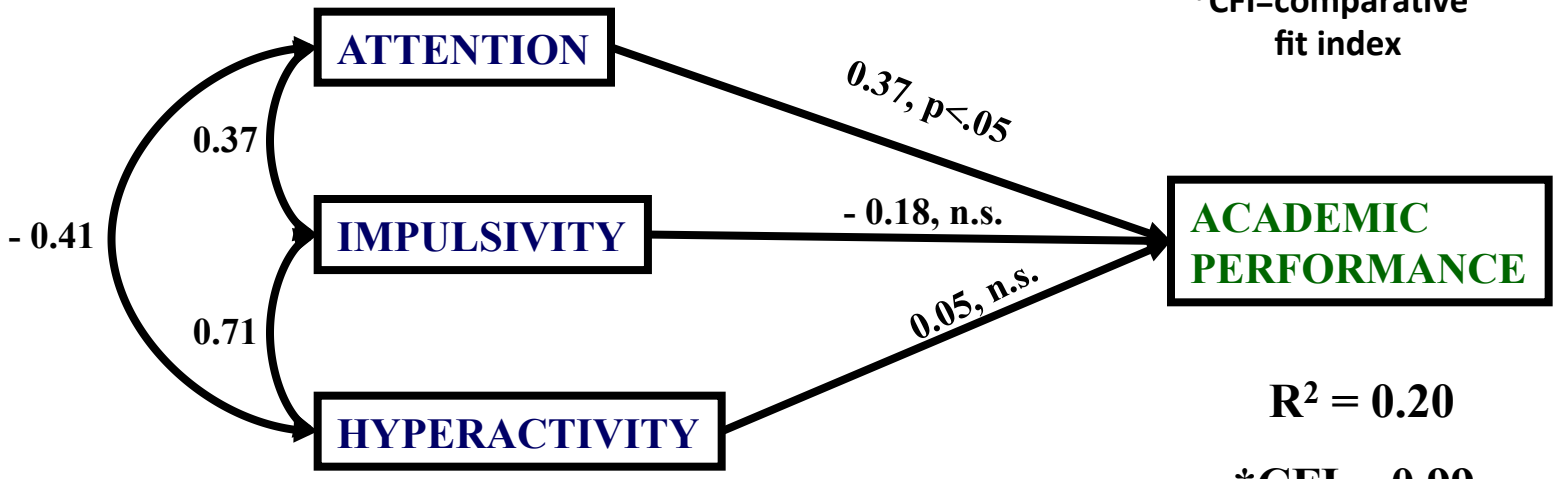


$R^2 = 0.27$

*CFI = 1.00

b TREATMENT MODEL

*CFI=comparative fit index

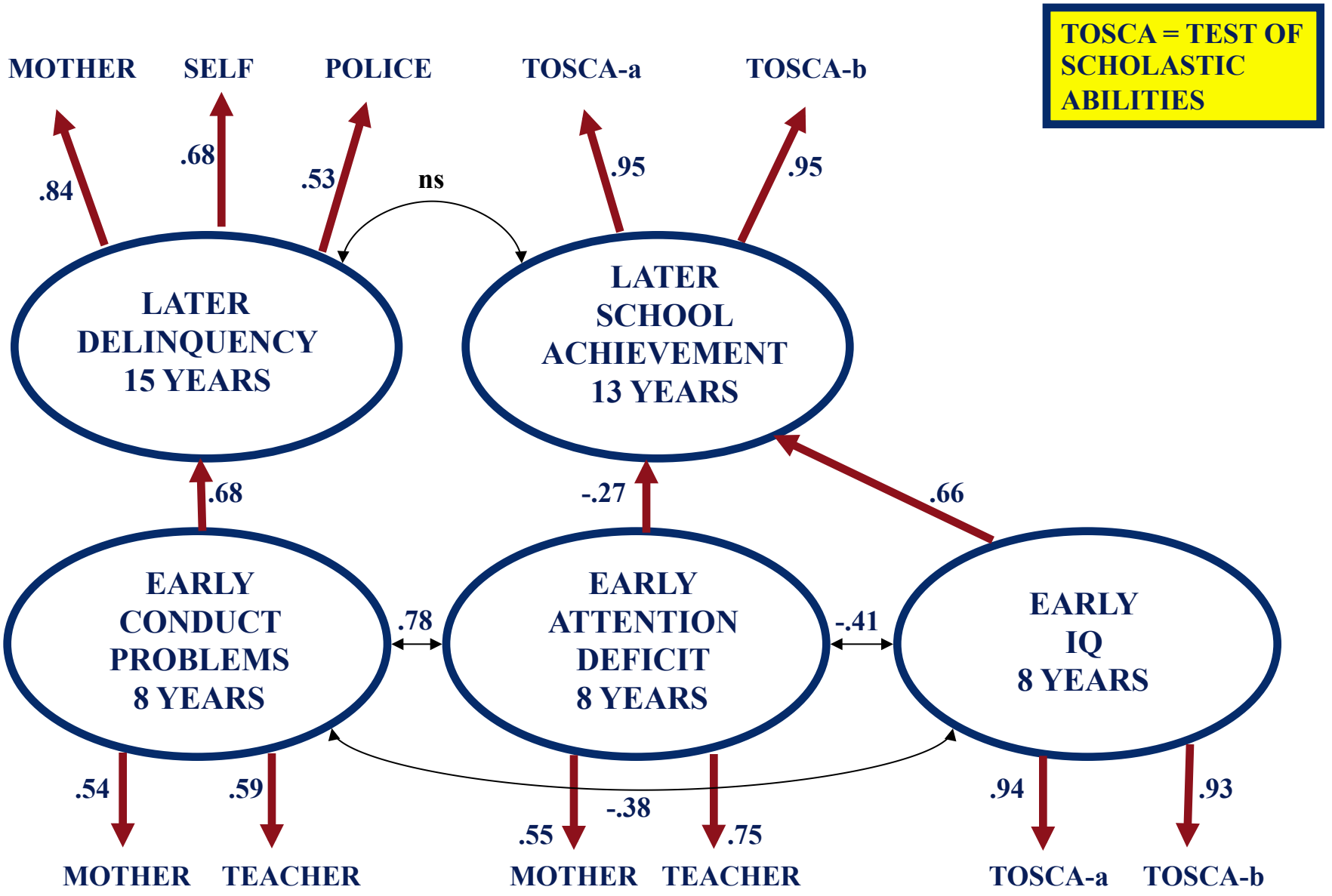


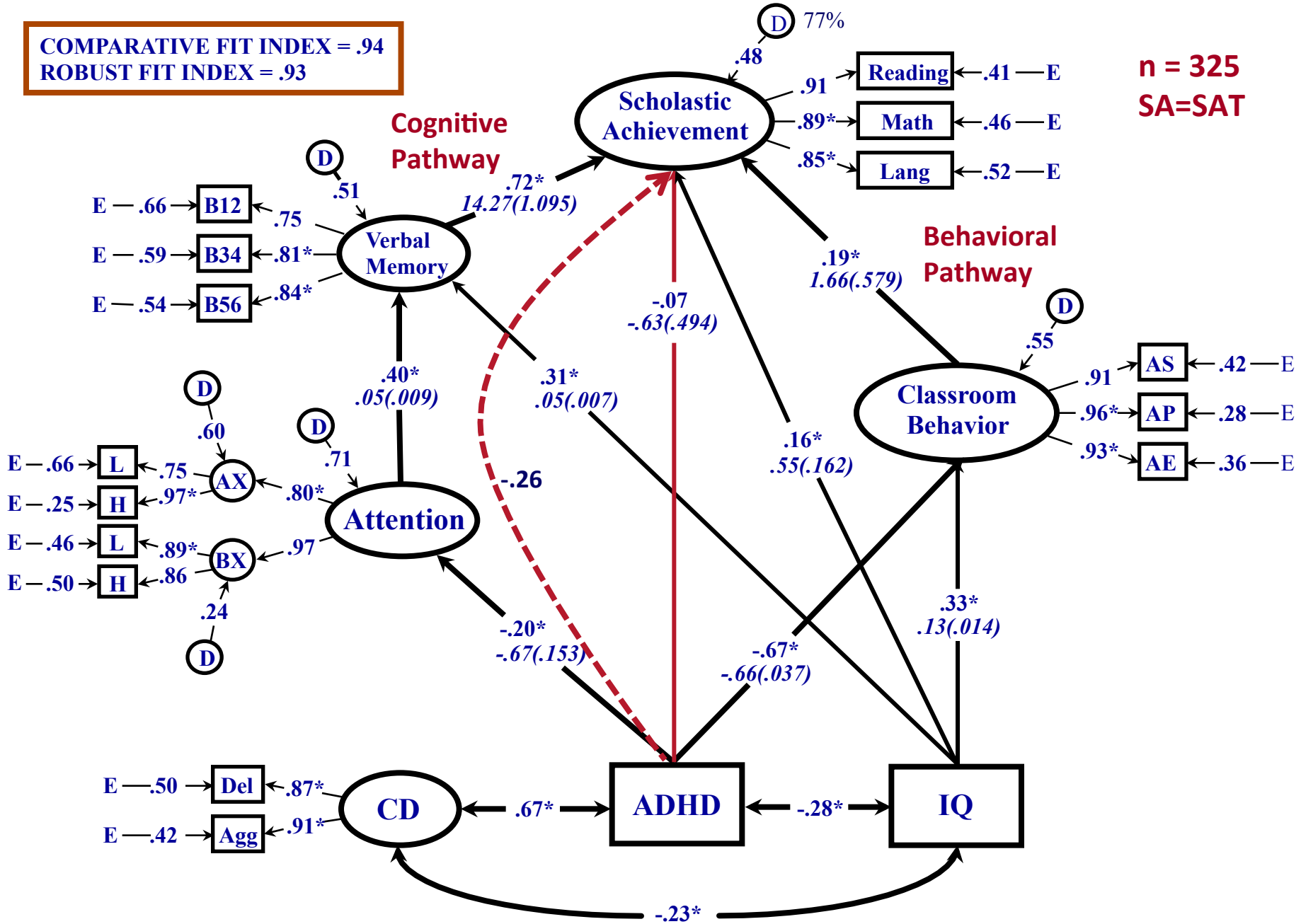
$R^2 = 0.20$

*CFI = 0.99

Rapport, Denney, DuPaul, & Gardner (1994). *J AM. ACAD. CHILD ADOLESC. PSYCHIATRY*

FITTED STRUCTURAL EQUATION MODEL OF EARLY BEHAVIOR, EARLY IQ, AND LATER DELINQUENCY AND SCHOLASTIC ABILITY. [FERGUSSON & HORWOOD, 1995, *J OF ABNORM CHILD PSYCHOLOGY, 23*, 183-199]





Rapport, Scanlan & Denney (1999) J. of Child Psychiatry and Psychology

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

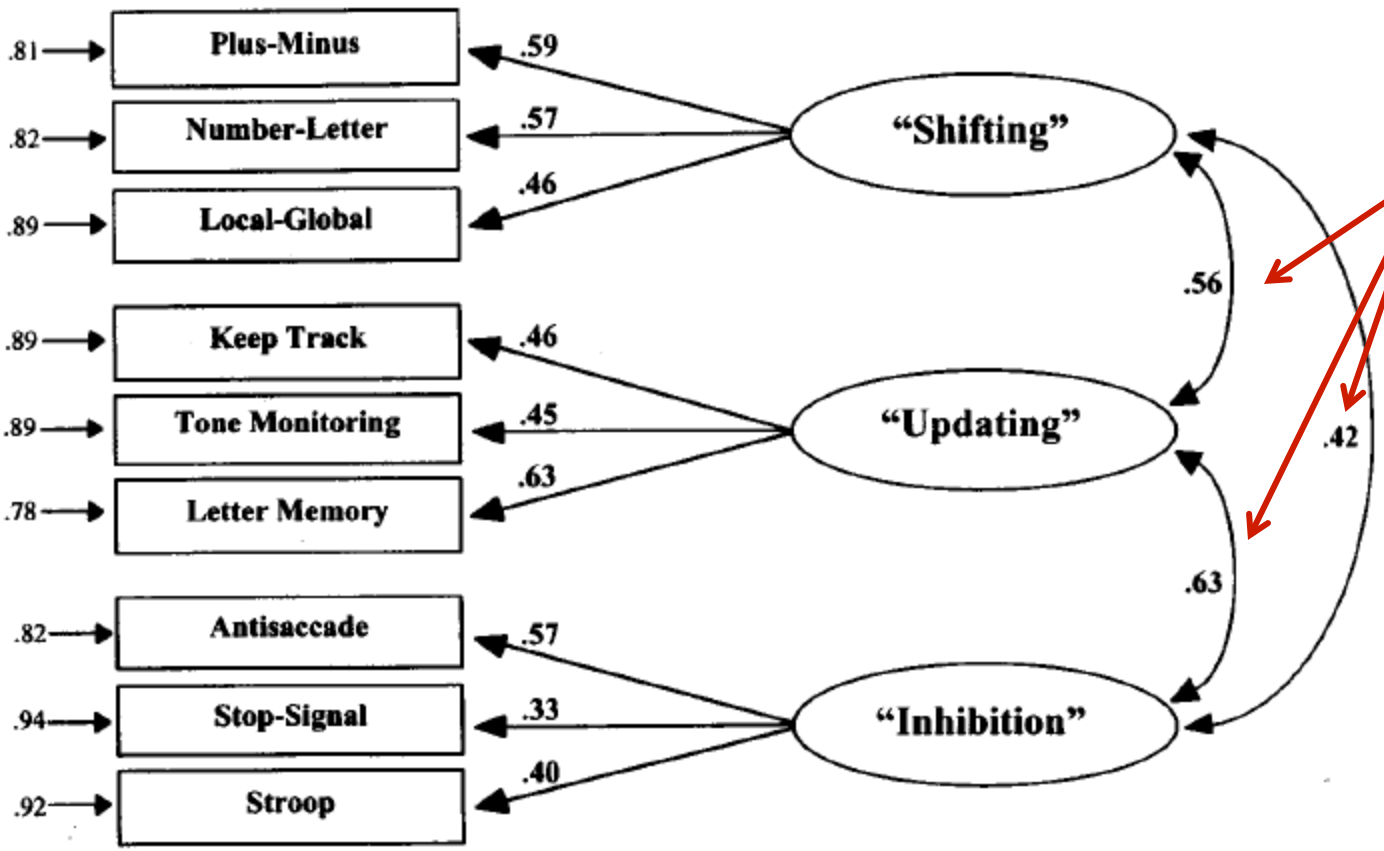
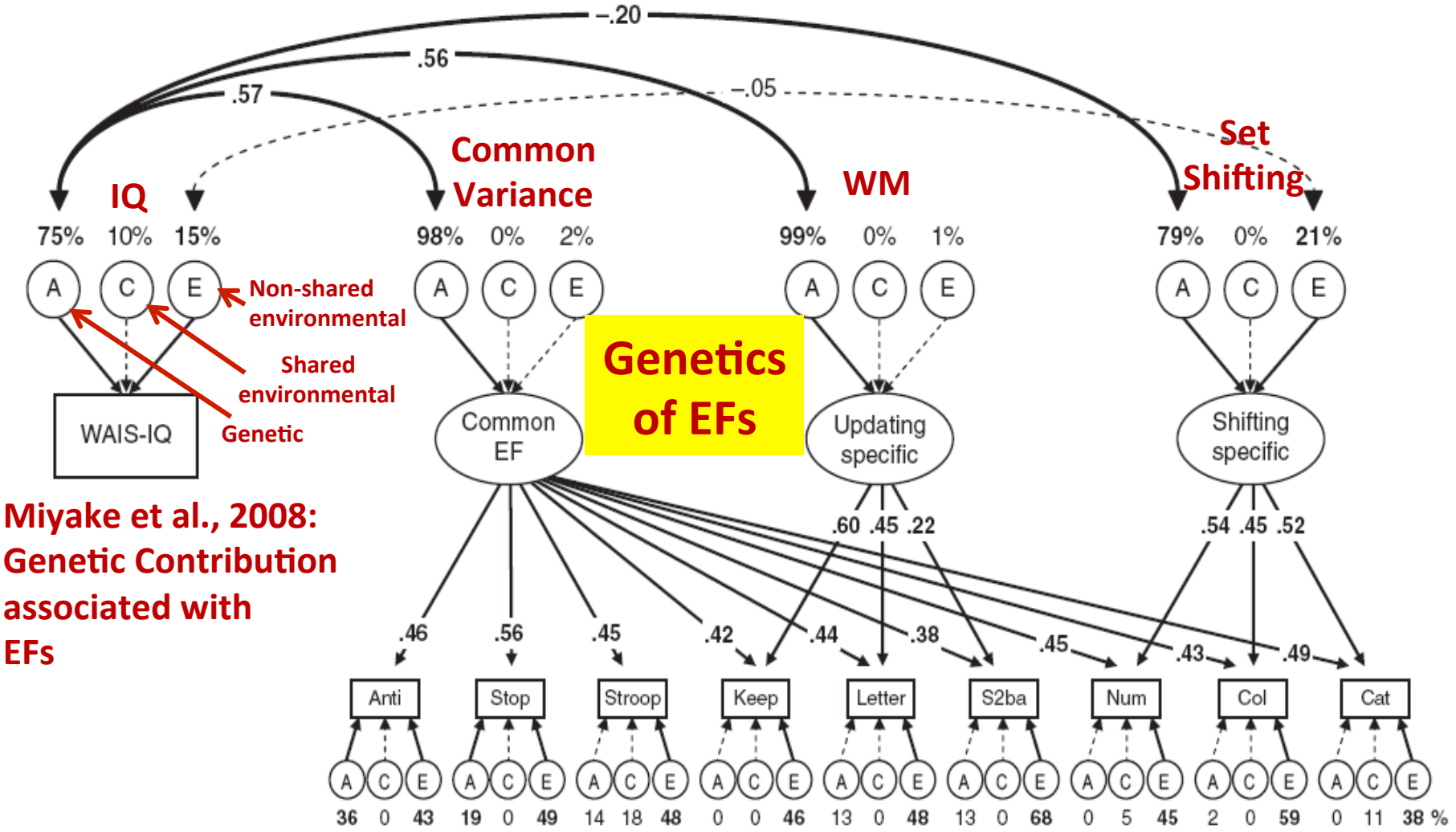


FIG. 2. The estimated three-factor model. Single-headed arrows have standardized factor loadings next to them. The loadings, all significant at the .05 level, are equivalent to standardized regression coefficients (beta weights) estimated with maximum likelihood estimation. The numbers at the ends of 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.

Supports a domain general executive controller

1
Lehto et al. (2003): replicated factor structure in 8-13 year old children

2
Huizinga et al. (2006): WM & set shifting are developmentally contiguous between 7 & 21 years of age

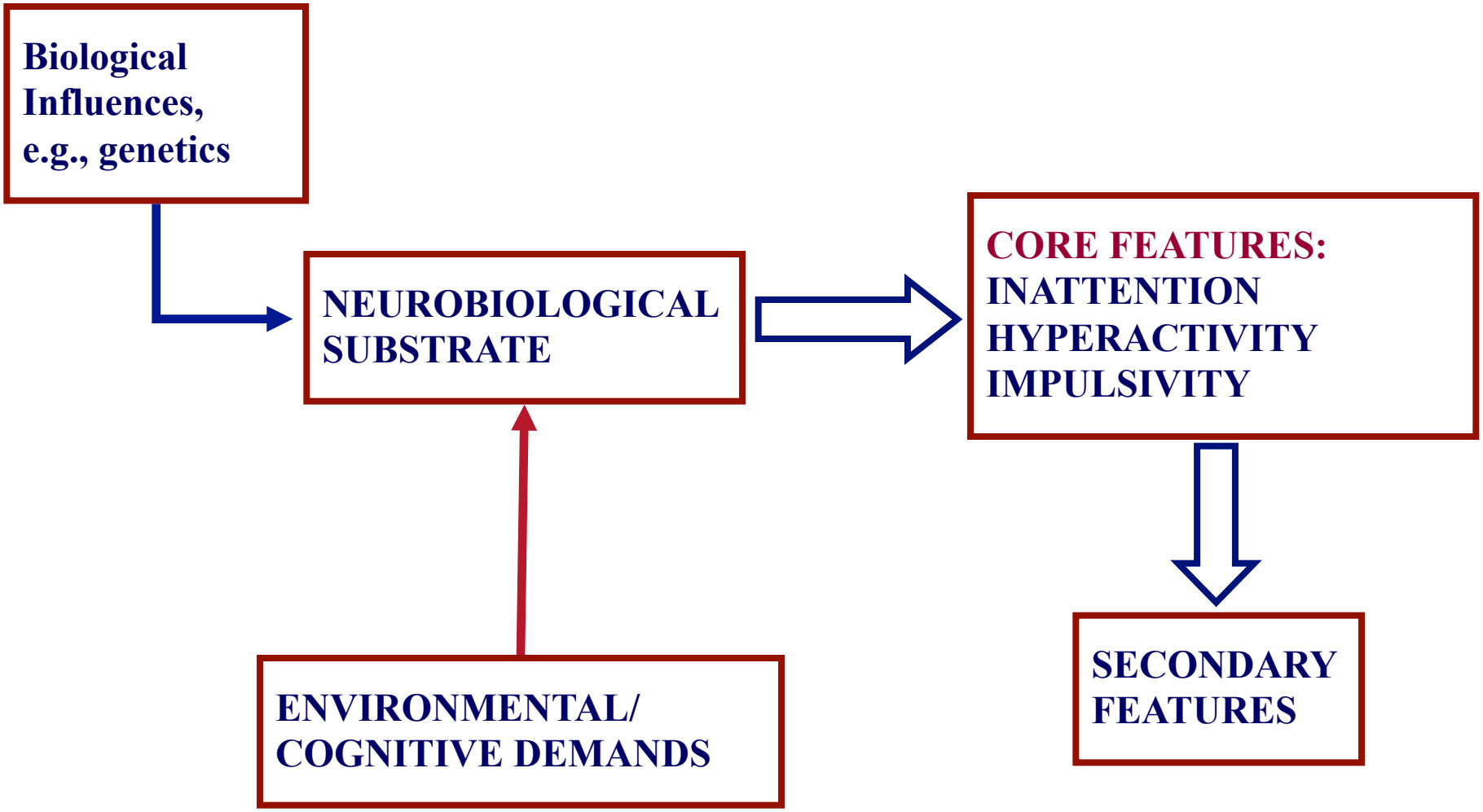


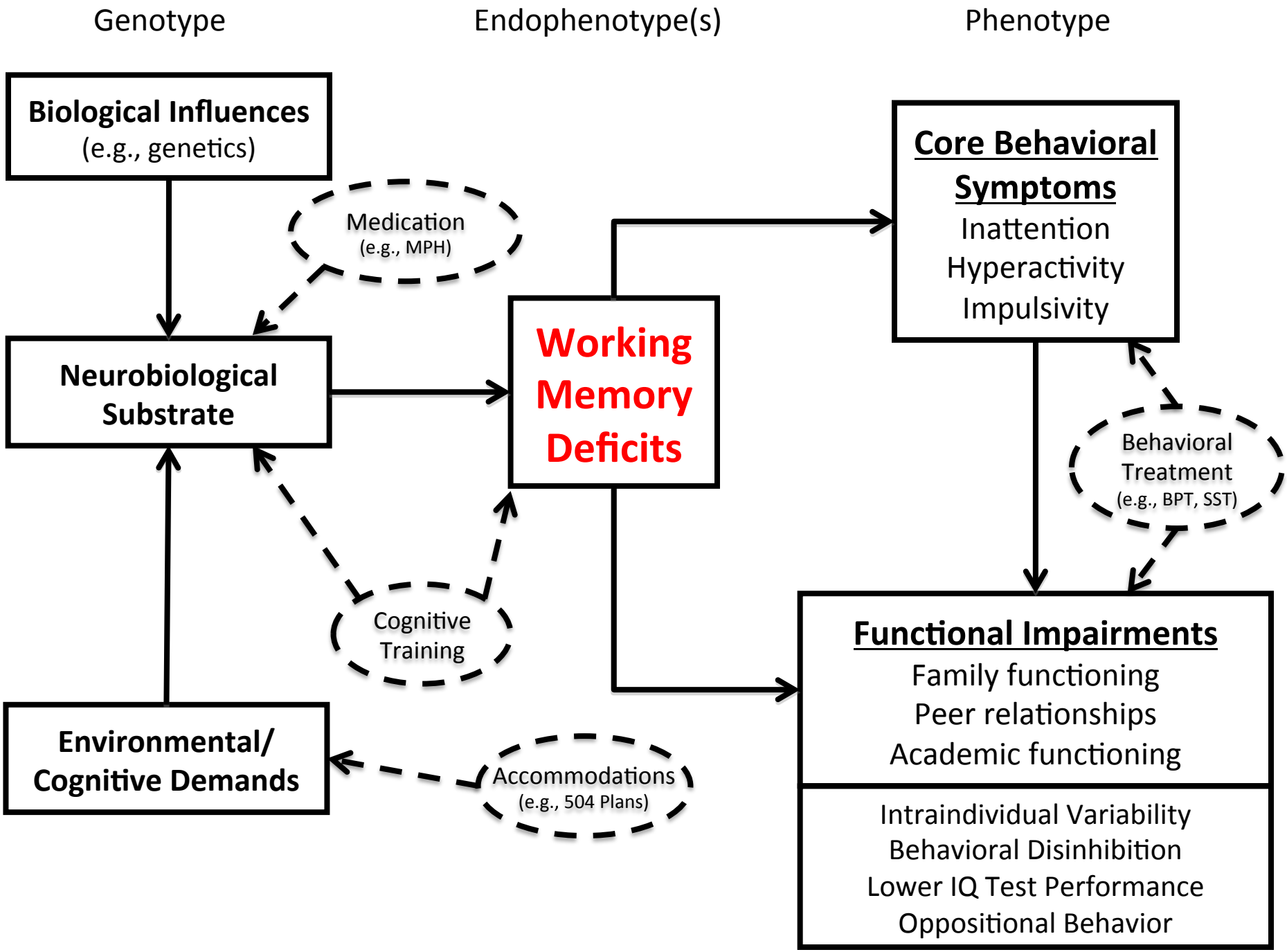
Miyake et al., 2008: Genetic Contribution associated with EFs

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.

WORKING MEMORY MODEL OF ADHD

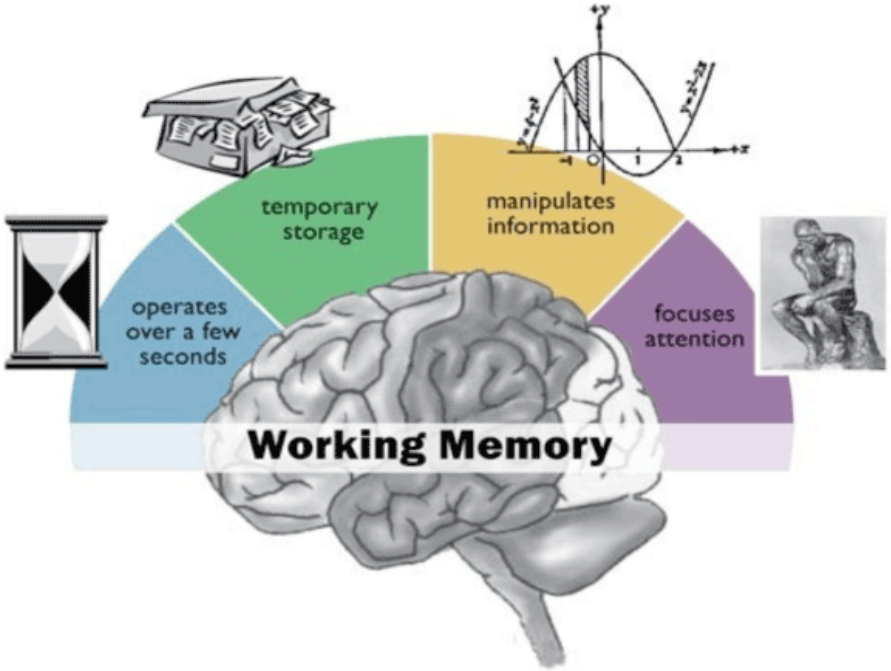
Rapport et al., 2001




Genotype
Endophenotype(s)
Phenotype
Biological Influences
(e.g., genetics)
Medication
(e.g., MPH)
Neurobiological Substrate
Working Memory Deficits
Core Behavioral Symptoms
Inattention
Hyperactivity
Impulsivity
Behavioral Treatment
(e.g., BPT, SST)
Cognitive Training
Environmental/ Cognitive Demands
Accommodations
(e.g., 504 Plans)
Functional Impairments
Family functioning
Peer relationships
Academic functioning
Intraindividual Variability
Behavioral Disinhibition
Lower IQ Test Performance
Oppositional Behavior

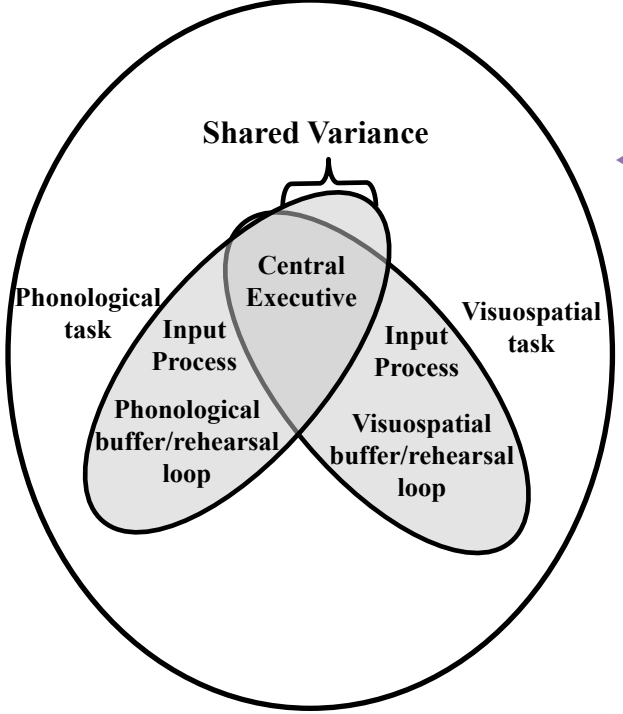
What is Working Memory?

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



http://usablealgebra.landmark.edu/wp-content/uploads/2008/12/working-memory-2.gif

Alan Baddeley's (2007) WM Model



Domain General

Central Executive

Auditory Input

Visual Input

Visual Input

Phonological Analysis

Visual analysis & STS

Visuospatial Analysis

Phonological

STS

Inferior parietal lobe

Orthographic to phonological recoding

Visuospatial

STS

Right hemisphere

Rehearsal Process

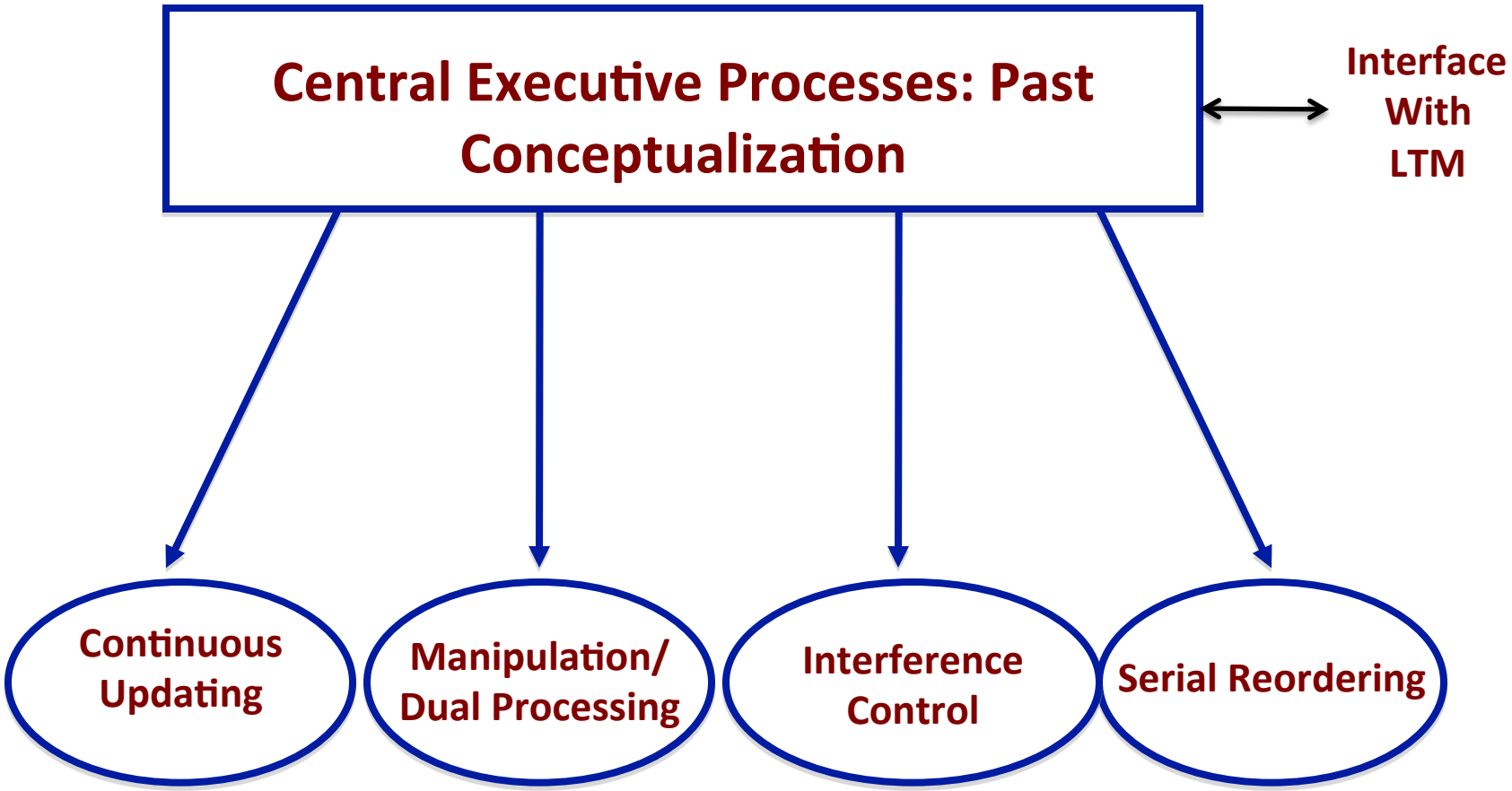
Rehearsal Process

Phonological output buffer
Broca's area-premotor cortex

Visuospatial output buffer
Right premotor cortex

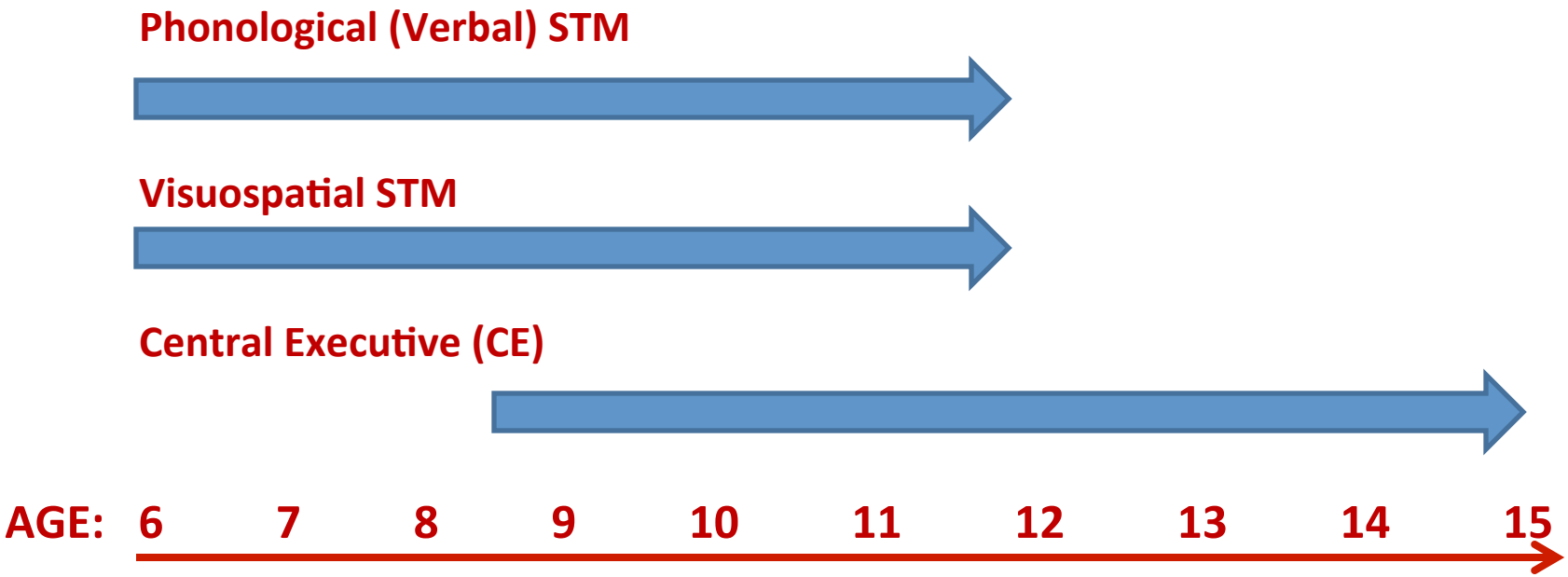
Spoken Output

Motor Output

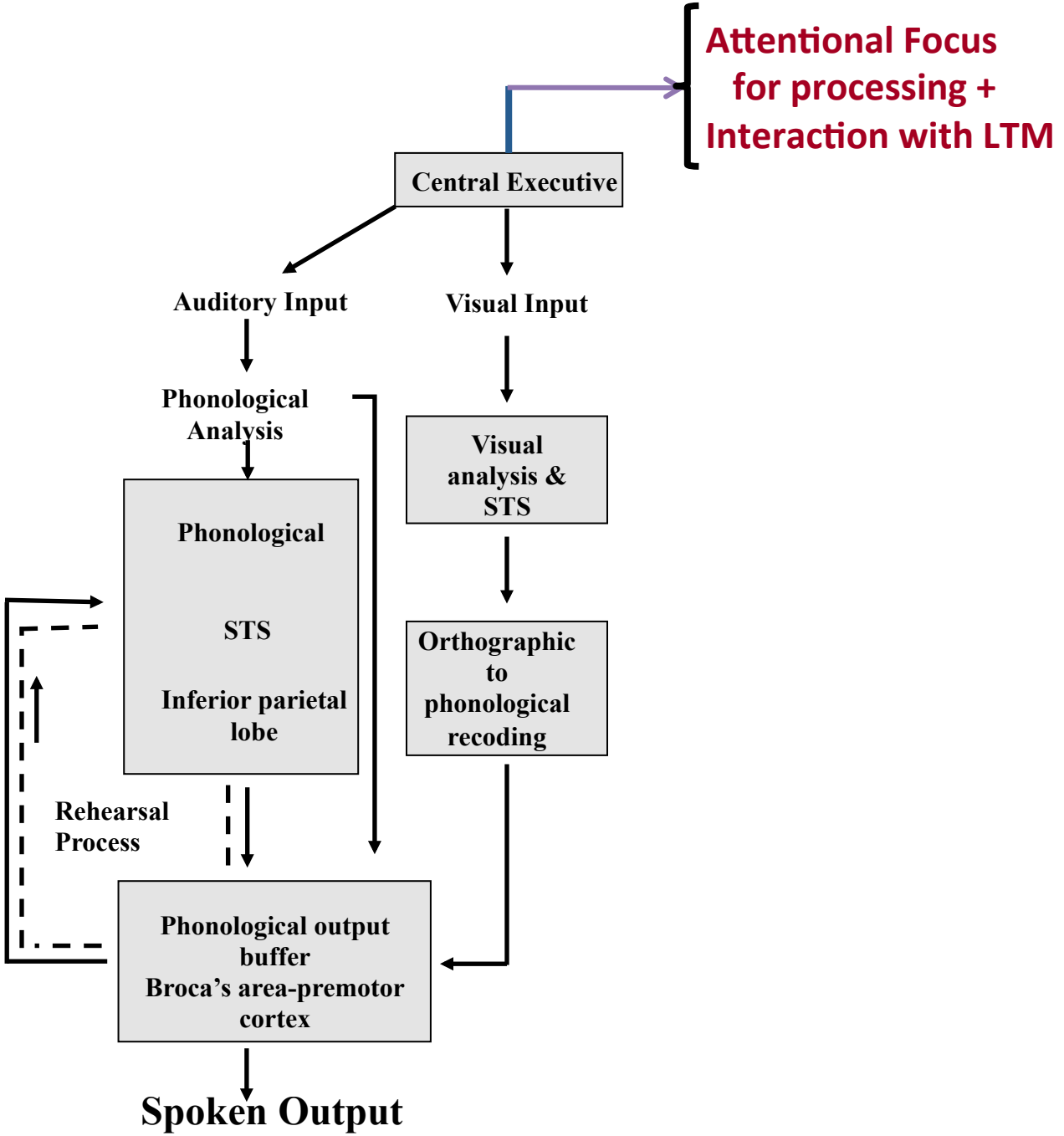


[Baddeley, 2007]

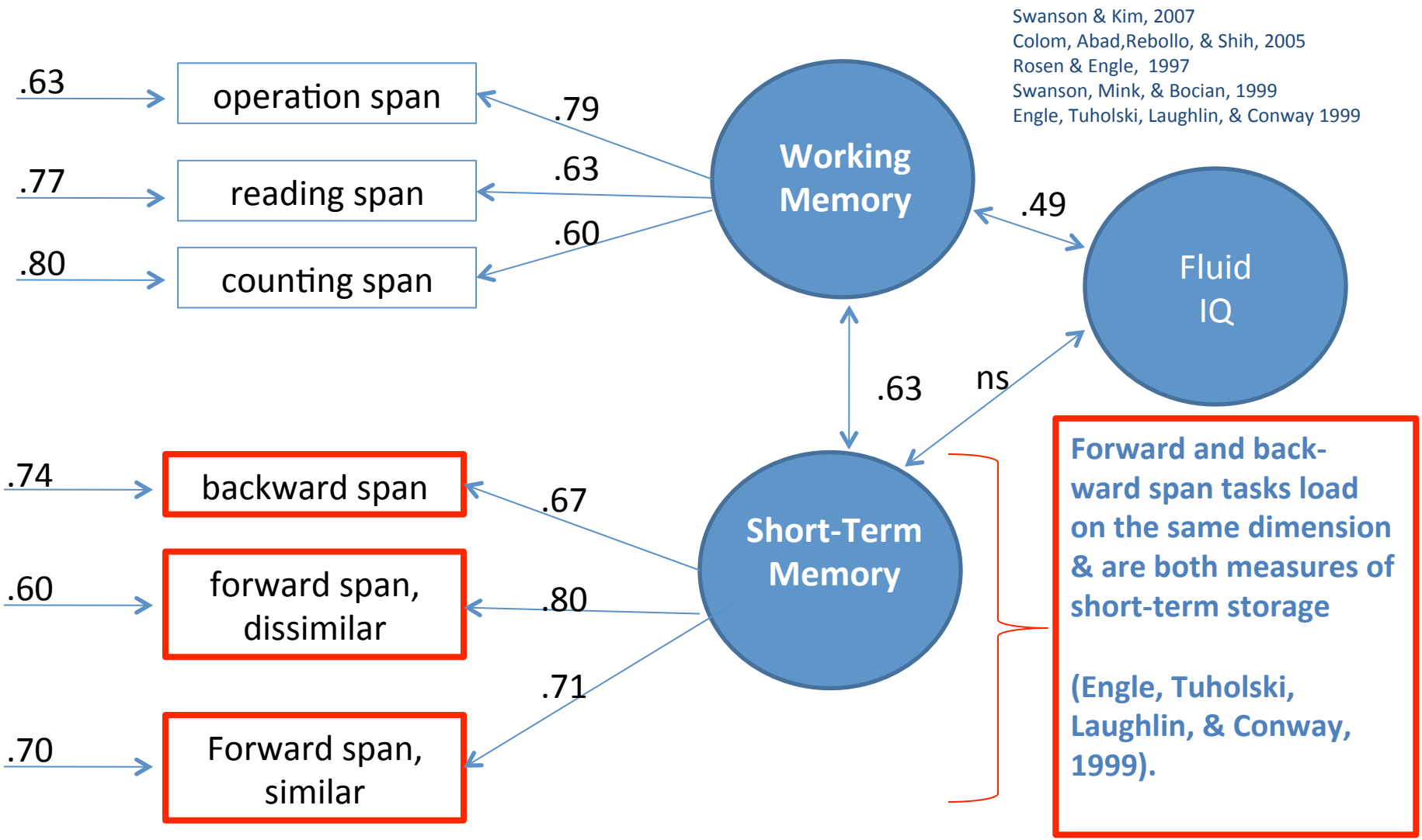
Development of Working Memory in Children: Peak Developmental Periods



Tillman et al. (2011). *Developmental Neuropsychology, 36*, 181-198


Attentional Focus
for processing +
Interaction with LTM
Central Executive
Auditory Input
Visual Input
Phonological
Analysis
Visual
analysis &
STS
Phonological
STS
Inferior parietal
lobe
Orthographic
to
phonological
recoding
Rehearsal
Process
Phonological output
buffer
Broca's area-premotor
cortex
Spoken Output

Forward and Backward Span Tasks



Journal of Experimental Psychology: General
1999, Vol. 128, No. 3, 309–331

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0096-3445/99/$3.00

Working Memory, Short-Term Memory, and General Fluid Intelligence: A Latent-Variable Approach

ENGLE, TUHOLSKI, LAUGHLIN, AND CONWAY

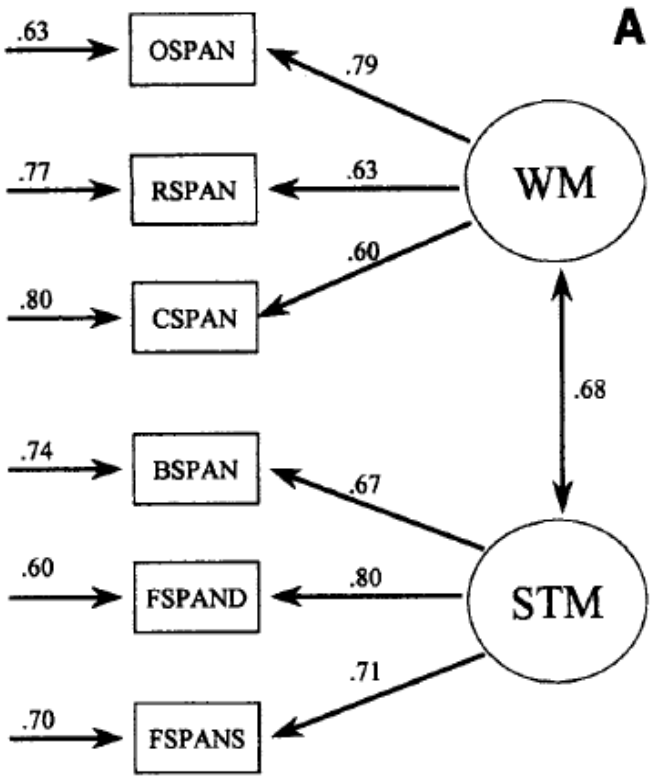


Figure 2. (a) Path model for two-factor model (A_1). All paths are significant at the .05 level. (b) Path model for two-factor model with additional tasks (B_2). Paths significant at the .05 level are indicated by solid lines. OSPAN = operation span; RSPAN = reading span; CSPAN = counting span; BSPAN = 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.

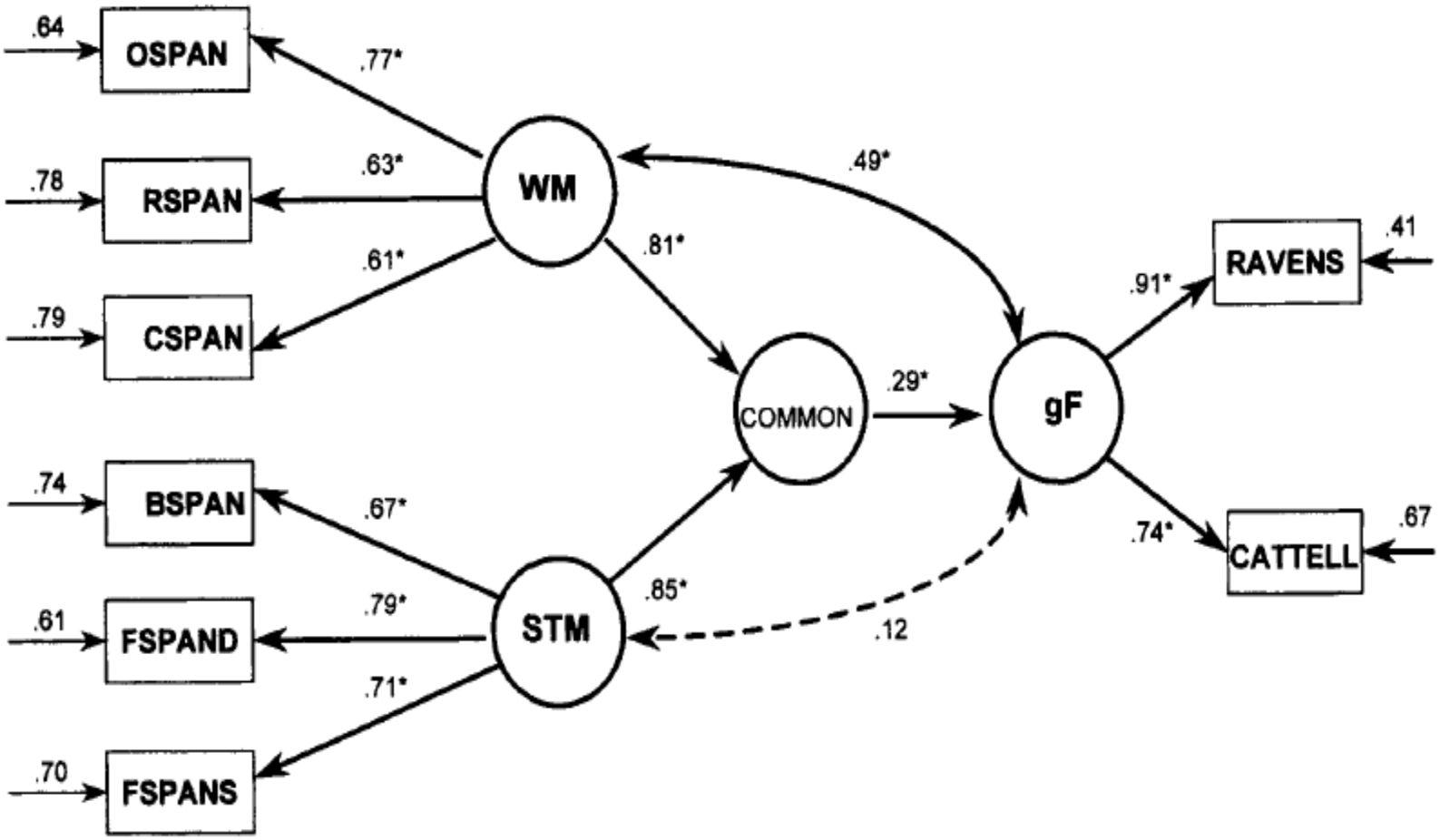
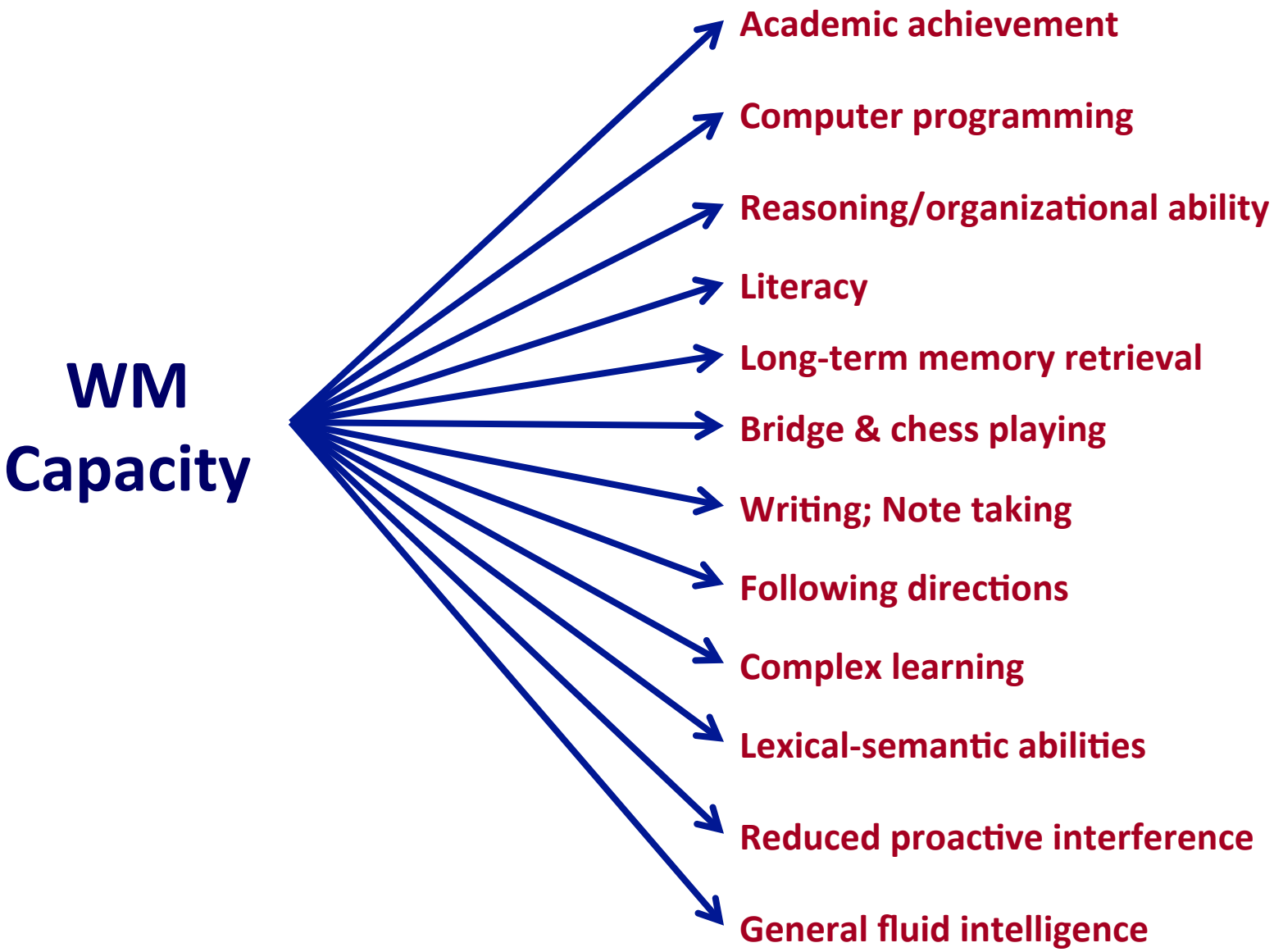


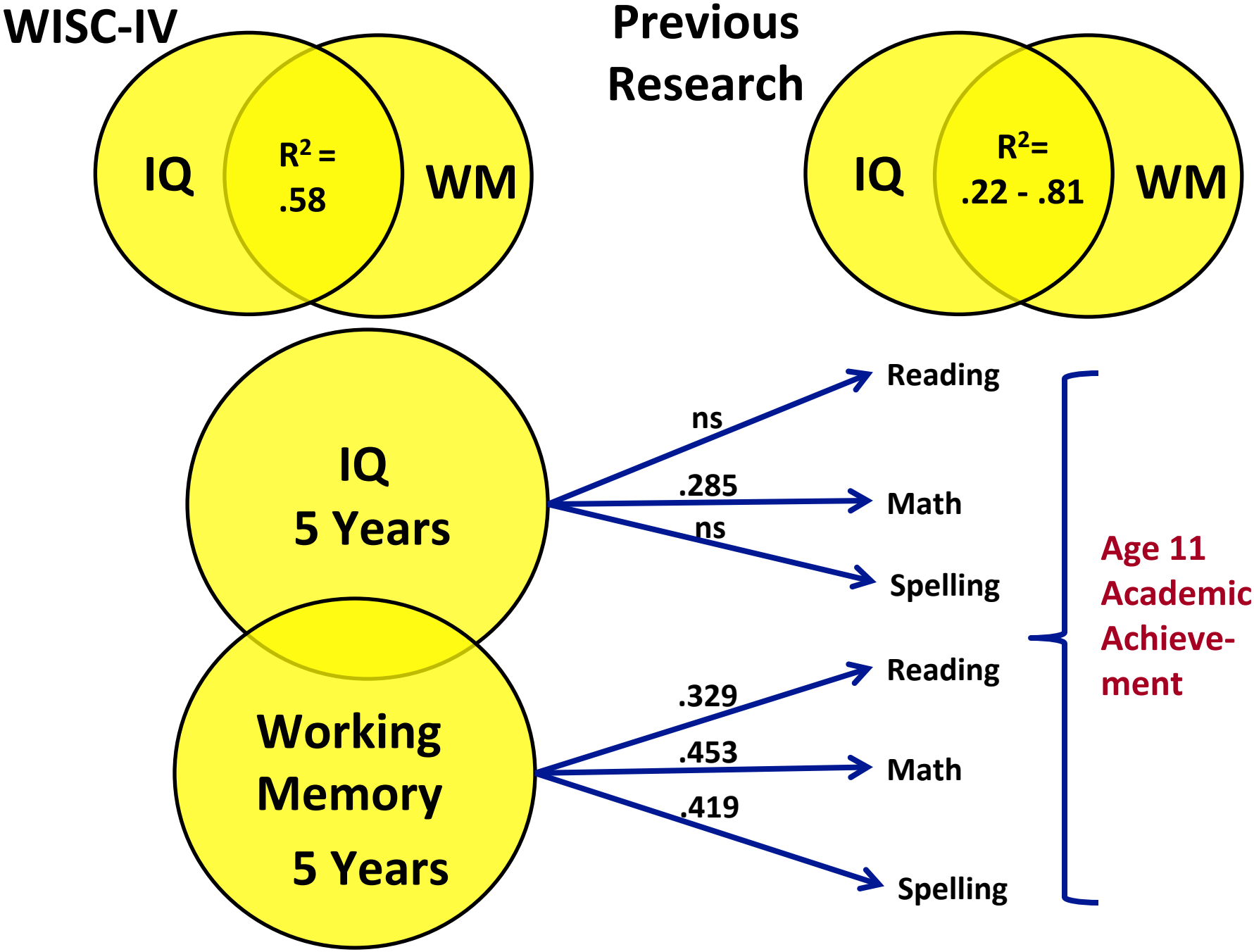
Figure 4. Path model for Model D. Significant paths are indicated by an asterisk. OSPAN = operation span; RSPAN = reading span; CSPAN = counting span; BSPAN = backward span; FSPAND = forward span, dissimilar; FSPANS = forward span, similar; WM = working memory; STM = short-term memory; *gF* = fluid intelligence.

The potential importance of working memory as a underlying core deficit in children with ADHD

Higher –order cognitive tasks, skills, and abilities dependent on working memory components

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


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)

Working memory impairments in children with ADHD

	WM Systems		WM Components		
	VS Working Memory	PH Working Memory	VS Storage/ Rehearsal	PH Storage/ Rehearsal	CE
Meta-analyses					
Martinussen et al. (2005)	--	--	0.85	0.47	0.43-1.06
Willcutt et al. (2005)	0.63	0.55	--	--	--
Brocki et al. (2008)	0.60	0.85	--	--	--
Martinussen & Tannock, (2006)	--	--	0.70	0.04	0.60-1.10
Marzocchi et al. (2008)	1.00	--	0.74	--	

Trends: (a) Deficits in both systems/all three subcomponents
(b) Deficits in CE > VS > PH

Working Memory Deficits in ADHD: The functional relationship between central executive processes, hyperactivity, and inattention

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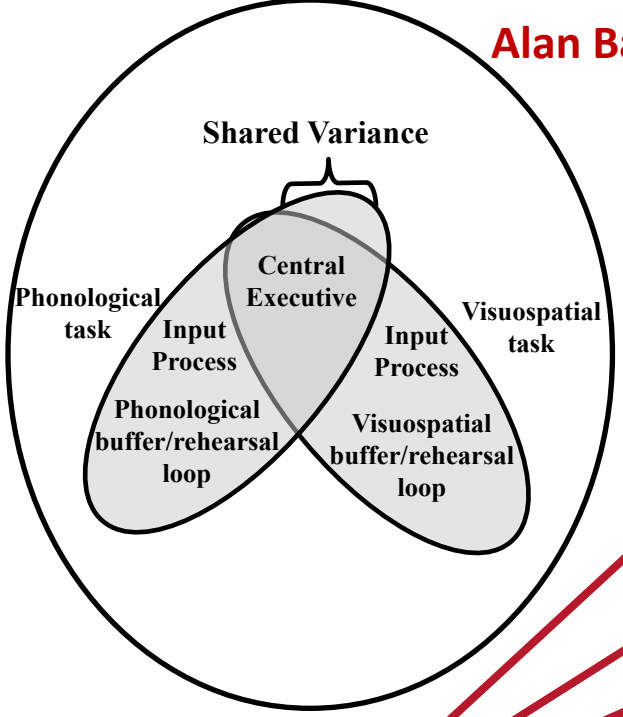
Alan Baddeley's (2007) WM Model



Domain General:
Internal Focus of Attention
Divided Attention
Interaction with LTM

Central Executive

Auditory Input

Visual Input

Visual Input

Phonological Analysis

Visuospatial Analysis

Visual analysis & STS

Phonological

STS

Inferior parietal lobe

Visuospatial

STS

Right hemisphere

Orthographic to phonological recoding

Rehearsal Process

Rehearsal Process

Phonological output buffer
Broca's area-premotor cortex

Visuospatial output buffer
Right premotor cortex

Spoken Output

Motor Output

Initial Focus:
Examining CE
& subsidiary
system processes

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)**

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:

	Time	Person
Detailed developmental history (includes pre/pari/post natal, 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	3 hr	Parent
TRF and CSI-T	.5 hr	Teacher
Additional Clinical Scales (CDI, Manifest Anxiety Scale, Behavioral/physical Complaints Scale)	.5 hr	Child
4, 3-hour assessment sessions, once per week x 4 consecutive weeks (Saturdays) x 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
	125 hours total per child	

30 participants require approximately 3750 hours
[excluding the r/o participants who fail to meet dx criteria]

Power Analysis

- **An average effect size (ES) of 0.70 was calculated based on the average magnitude of ADHD PH and VS deficits reported by Martinussen et al. (2005).**

- **GPower software version 3.0.5 (Faul, Erdfelder, Lang, & Buchner, 2007) was used to determine needed sample size using this ES, with power set to .80 as recommended by Cohen (1992).**

- **For an ES of 0.70, $\alpha = .05$, power $(1 - \beta) = .80$, 2 groups, and 4 repetitions (i.e., set sizes), 20 total subjects are needed for a repeated measures ANOVA to detect differences and reliably reject H_0. 23 total children participated in the study**

Sample and Demographic Variables

Variable	ADHD (n = 12)		Typically Developing (n = 11)		
	Mean	SD	Mean	SD	*F*
Age	8.75	1.29	9.36	1.43	1.17
FSIQ	100.92	15.22	110.18	13.11	2.43
SES	43.46	12.25	52.50	7.57	6.13*
CBCL					
Attention Problems	78.50	10.53	55.64	7.06	36.68***
TRF					
Attention Problems	66.25	8.83	48.73	16.92	9.94**
CSI-Parent					
ADHD, Combined	12.67	3.85	3.00	4.98	27.42***
CSI-Teacher					
ADHD, Combined	9.83	5.32	2.73	3.93	13.06**

Note: ADHD = attention-deficit/hyperactivity disorder; CBCL = Child Behavior Checklist; CSI = Child Symptom Inventory; FSIQ = Full Scale Intelligence Quotient; SES = Socioeconomic Status; TRF = Teacher Report Form.
* $p \leq .05$, ** $p \leq .01$, *** $p \leq .001$

Phonological (PH) Working Memory Task

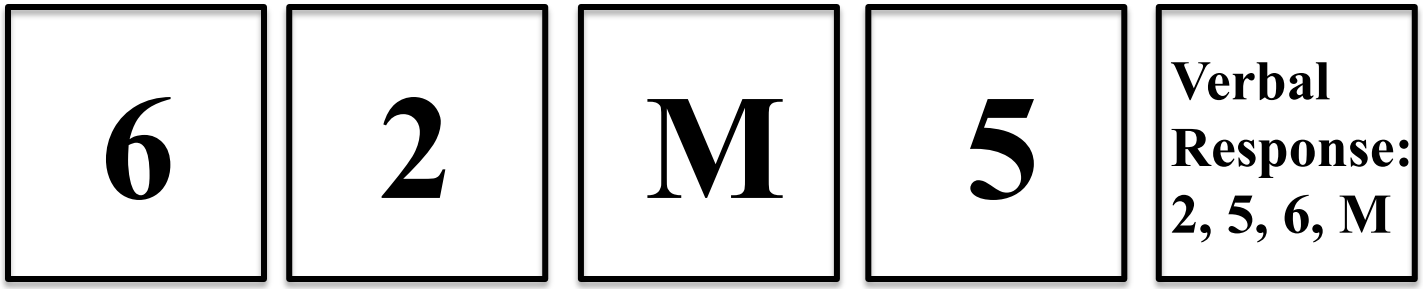
Storage component: child must hold 3 to 6 stimuli in memory

Processing component: child must manipulate the order of stimuli from low to high, and mentally move the letter to the last place during recall

Phonological (PH) WM Task

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

Phonological Task



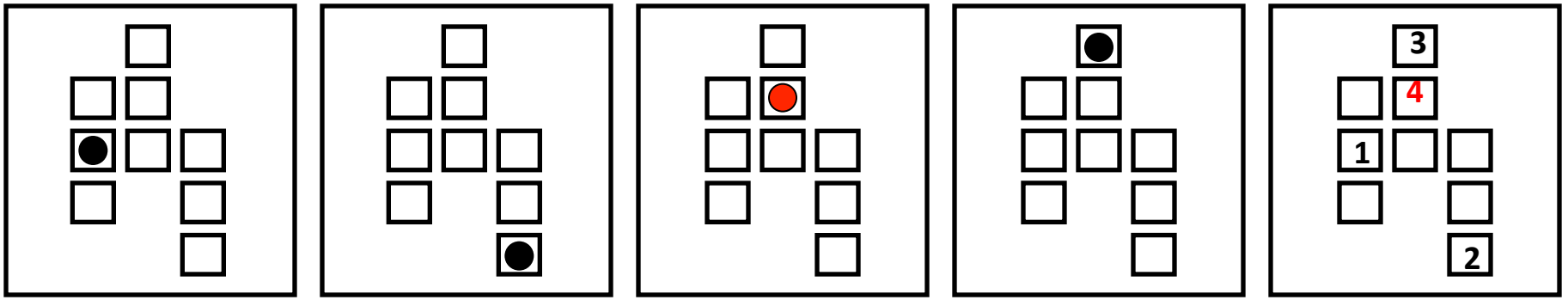
Correct Response Sequence

3, 4, 5, 6 stimuli sequences

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.

Visuospatial Task

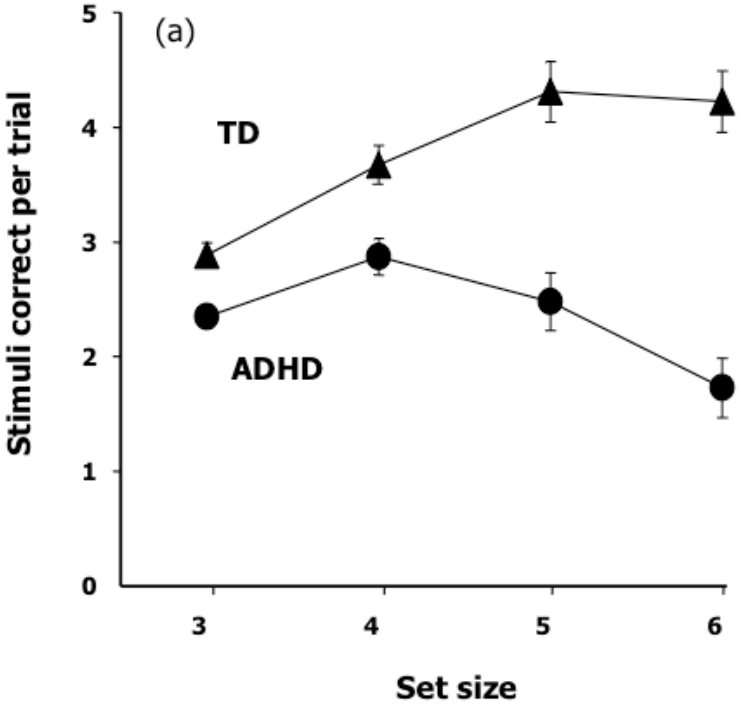


Black Dot 1 | **Black Dot 2** | **Red Dot** | **Black Dot 3** | **Correct Response Sequence**

3, 4, 5, 6 stimuli sequences

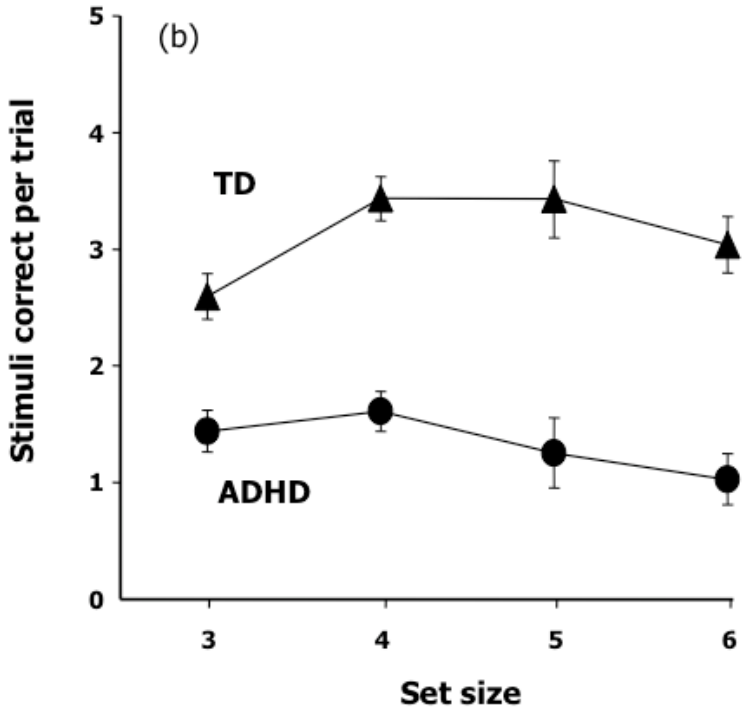
Phonological and Visuospatial WM Deficits in boys with ADHD

ES = 1.89



Phonological WM

ES = 2.31

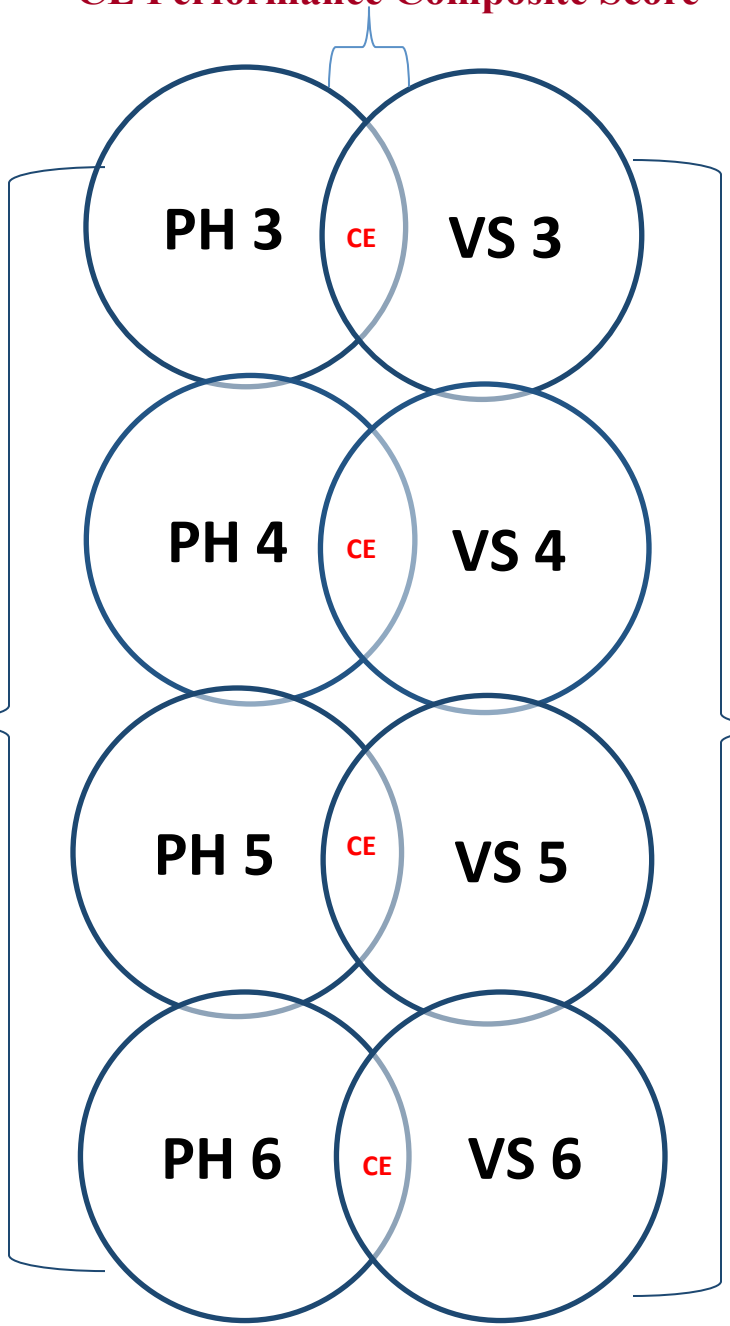


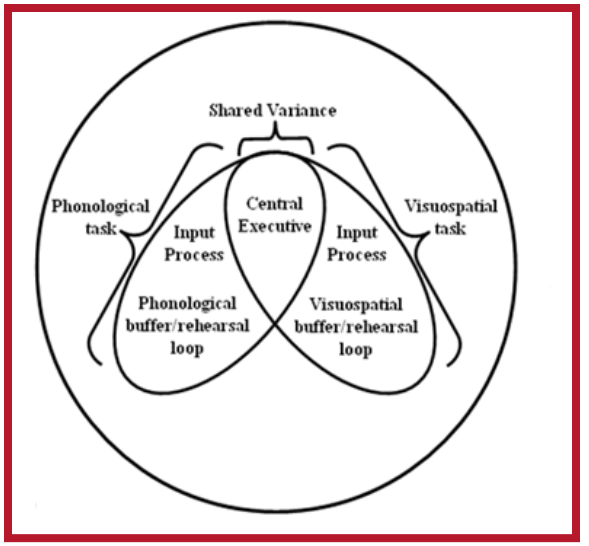
Visuospatial WM

Rapport, Alderson, Kofler, Sarver, Bolden, & Sims (2008).
***J of Abnormal Child Psychology*, *36*, 825-837.**

PH, VS, and CE Performance Composite Scores

CE Performance Composite Score





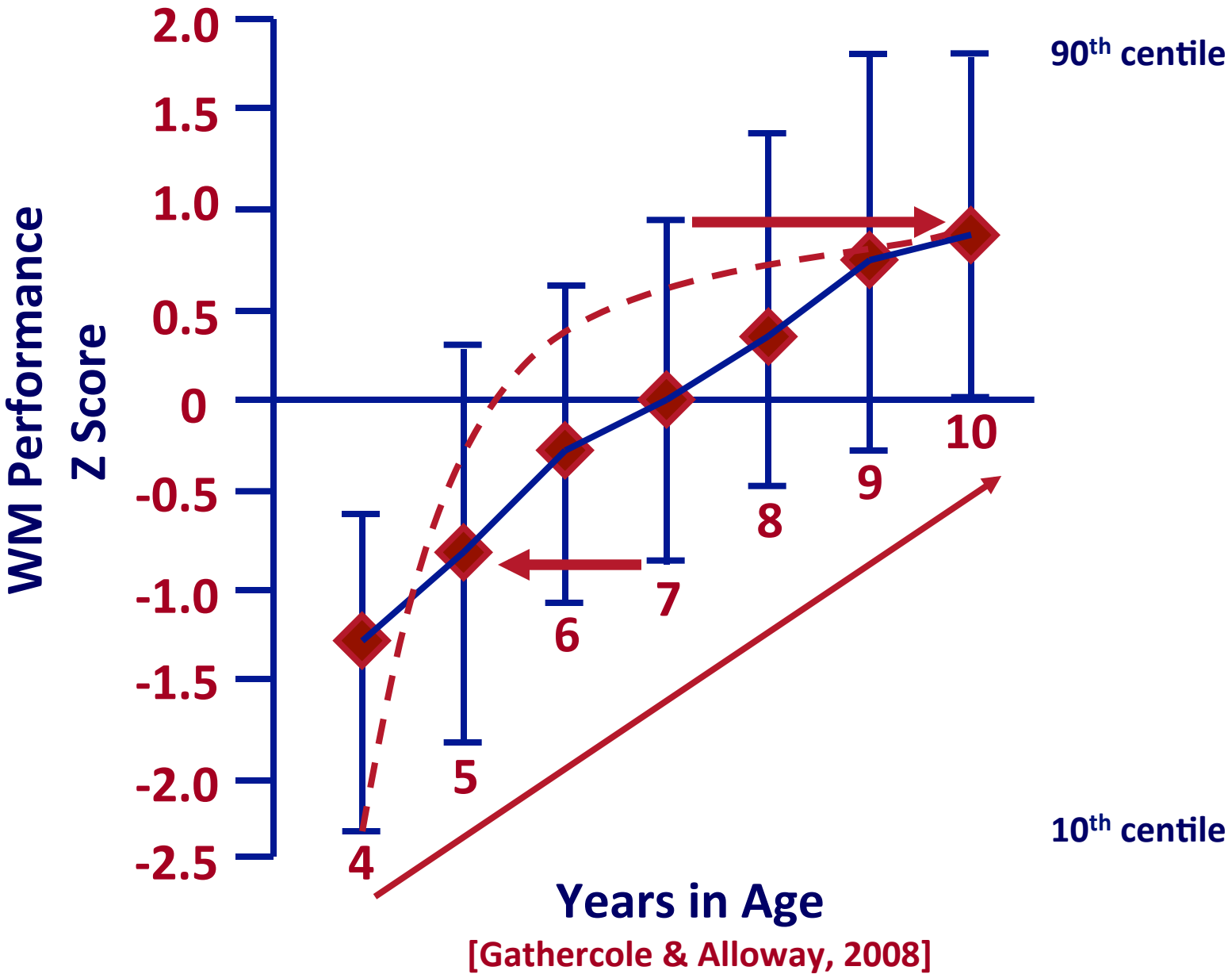
CE ES = 2.76

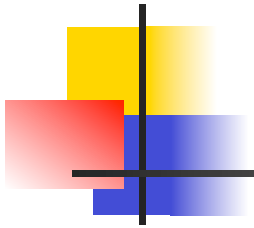
PH Storage/Rehearsal Performance Composite Score

PH ES = .55
[1.89 w/CE]

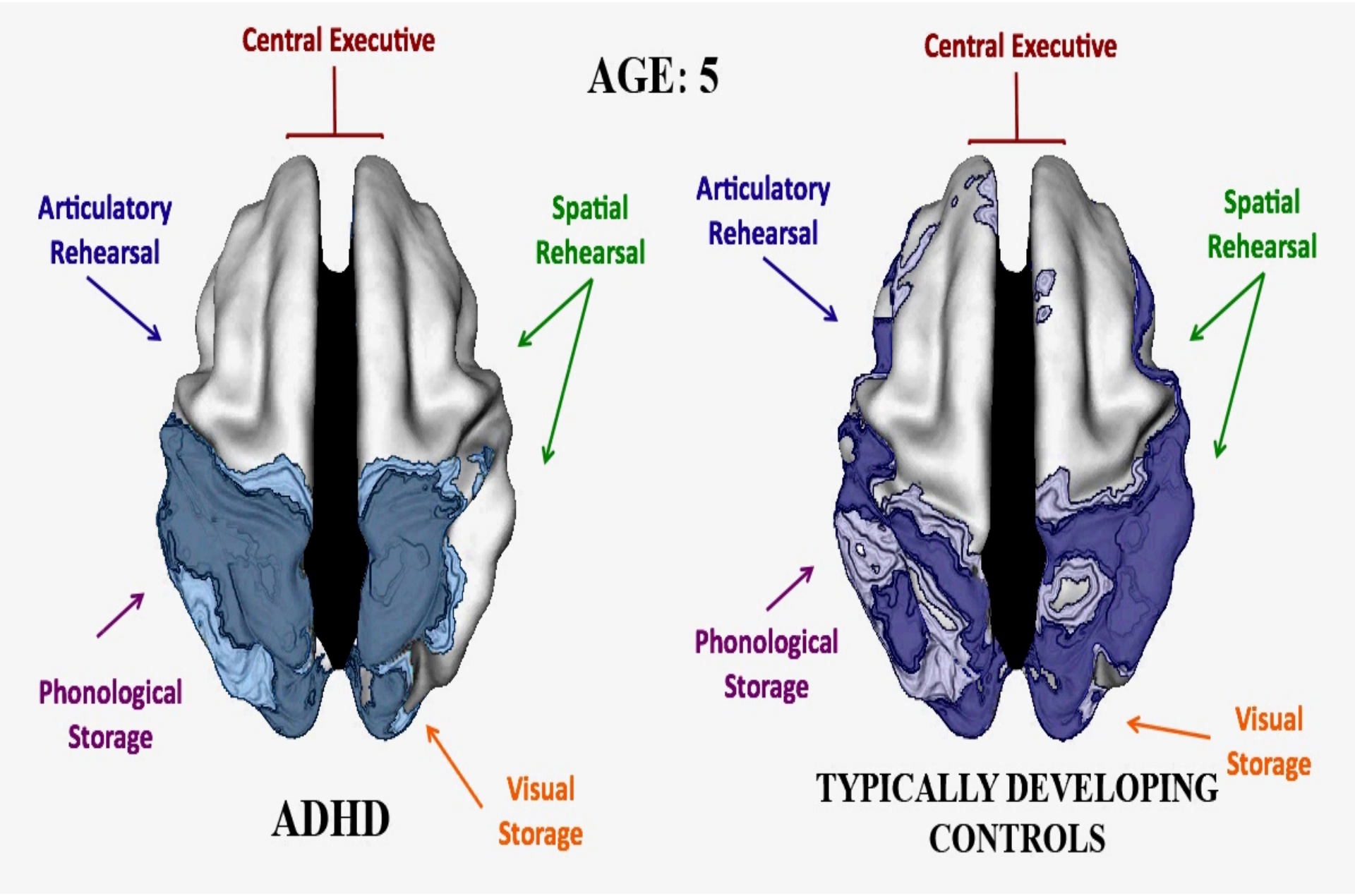
VS Storage/Rehearsal Performance Composite Score

VS ES = .89
[2.31 w/CE]

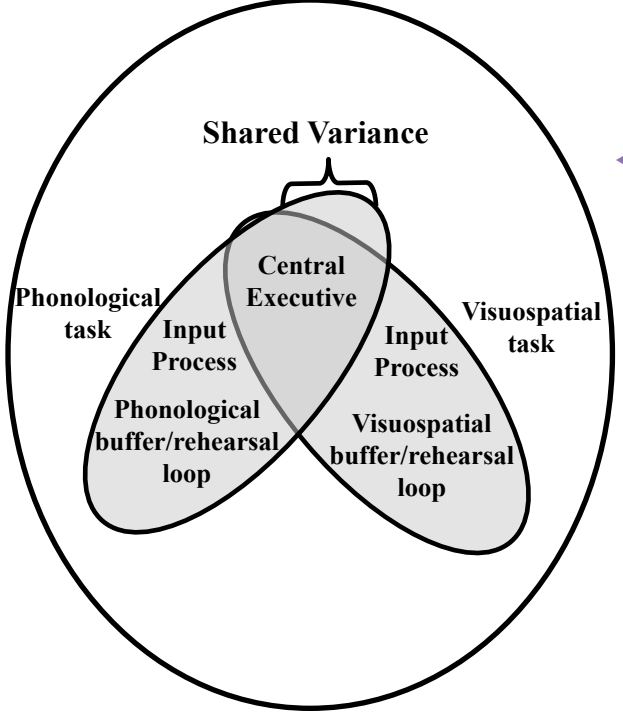

WM Performance
Z Score
2.0
1.5
1.0
0.5
0
-0.5
-1.0
-1.5
-2.0
-2.5
4
5
6
7
8
9
10
90th centile
10th centile
Years in Age
[Gathercole & Alloway, 2008]



Shaw et al. 2007 ADHD & Cortical Development


AGE: 5
Central Executive
Articulatory Rehearsal
Spatial Rehearsal
Phonological Storage
Visual Storage
ADHD
Central Executive
Articulatory Rehearsal
Spatial Rehearsal
Phonological Storage
Visual Storage
TYPICALLY DEVELOPING CONTROLS

Alan Baddeley's (2007) WM Model



Domain General

Central Executive

Auditory Input

Visual Input

Visual Input

Phonological Analysis

Visual analysis & STS

Visuospatial Analysis

Phonological

STS

Inferior parietal lobe

Orthographic to phonological recoding

Visuospatial

STS

Right hemisphere

PH Store

Subvocal Rehearsal

Rehearsal Process

Rehearsal Process

Phonological output buffer
Broca's area-premotor cortex

Visuospatial output buffer
Right premotor cortex

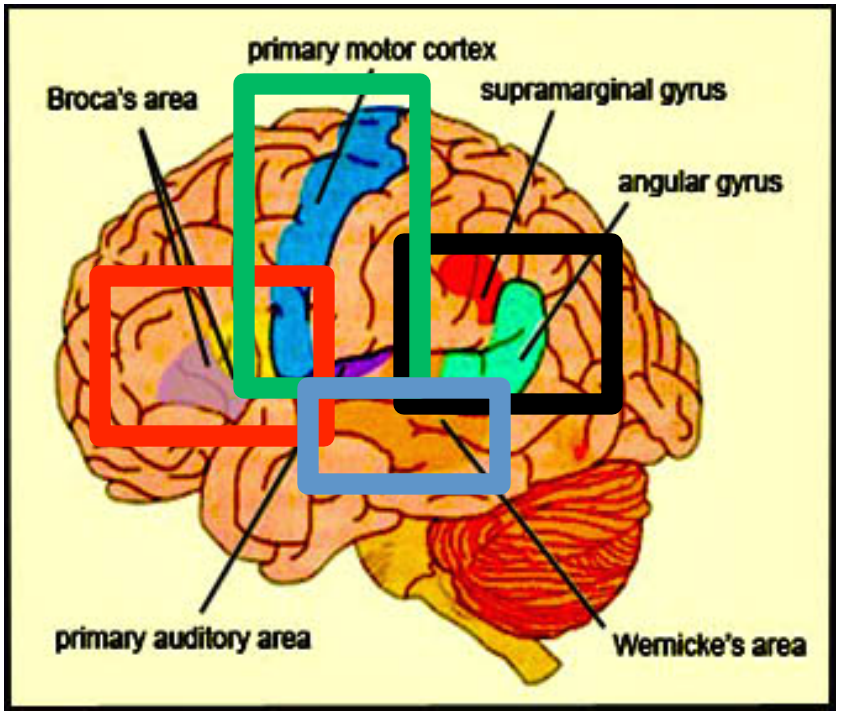
Spoken Output

Motor Output

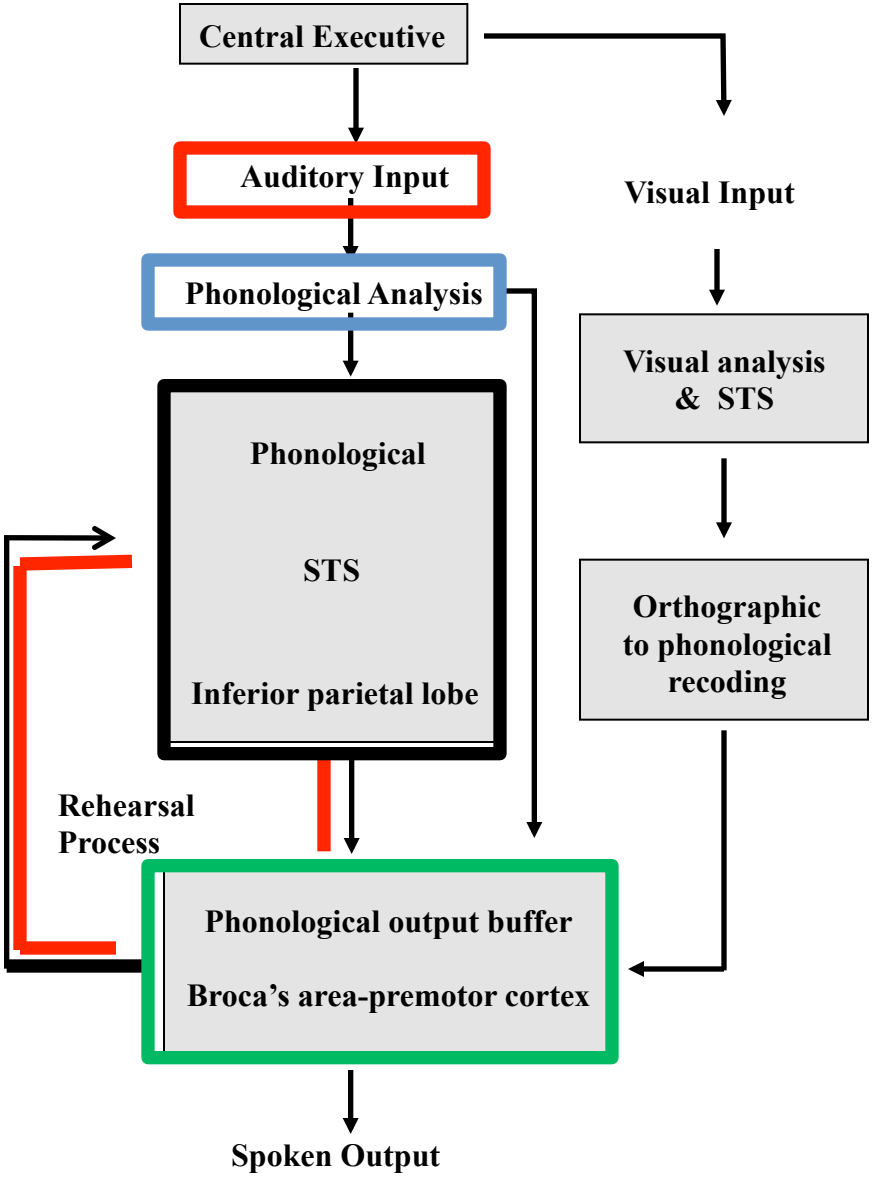
To what extent do WM related phonological (PH) deficits reflect short-term storage as opposed to articulatory (covert) rehearsal deficiencies?

Bolden, J., Rapport, M.D., Raiker, J.S., Sarver, D.E., & Kofler, M.J. (2012). Understanding Phonological Memory Deficits in Boys with Attention-Deficit/Hyperactivity Disorder (ADHD): Dissociation of Short-term Storage and Articulatory Rehearsal Processes. *Journal of Abnormal Child Psychology, 40*, 999-1011.

Phonological Working Memory

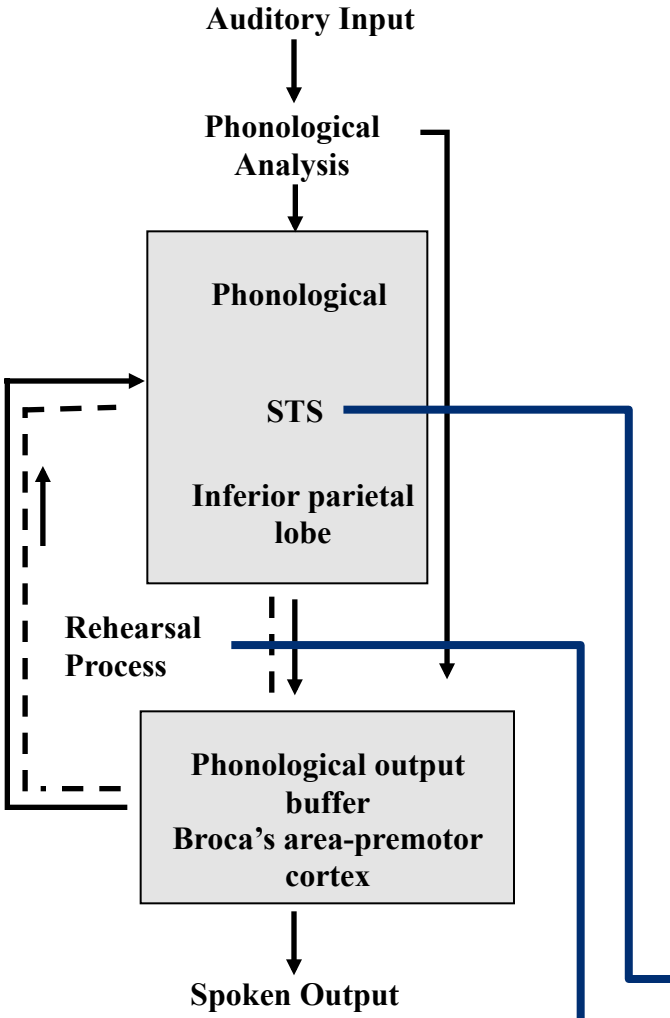


http://docsbrainblocks.com/images/dyslexia_1.jpg



Baddeley, 2007

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)

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

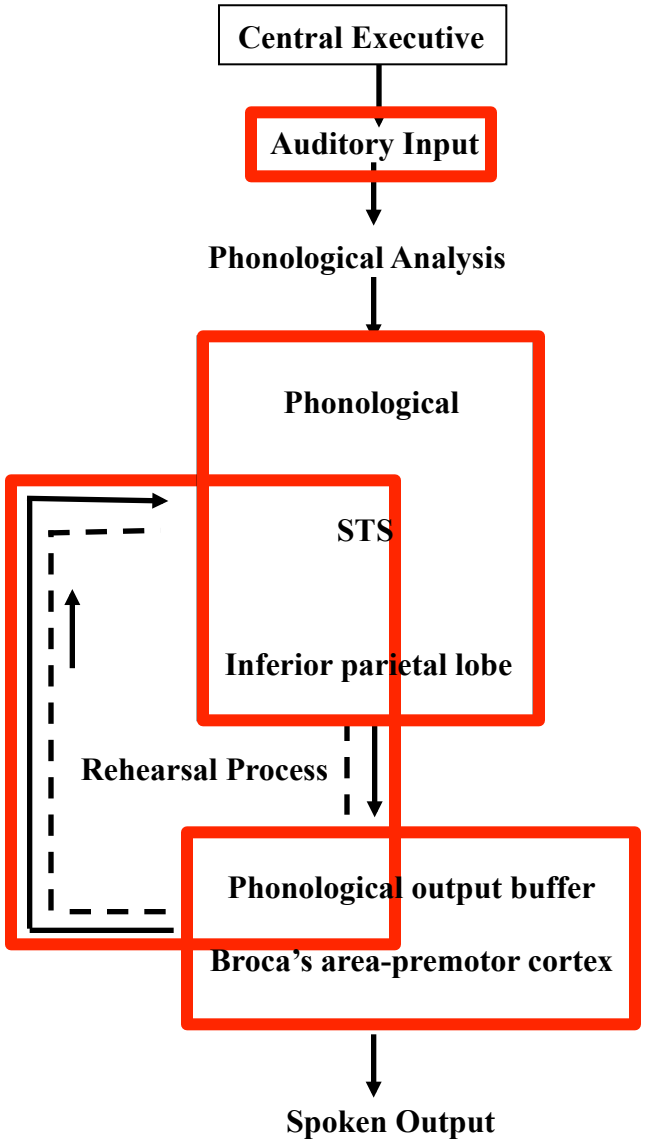
Storage/Rehearsal

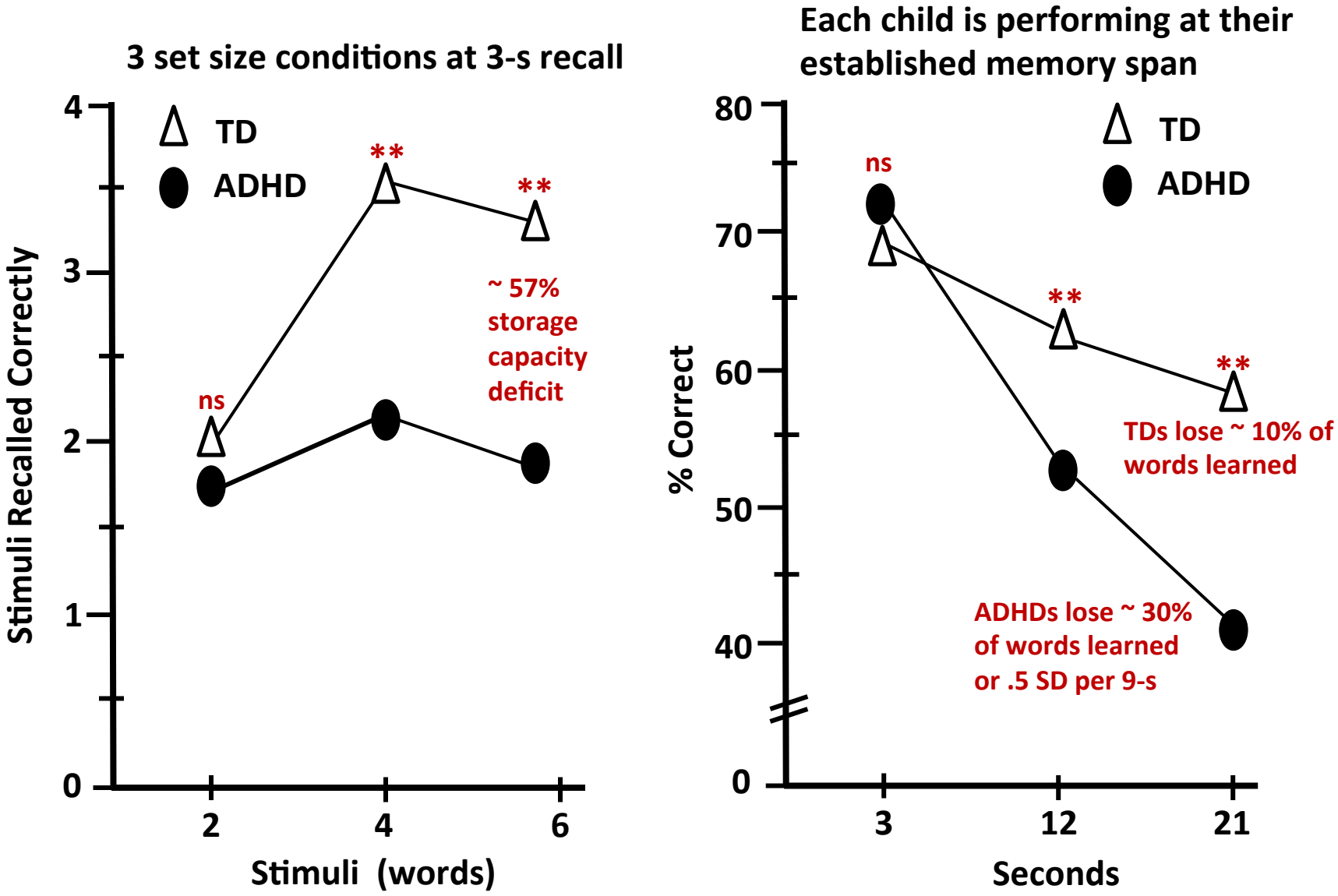
3-seconds delay
12-seconds delay
21-seconds delay

Recall Phase

21 distinct trials at each list length

List length set based on each child's span



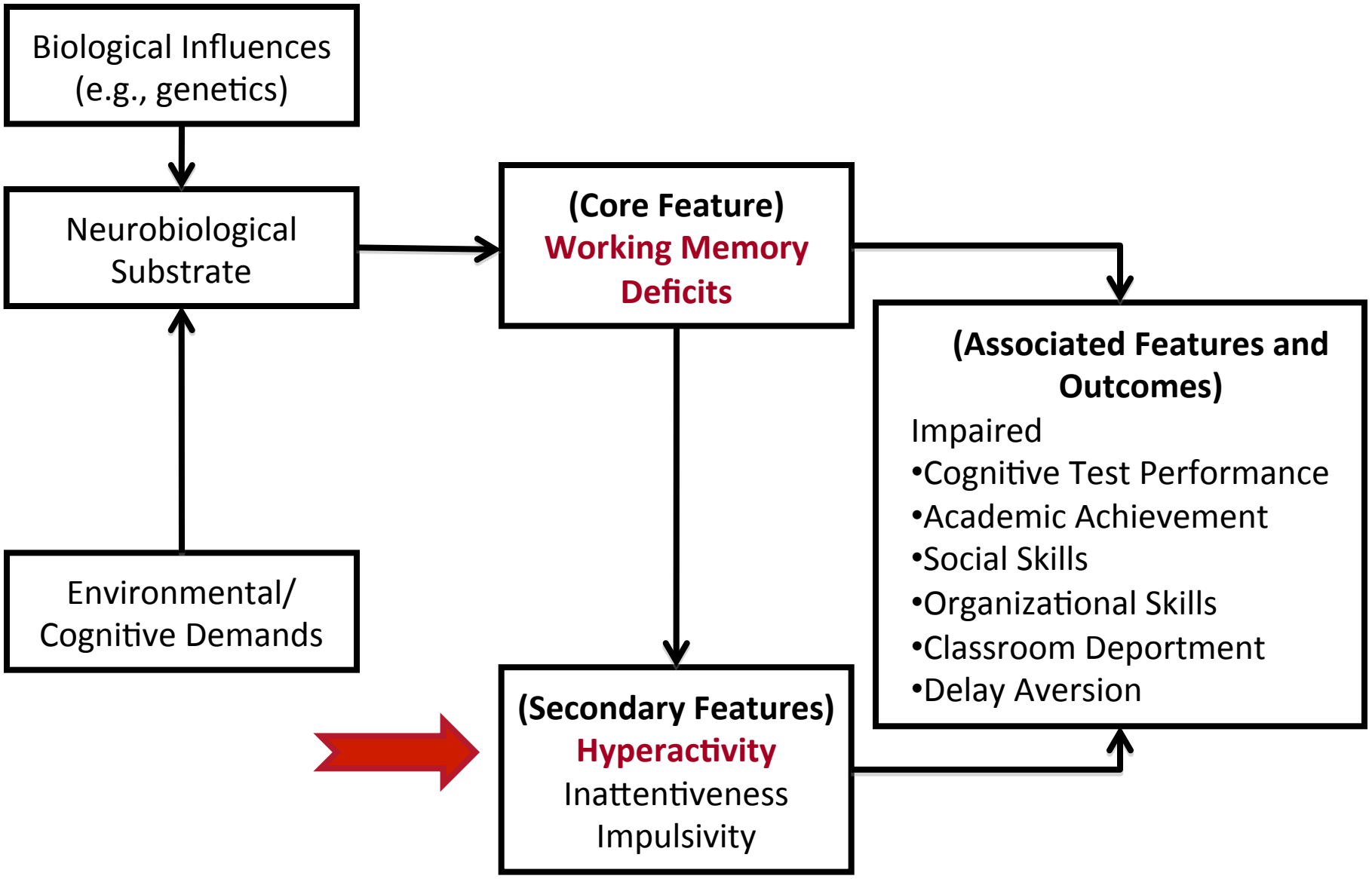


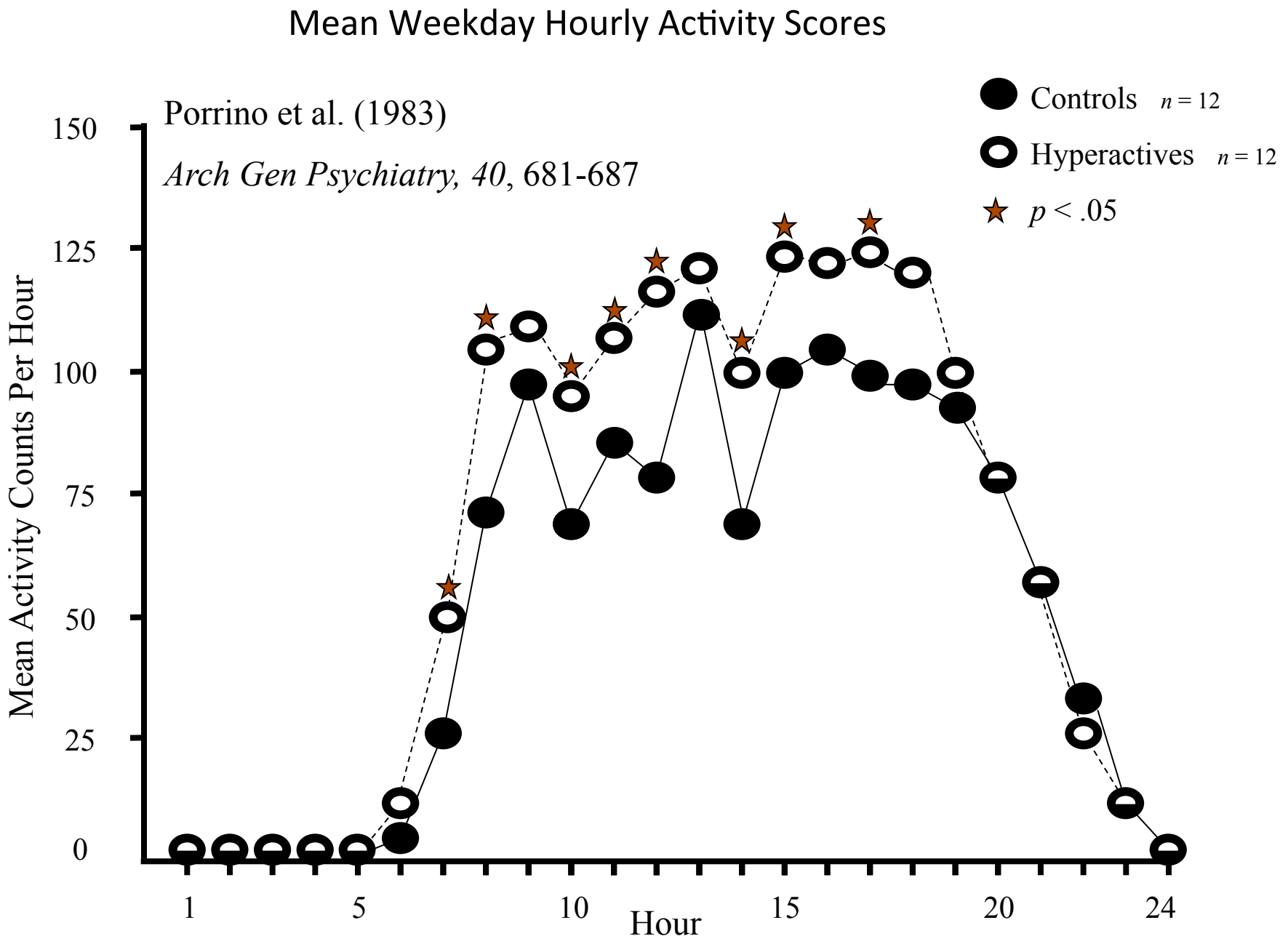
Short-term storage capacity ES = 1.15 to 1.98
Articulatory rehearsal ES = .47 to 1.02

Are components of working memory functionally related to hyperactivity?

Rapport, M.D., Bolden, J., Kofler, M.J., Sarver, D.E., Raiker, J.S., Alderson, R.M. (2009). Hyperactivity in Boys with Attention-Deficit/Hyperactivity Disorder (ADHD): A Ubiquitous Core Symptom or Manifestation of Working Memory Deficits? *Journal of Abnormal Child Psychology*, *37*, 521-534.

Working Memory Model of ADHD




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
150
125
100
75
50
25
0
1
5
10
15
20
24
Hour

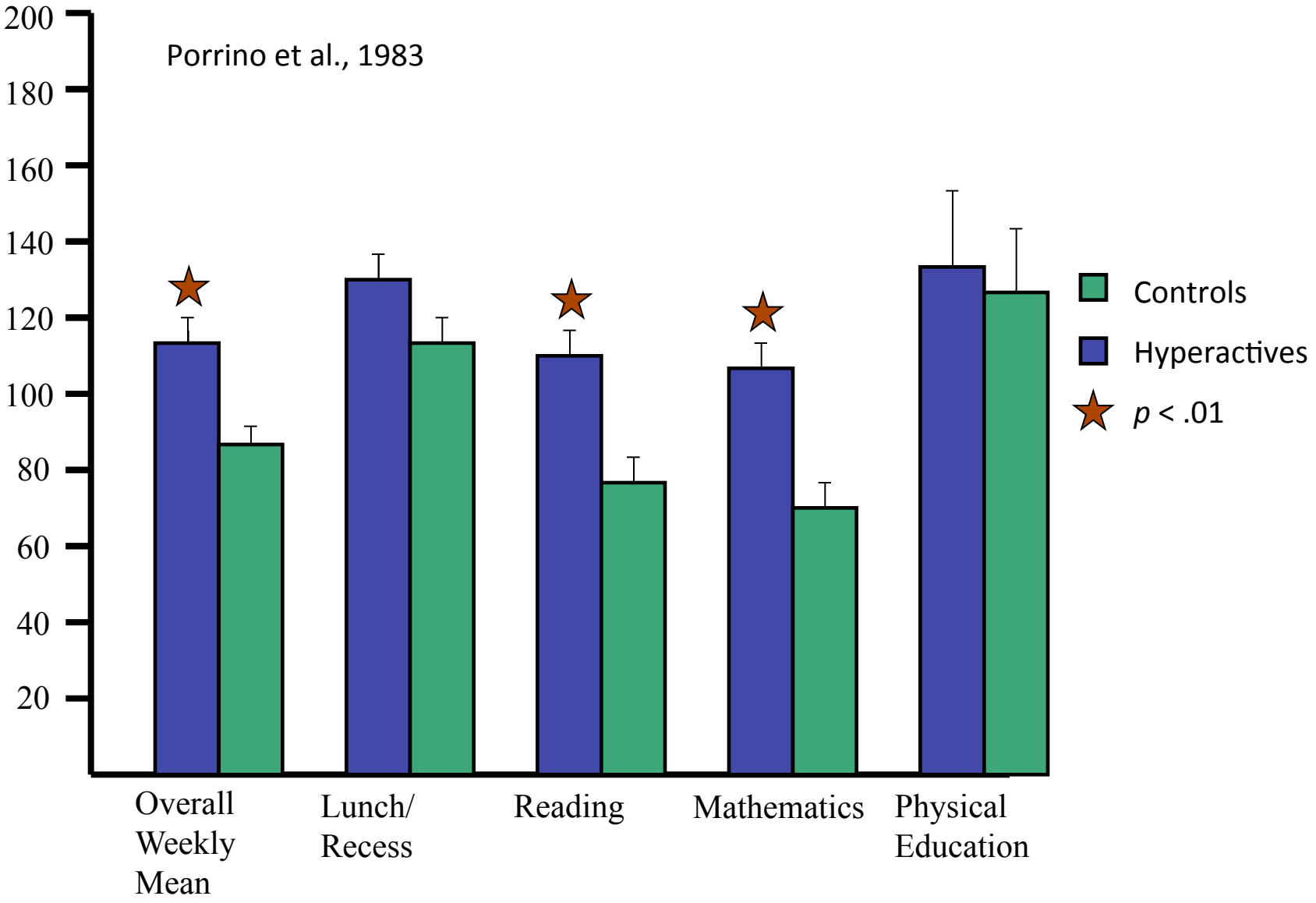
“Little evidence was found, however, to support the hypothesis that hyperactivity is simply an artifact of the structure and attentional demands of a given setting.” p.681

“… 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

Porrino et al. (1983). *Archives of General Psychiatry, 40*, 681-687.

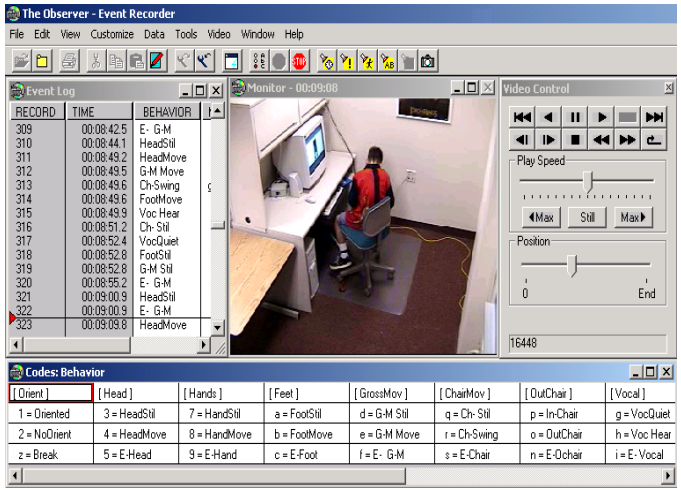
Mean Hourly Activity Scores During the Week



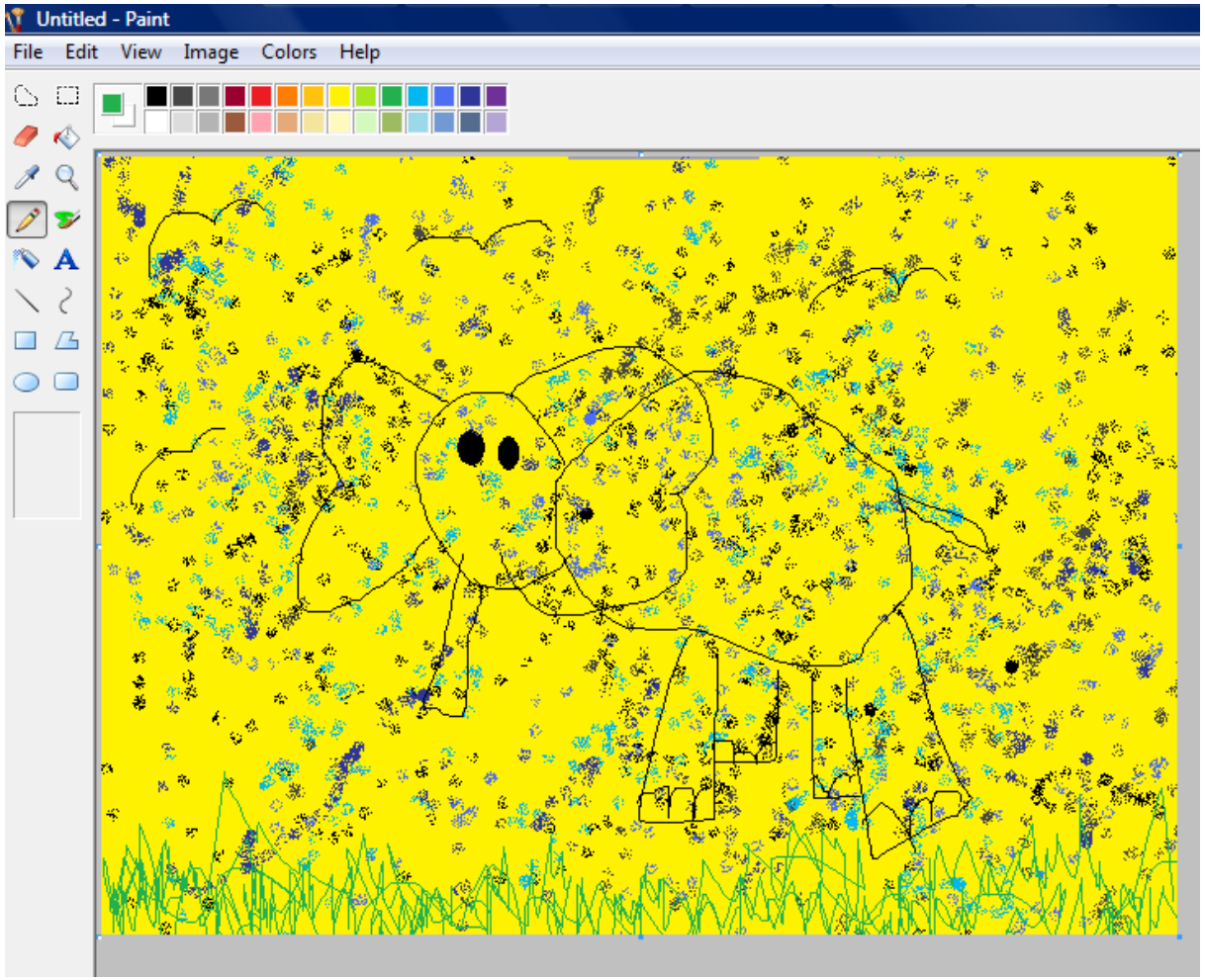
DEPENDENT MEASURES AND TECHNIQUES

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



Control Conditions



- Children were instructed to use the Microsoft® Paint program for five consecutive minutes both prior to (C1) and after (C2) completing the VS and PH tasks during four consecutive Saturday assessment sessions.
- The Paint program served as pre and post conditions to control for potential within-day fluctuations in attention and fatigue effects, and because it requires no storage or CE processing

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.

Power Analysis

- **An average effect size (ES) of 0.72 was calculated from two studies providing actigraph means and *SD*s for children with ADHD and typically developing (TD) children during laboratory tasks (Dane, Schachar, & Tannock, 2000; Halperin et al., 1992).**

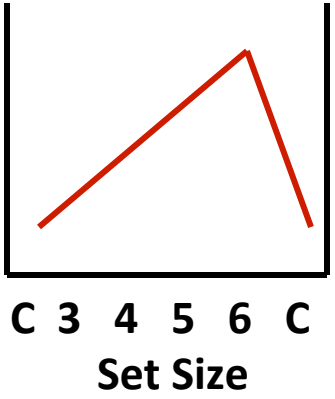
- **GPower software version 3.0.5 (Faul, Erdfelder, Lang, & Buchner, 2007) was used to determine needed sample size using this ES, with power set to . 80 as recommended by Cohen (1992).**

- **For an ES of 0.72, $\alpha = .05$, power $(1 - \beta) = .80$, 2 groups, and 6 repetitions (C1, set sizes 3-6, C2 as described below), 18 total subjects are needed for a repeated measures ANOVA to detect differences and reliably reject H_0.**

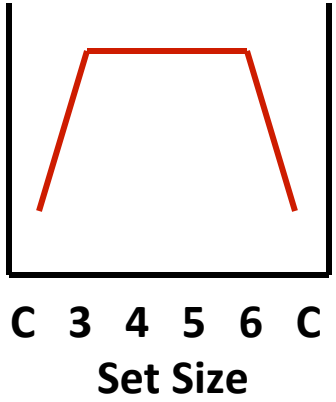
- **23 total children participated in the study**

Primary Hypothesis

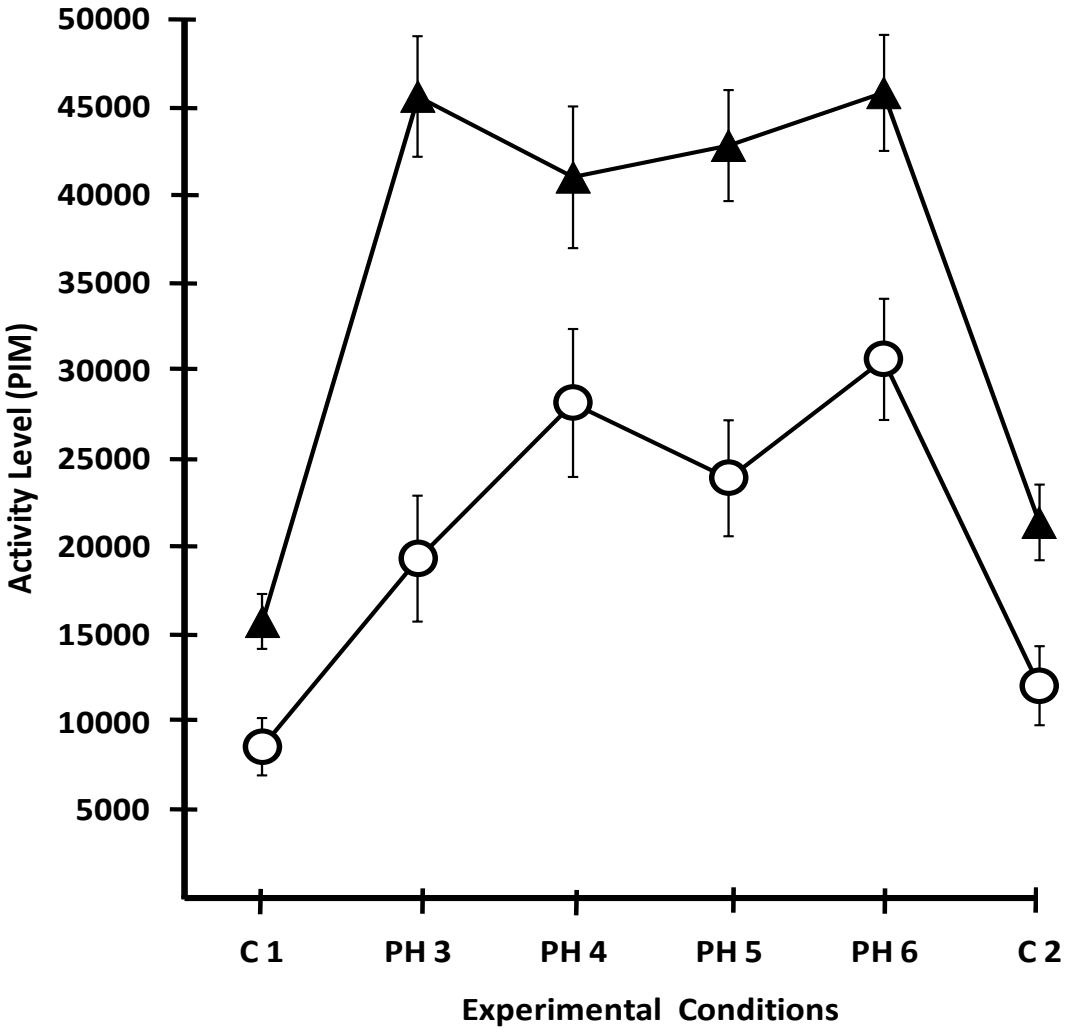
- If activity level is functionally related to PH/VS subsidiary system processes, we would expect movement to vary systematically as greater demands are imposed on the storage/rehearsal systems.



- 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).



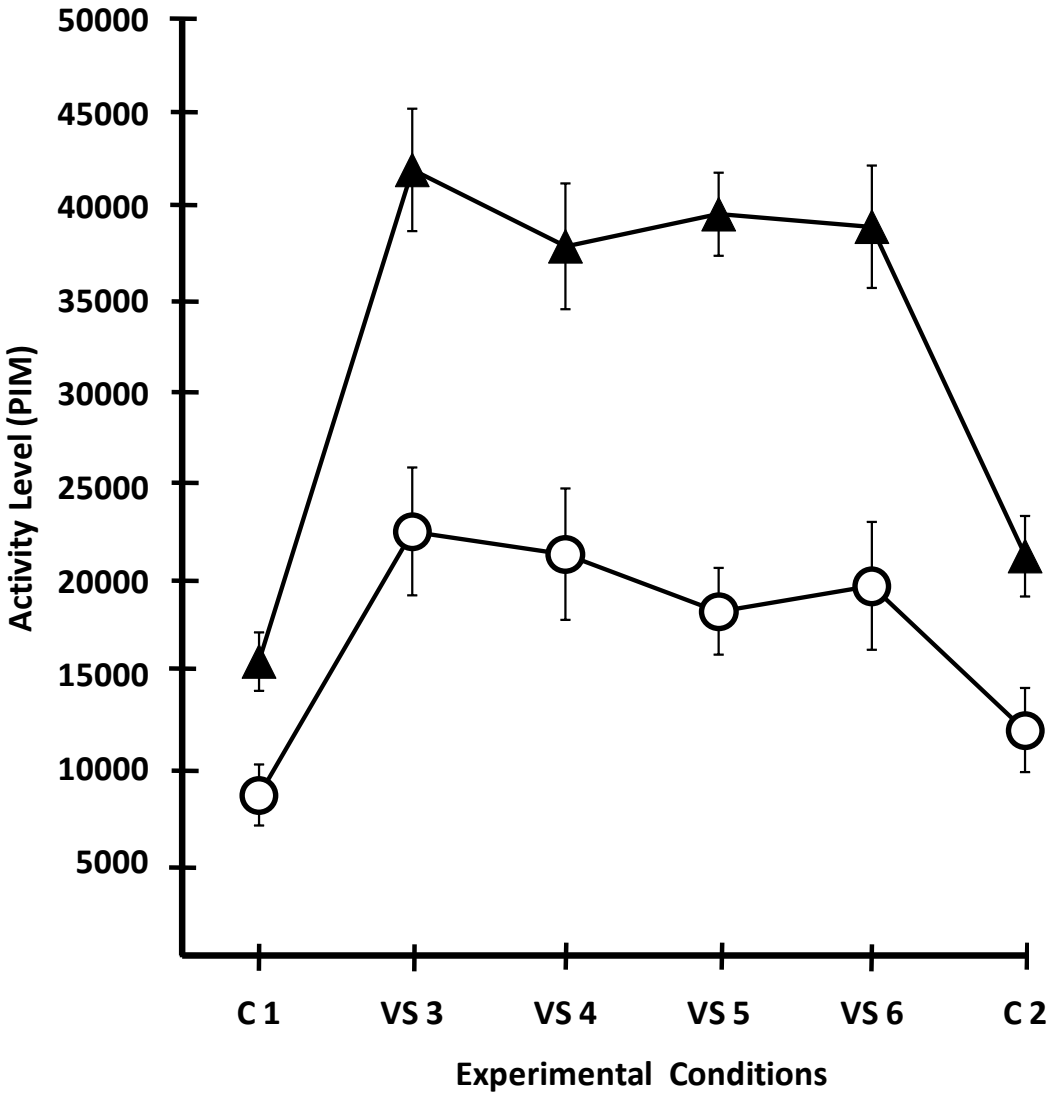
Activity Level Assessed During the PH and Control Conditions



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

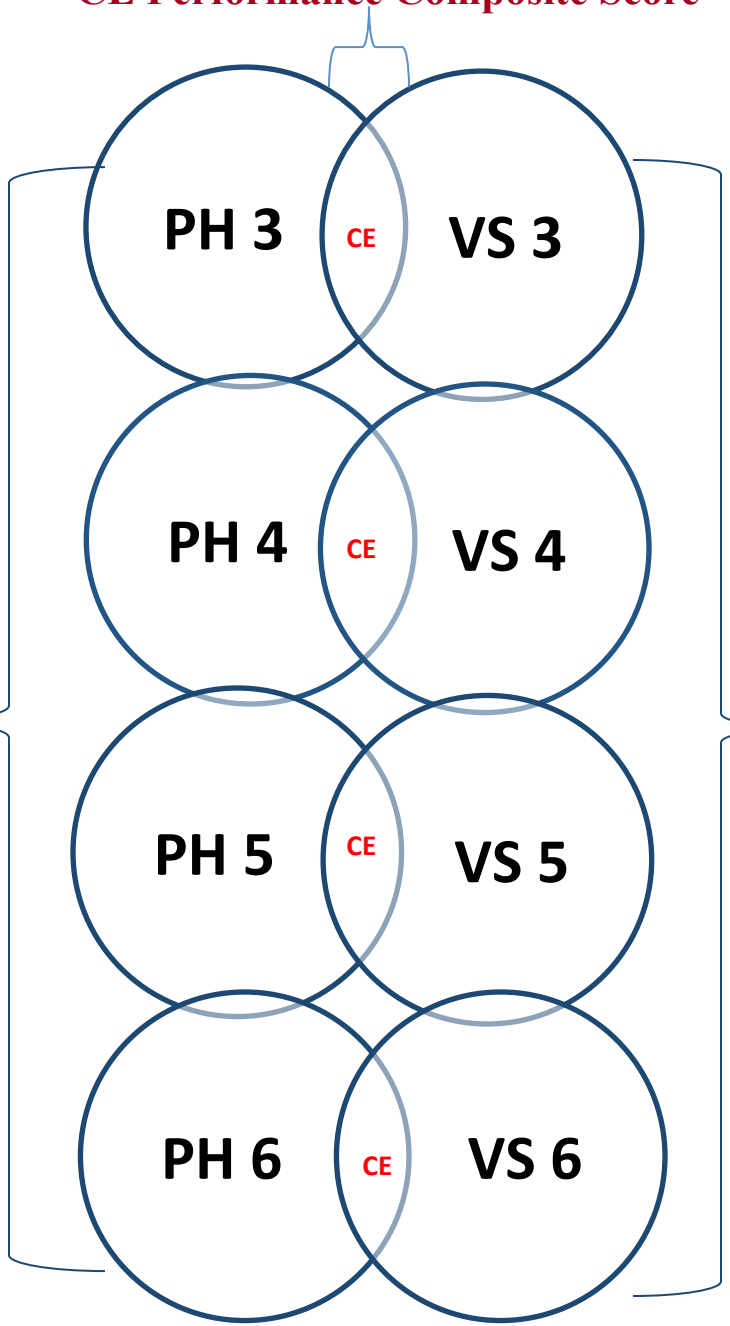


Hedges' *g* effect size indicated that the average magnitude difference in activity level between children with ADHD and TD children during visuospatial WM tasks was 1.83 standard deviation units (range=1.47 to 2.67).

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.

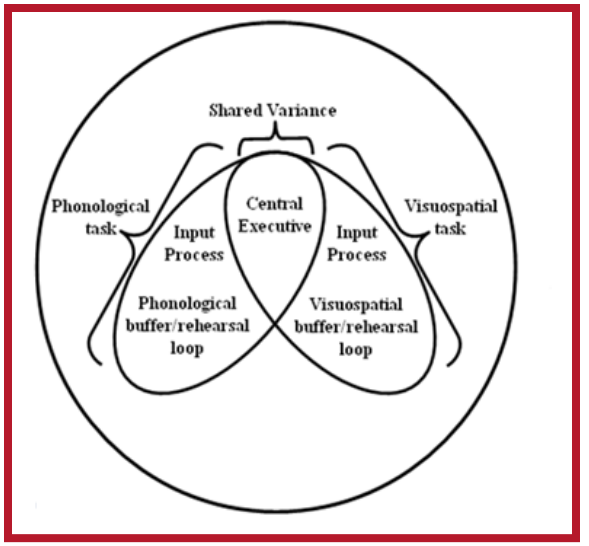
STEP 1:
PH, VS, and CE Performance Composite Scores

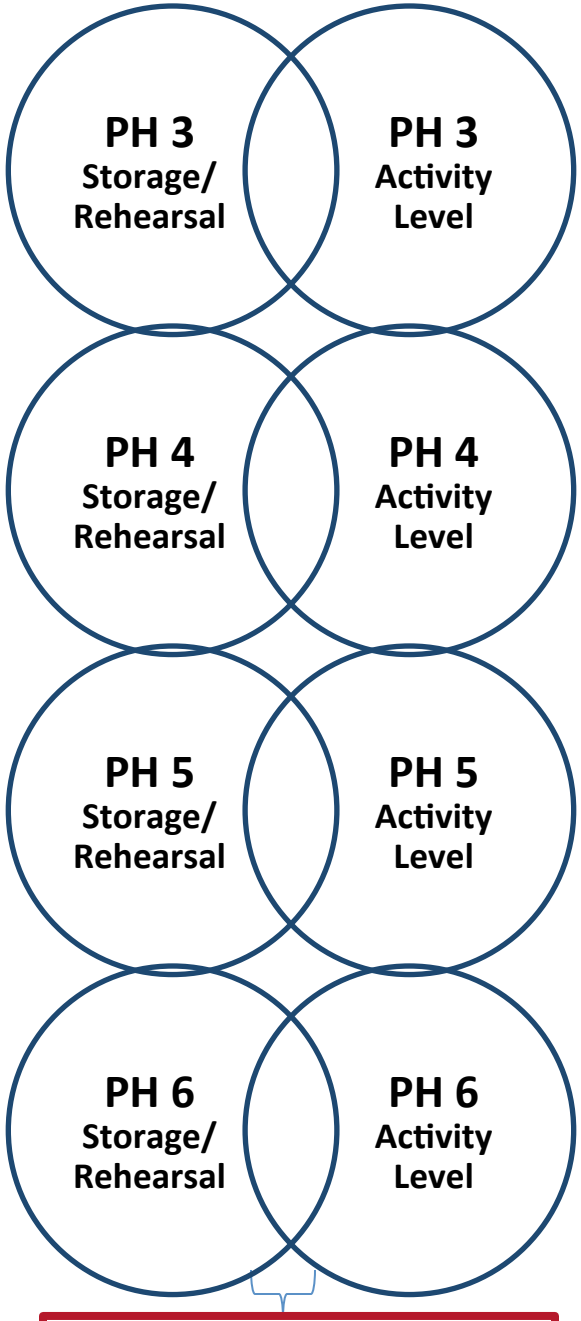
CE Performance Composite Score



PH Storage/Rehearsal Performance Composite Score

VS Storage/Rehearsal Performance Composite Score



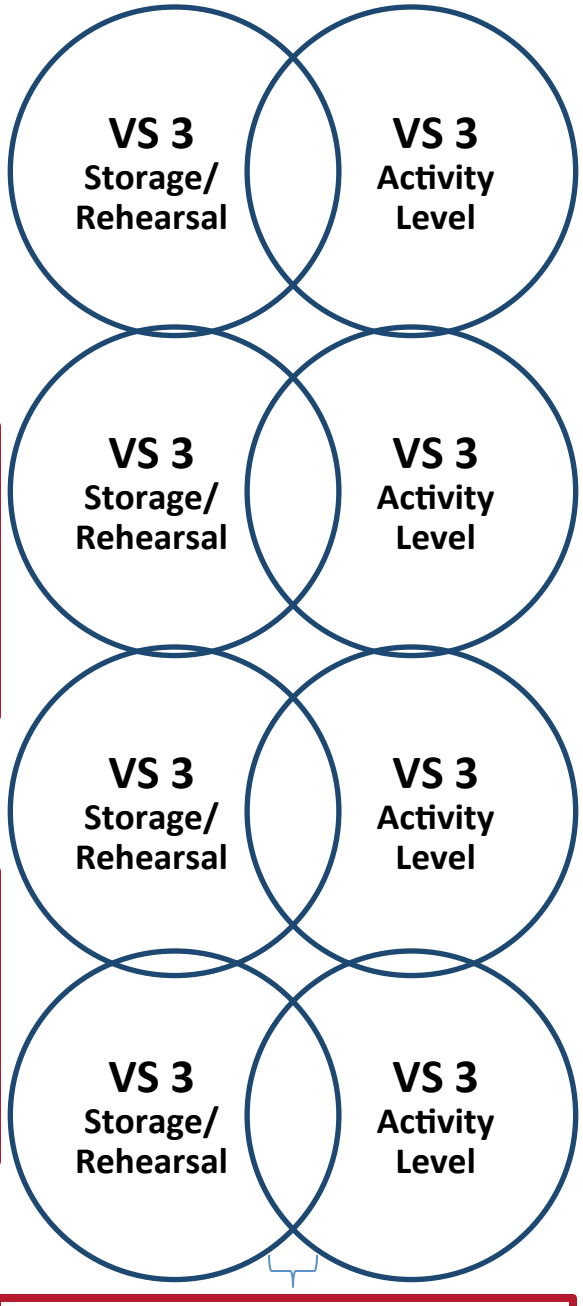


Activity level directly related to PH Storage/Rehearsal

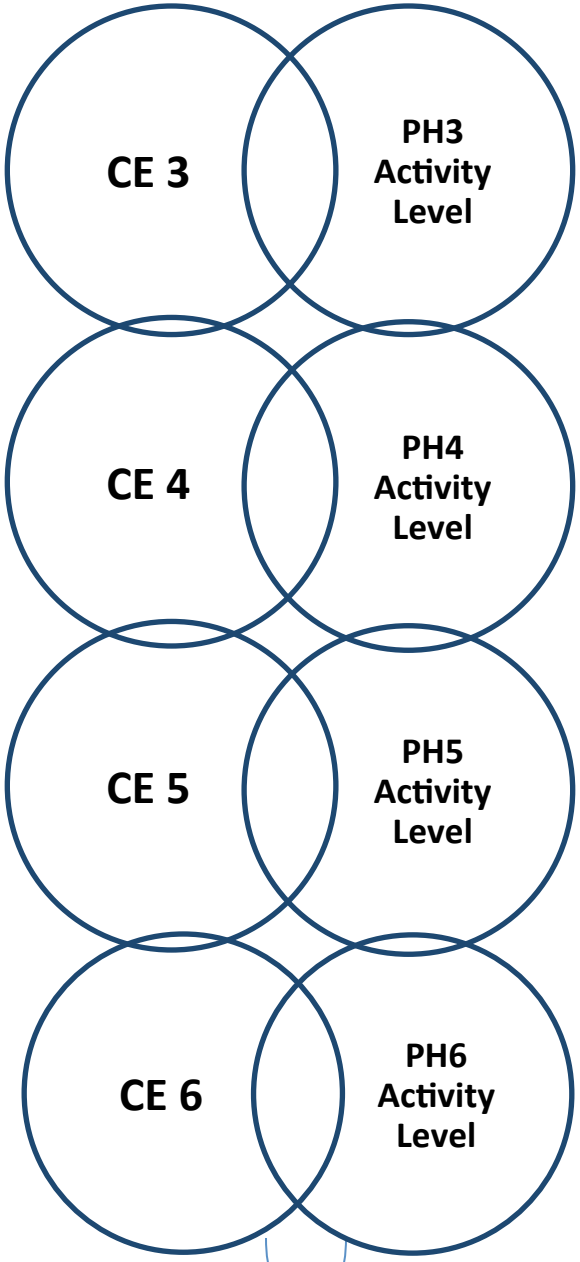
STEP 2:
Activity Level Directly Related to PH and VS Storage/Rehearsal Functioning

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).



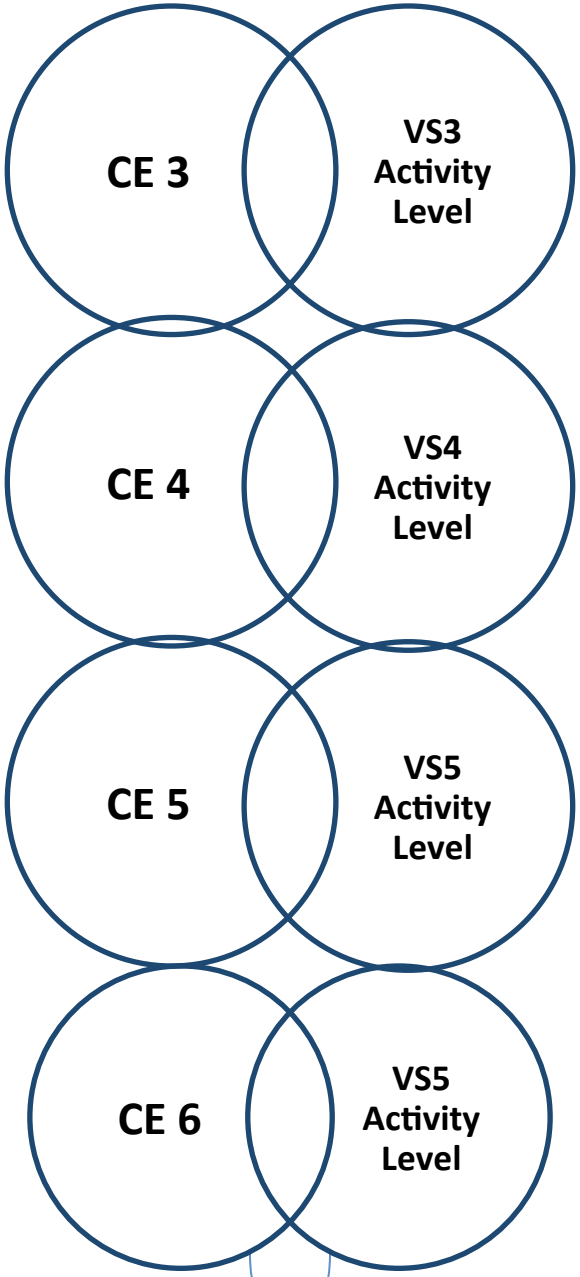
Activity level directly related to VS Storage/Rehearsal functioning



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).

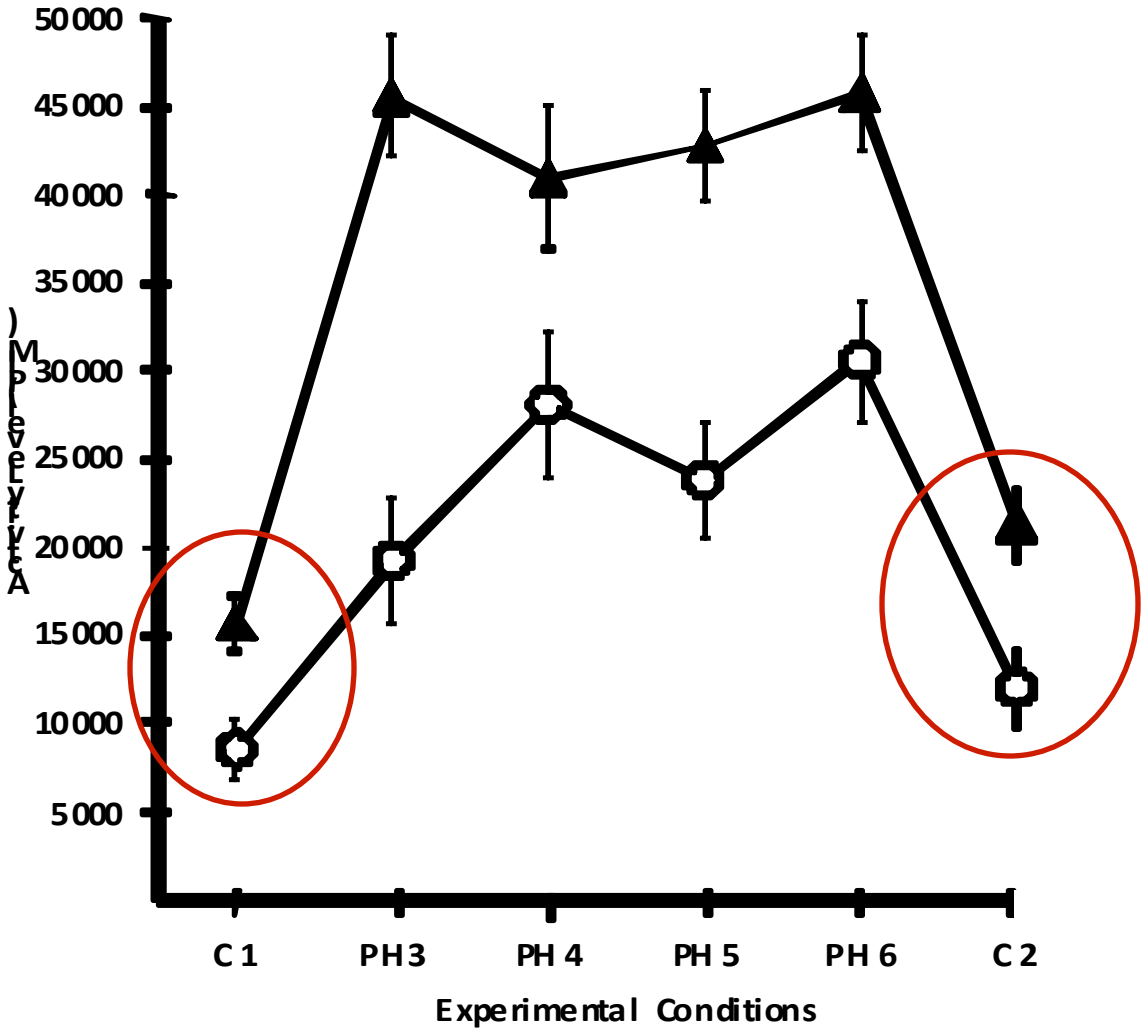


STEP 3: Activity Level Directly Related to CE Functioning

Activity level during the PH task that is directly related to CE functioning

Activity level during the VS task that is directly related to CE functioning

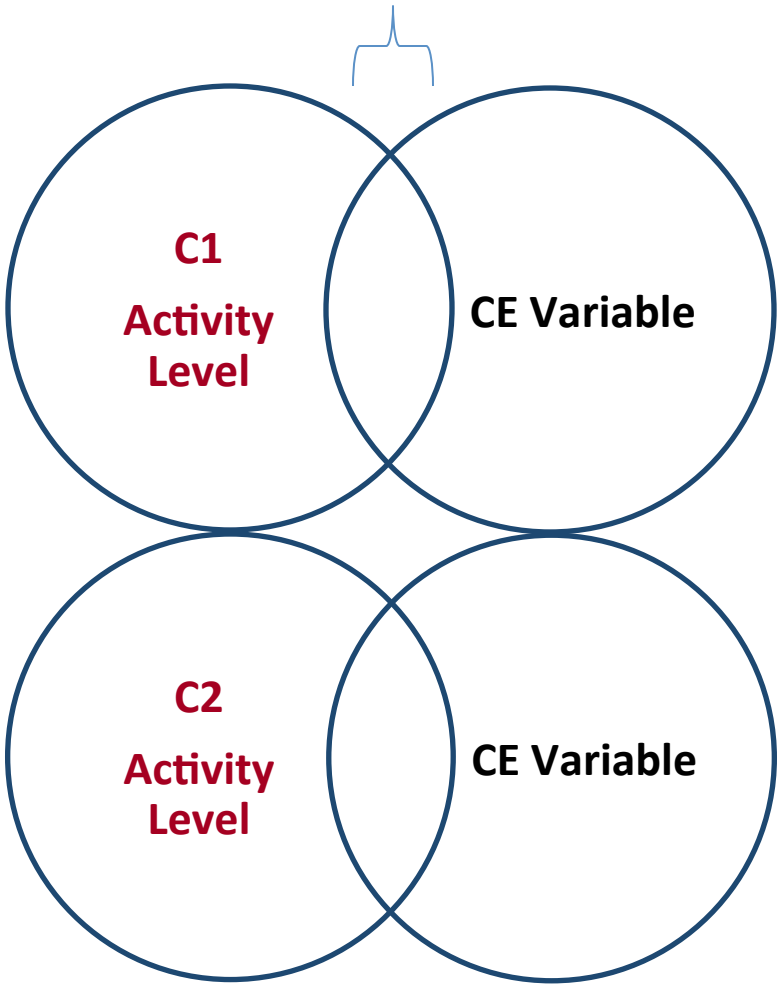
Activity Level Assessed During the PH and Control Conditions



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.

STEP 4:
Activity Level Assessed During the Control Conditions that is unrelated to CE Functioning

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.

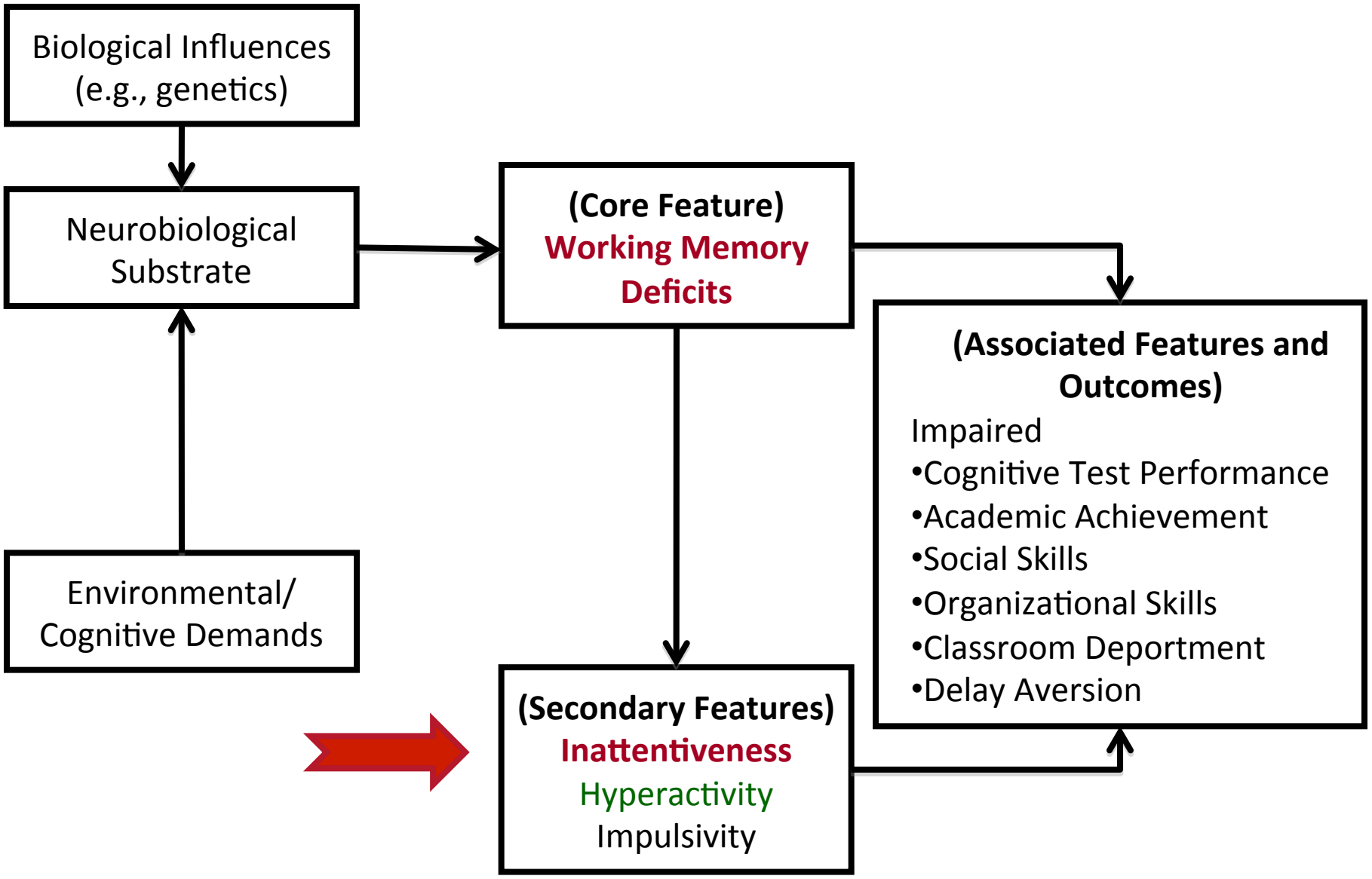
Video examples of children while performing the phonological and visuospatial task

Control Condition

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.**

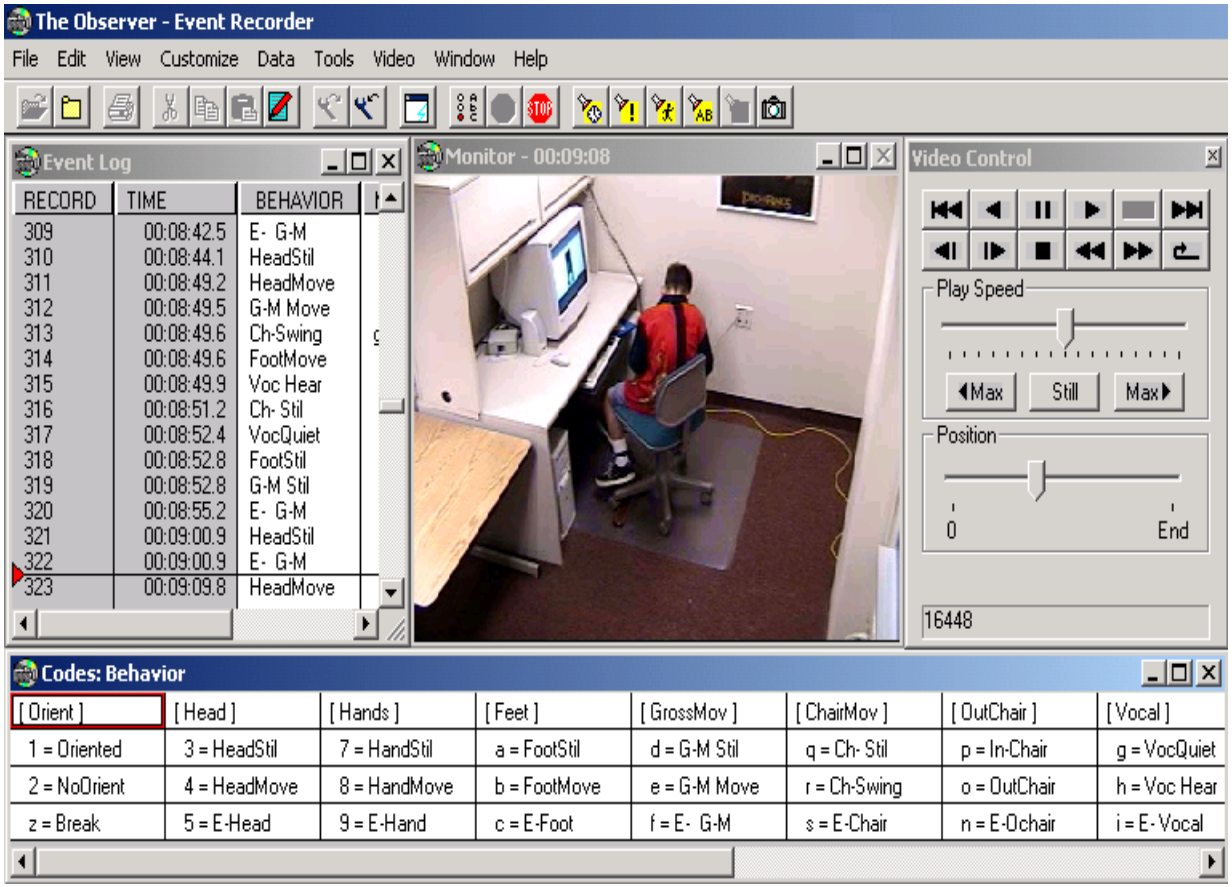
Working Memory Model of ADHD



Dependent Measures and Techniques

Noldus Observer

- Mutually exclusive Behavioral Codes
  - Oriented to task
    - Head is directed within 45° 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



Power analysis

- GPower 3.0.5 (Faul et al., 2007)
- Power = .80 (Cohen, 1992)
- ES = 1.4 (Kofler et al., 2008)
- 2 groups (ADHD, TDC)
- 6 repetitions (C1, set sizes 3-6, C2)
- Needed N = 12
  - Current study N = 29

Sample and demographic variables

Variable	ADHD		Typically Developing		
	$\bar{X}$	SD	$\bar{X}$	SD	*F*
Age	9.22	1.06	10.29	1.46	5.12*
FSIQ	100.93	13.75	111.57	11.93	4.92*
SES	43.80	11.50	52.46	10.15	4.60*
CBCL					
AD/HD Problems	72.47	5.79	56.64	8.87	32.79***
TRF					
AD/HD Problems	65.67	8.62	55.21	5.90	14.30***
CSI-Parent					
ADHD, Combined	76.33	10.72	52.00	13.34	29.49***
CSI-Teacher					
ADHD, Combined	64.00	10.95	51.00	8.45	12.68***

Note: ADHD = attention-deficit/hyperactivity disorder; CBCL = Child Behavior Checklist; CSI = Child Symptom Inventory; FSIQ = Full Scale Intelligence Quotient; SES = socioeconomic status; TRF = Teacher Report Form.
* $p \leq .05$, ** $p \leq .01$, *** $p \leq .001$

IQ as a covariate of WM

- **Share significant variance (r = .47 to .90)**
  - **Ackerman et al., 2005; Colom et al., 2005; Engle et al., 1999**
- **WM = 1 of 4 factors on IQ test**
  - **WMI-FSIQ: r = .76 (Wechsler, 2003)**
    - **r = .40 to .56 with PSI, PRI, & VCI**
- **Latent variable analysis**
  - **Regression: CE, phonological S/R, and visuospatial S/R variance removed from FSIQ (R^2 = .31, p = .02)**
- **Residual FSIQ (IQ unrelated to WM)**
  - **ADHD = TDC (p = .92)**

Working Memory and Children's Inattentive behavior

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]**

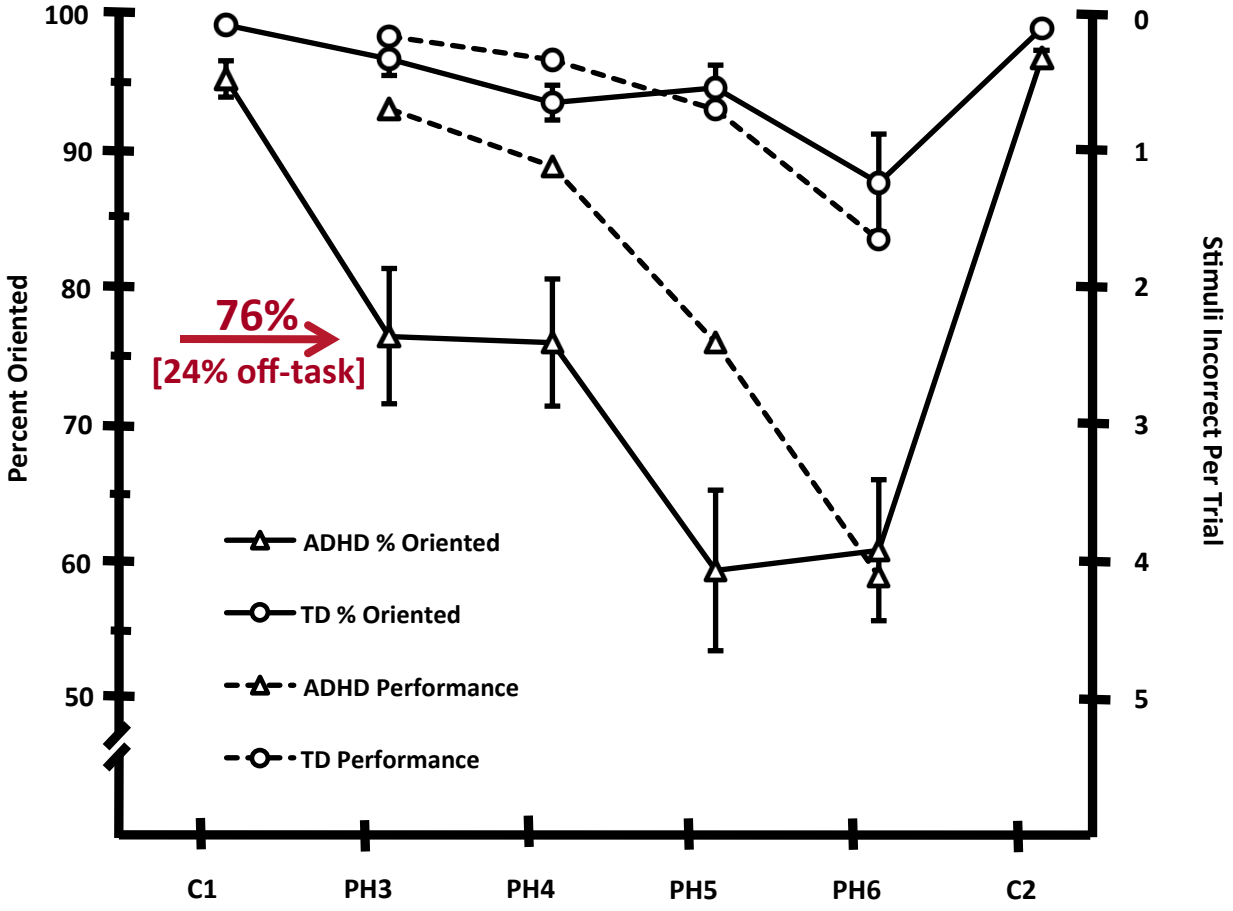
III. **Deficiencies in both the CE and PH/VS storage capacity**

IV. **Ubiquitous inattentiveness unrelated to WM processes**

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.
- Control conditions (C-1, C-2): Children used the Paint Program the initial and last condition for each session.

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 = 4 > 5 = 6
  - TDC: Pre = Post > 3 = 4 = 5 > 6
  - Pre = Post ($p \geq .18$)
  - Hedges' g = 1.55 (SE = 0.42)

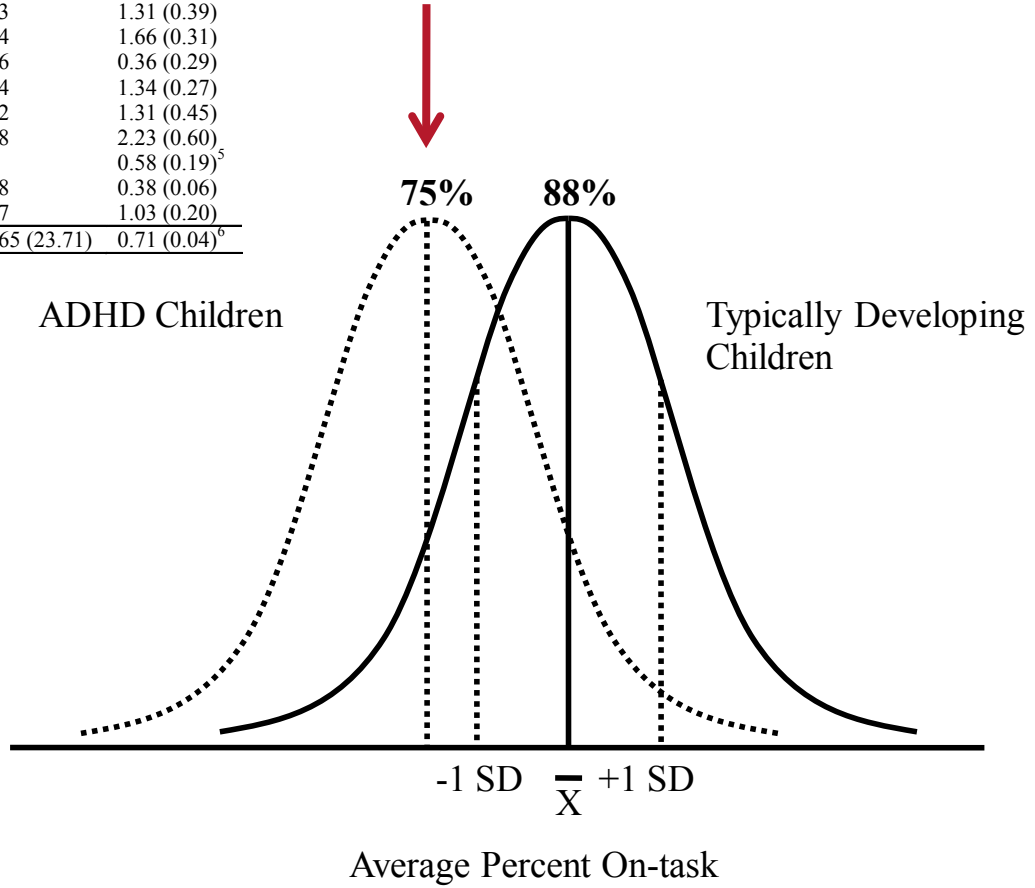
Table 2. Mean Off-task Rates, Standard Difference Scores, and Effect Sizes in Children with ADHD and Typically Developing Children

Study	ADHD % Off-task M (SD)	Control % Off-task M (SD)	Std. Diff. Scores (%)	Hedges' *g* Effect Sizes (Std. Error)
Werry & Quay (1969)	46.3 (12.8)	23 (15.4)	50.3	2.09 (0.53)
Forness & Esveldt (1975)	47.0 (16.5)	34 (12.4)	27.7	0.88 (0.30)
Shecket & Shecket (1976)	*NR*	*NR*	*NR*	0.00[4]
Abikoff et al. (1977)	13.1 (10.0)	2.1 (2.6)	84.2	1.50 (0.21)
Campbell et al. (1978)	16.73 (15.15)	12.41 (10.88)	25.8	0.32 (0.35)
Jacob et al. (1978)	15.8 (NR)	10.5 (NR)	33.3	1.41 (0.53)[3]
Klein & Young (1979)	39.8 (9.0)	26.6 (5.0)	33.1	1.78 (0.40)
Abikoff et al. (1980)	15.1 (23.4)	4.1 (7.8)	72.8	0.62 (0.19)
Zentall (1980)	15.0 (NR)	7.1 (NR)	52.2	0.45 (0.25)
Abikoff & Gittelman (1984)	17.4 (12.3)	3.5 (6.6)	79.7	1.39 (0.29)
Abikoff & Gittelman (1985)	15.7 (10.4)	2.5 (4.6)	84.1	1.71 (0.31)
Atkins et al. (1985)	*NR*	*NR*	*NR*	0.59 (0.30)[1]
Book & Skeen (1987)	5.11 (4.82)	0.78 (1.47)	84.7	1.21 (0.17)
Cunningham & Siegel (1987)	33.0 (NR)	26.4 (NR)	19.9	0.51 (0.26)[2]
Roberts (1990)	39.5 (18.8)	12.9 (20.9)	67.3	1.31 (0.39)
DuPaul & Rapport (1993)	44.26 (16.56)	19.72 (11.56)	55.4	1.66 (0.31)
Lett & Kamphaus (1997)	18.3 (16.5)	12.7 (12.7)	30.6	0.36 (0.29)
Nolan & Gadow (1997)	30.5 (15.9)	13.3 (8.3)	56.4	1.34 (0.27)
DuPaul et al. (1998)	33.0 (19.2)	9.5 (11.9)	71.2	1.31 (0.45)
Skansgaard & Burns (1998)	23.8 (10.3)	4.8 (6.1)	79.8	2.23 (0.60)
Solanto et al. (2001)	*NR*	*NR*	*NR*	0.58 (0.19)[5]
Abikoff et al. (2002)	10.6 (24.0)	3.3 (13.2)	68.8	0.38 (0.06)
Lauth & Mackowiak (2004)	83.0 (12.0)	70.0 (13.0)	15.7	1.03 (0.20)
Column M (SD) =	28.15 (18.28)	14.96 (16.47)	54.65 (23.71)	0.71 (0.04)[6]

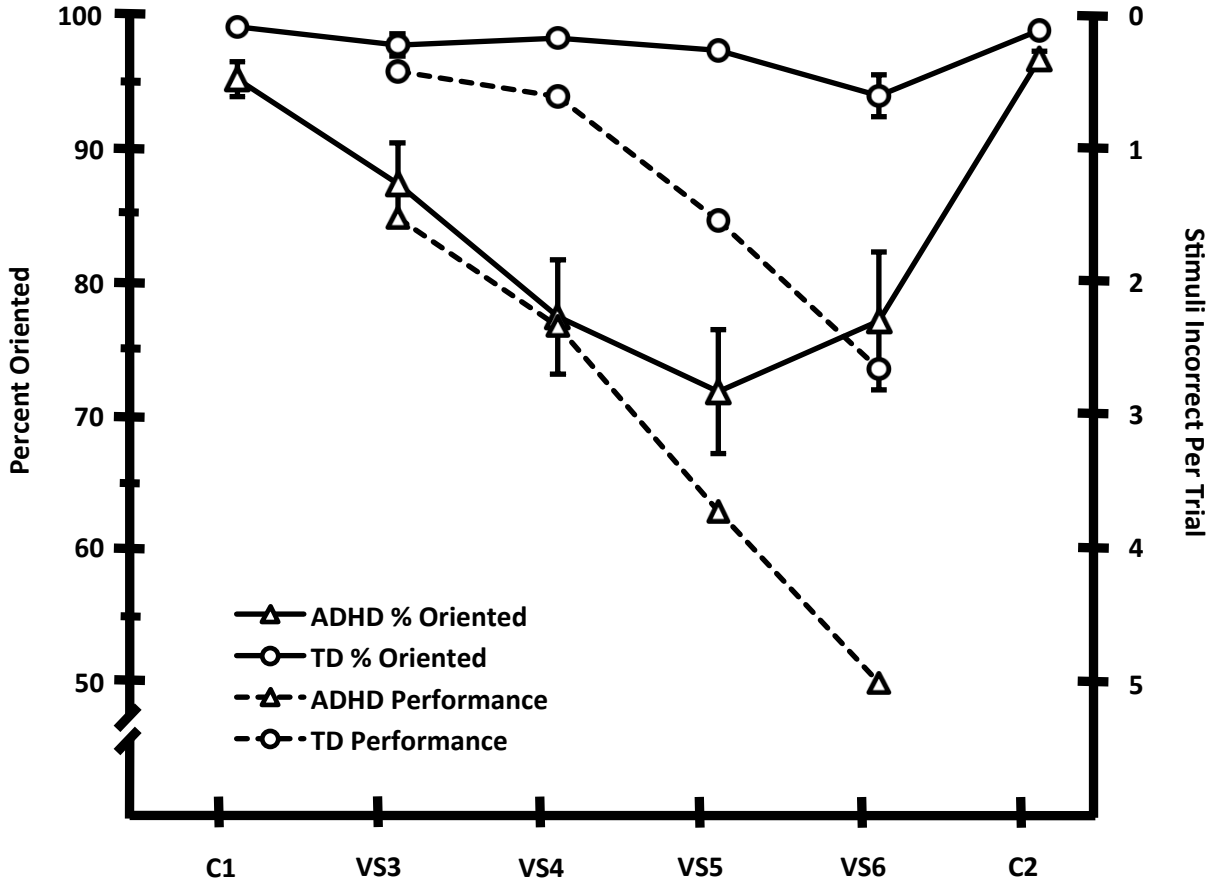
Kofler, Rapport, & Alderson (2008). Quantifying ADHD classroom inattentiveness,its moderators, and variability: a meta-analytic review. *Journal of Child Psychology & Psychiatry* 49, 59–69.

Best case estimation:

ES = 1.40



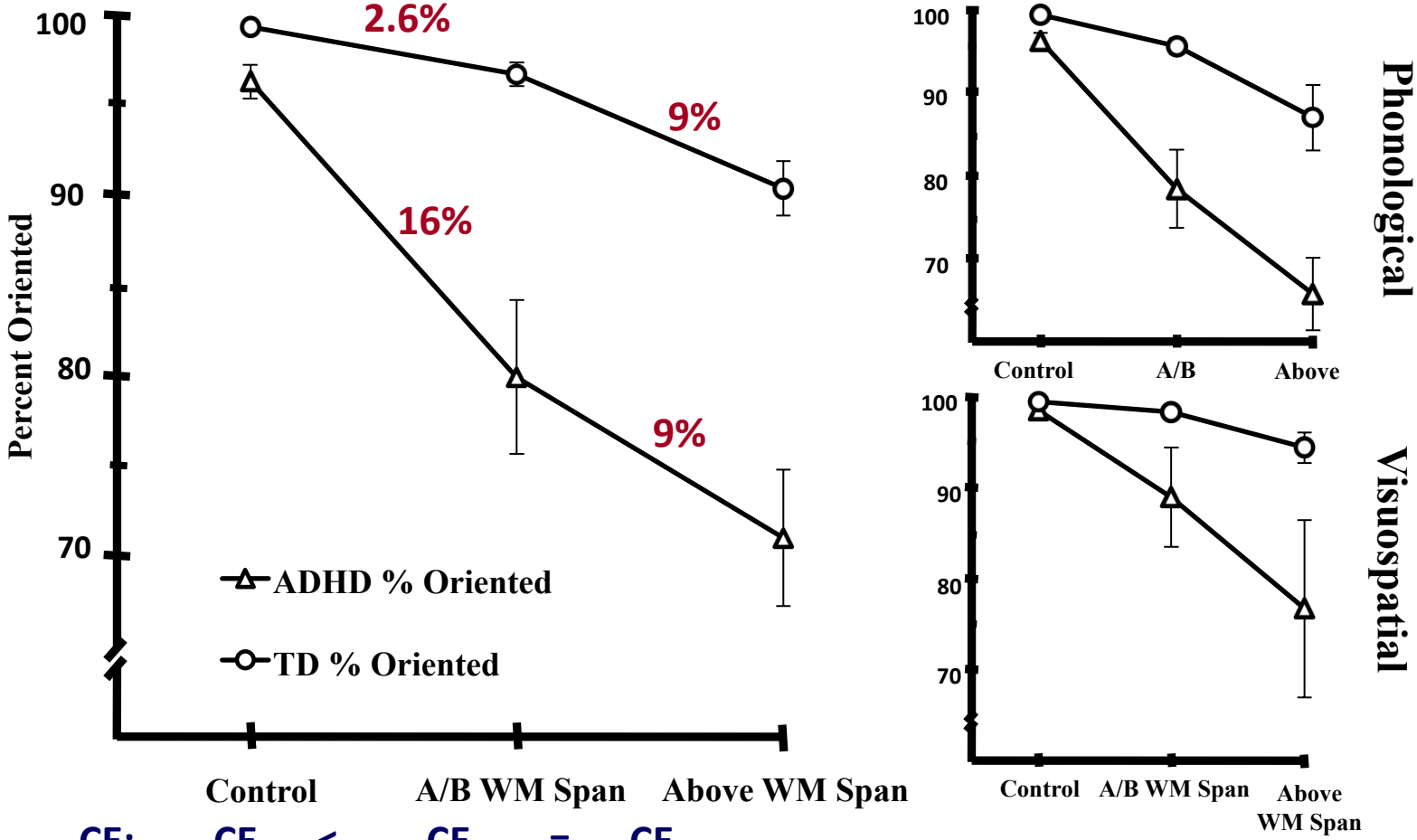
Tier I: Attentive behavior and visuospatial memory load



- 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]

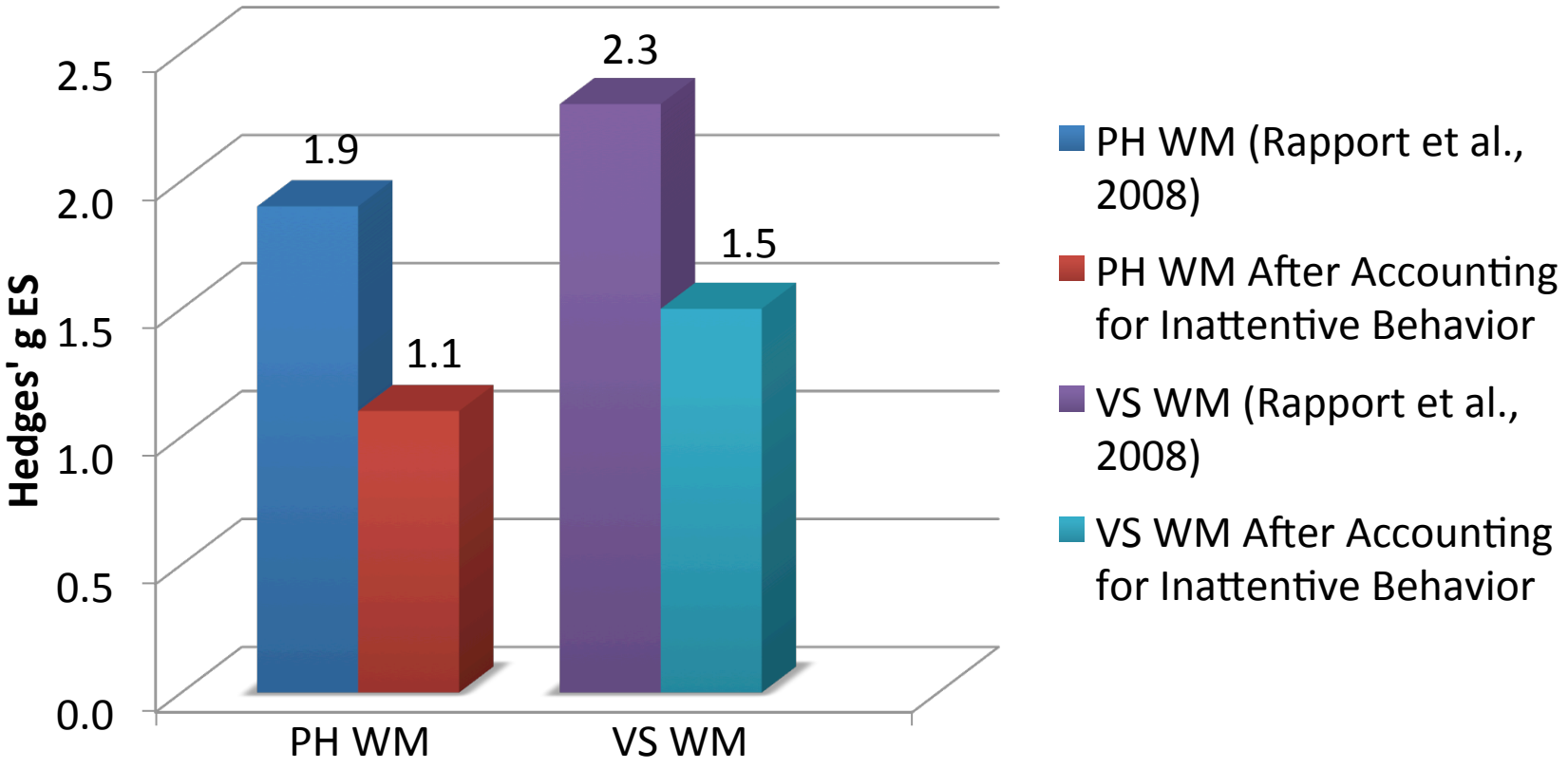


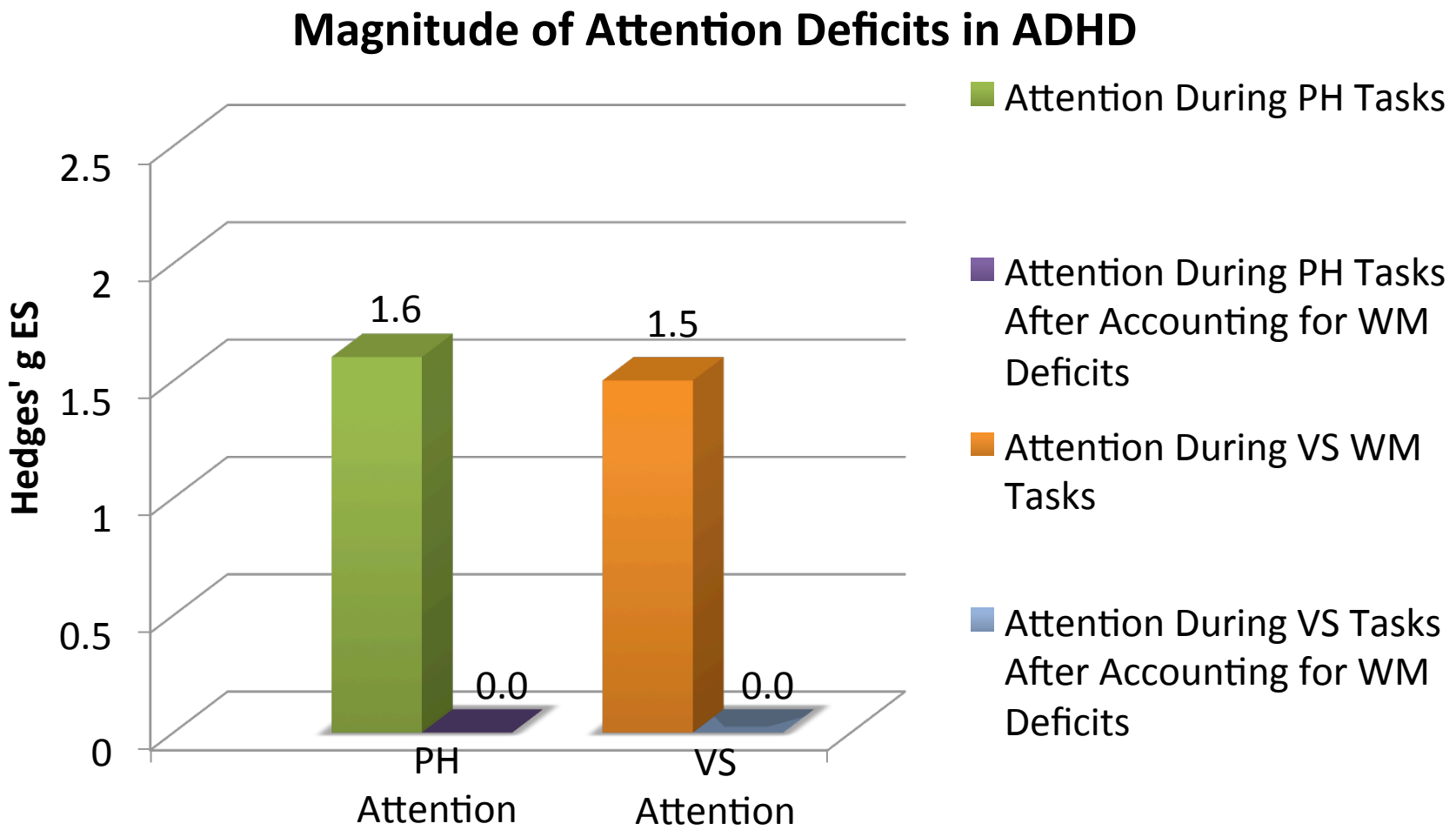
CE: CE < CE = CE

S/R: S/R ≈ S/R < S/R

(S/R Not Overwhelmed) (S/R Overwhelmed)

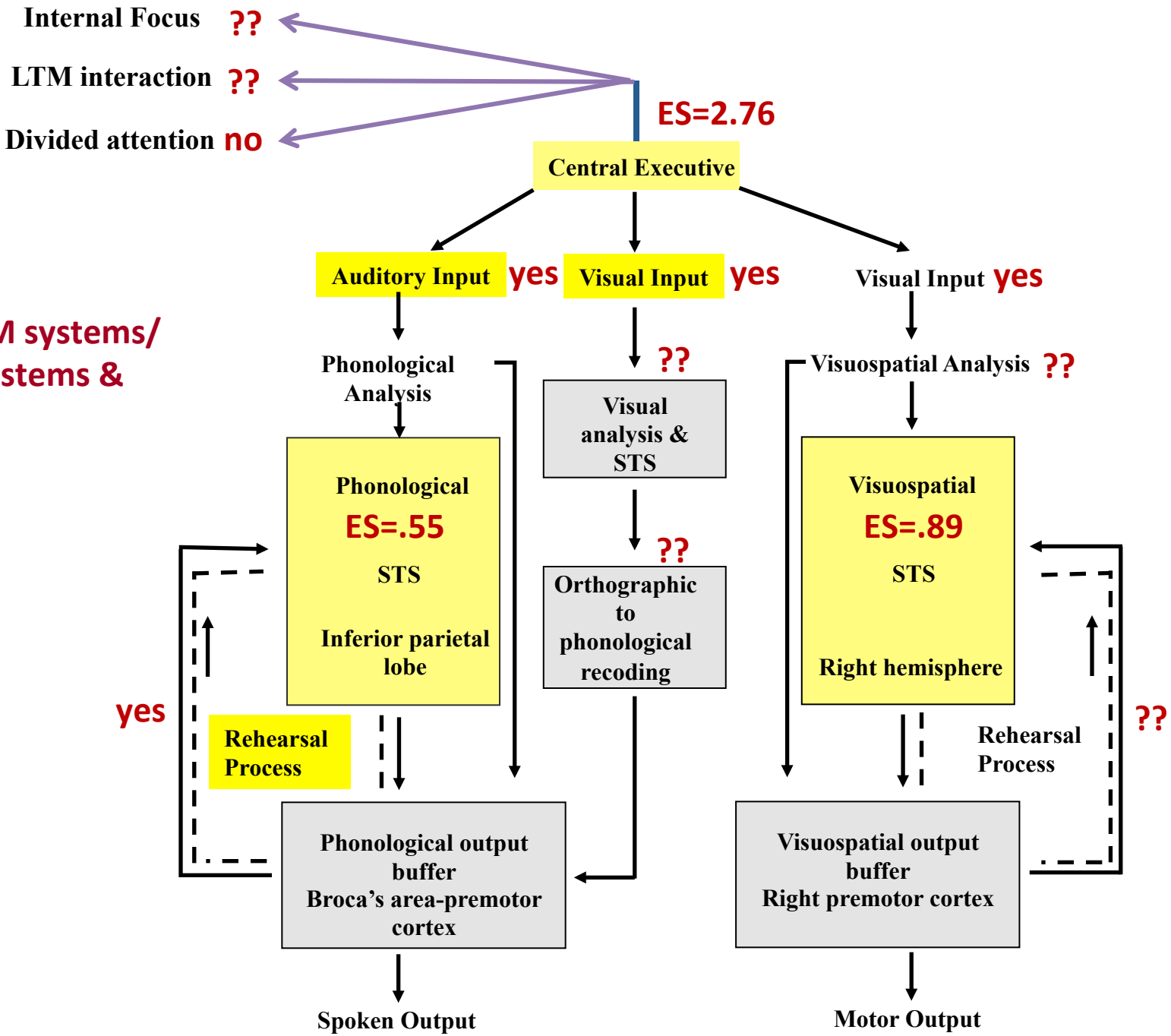
Magnitude of Working Memory Deficits in ADHD




Magnitude of Attention Deficits in ADHD
Hedges' g ES
2.5
2
1.5
1
0.5
0
1.6
0.0
1.5
0.0
PH Attention
VS Attention
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

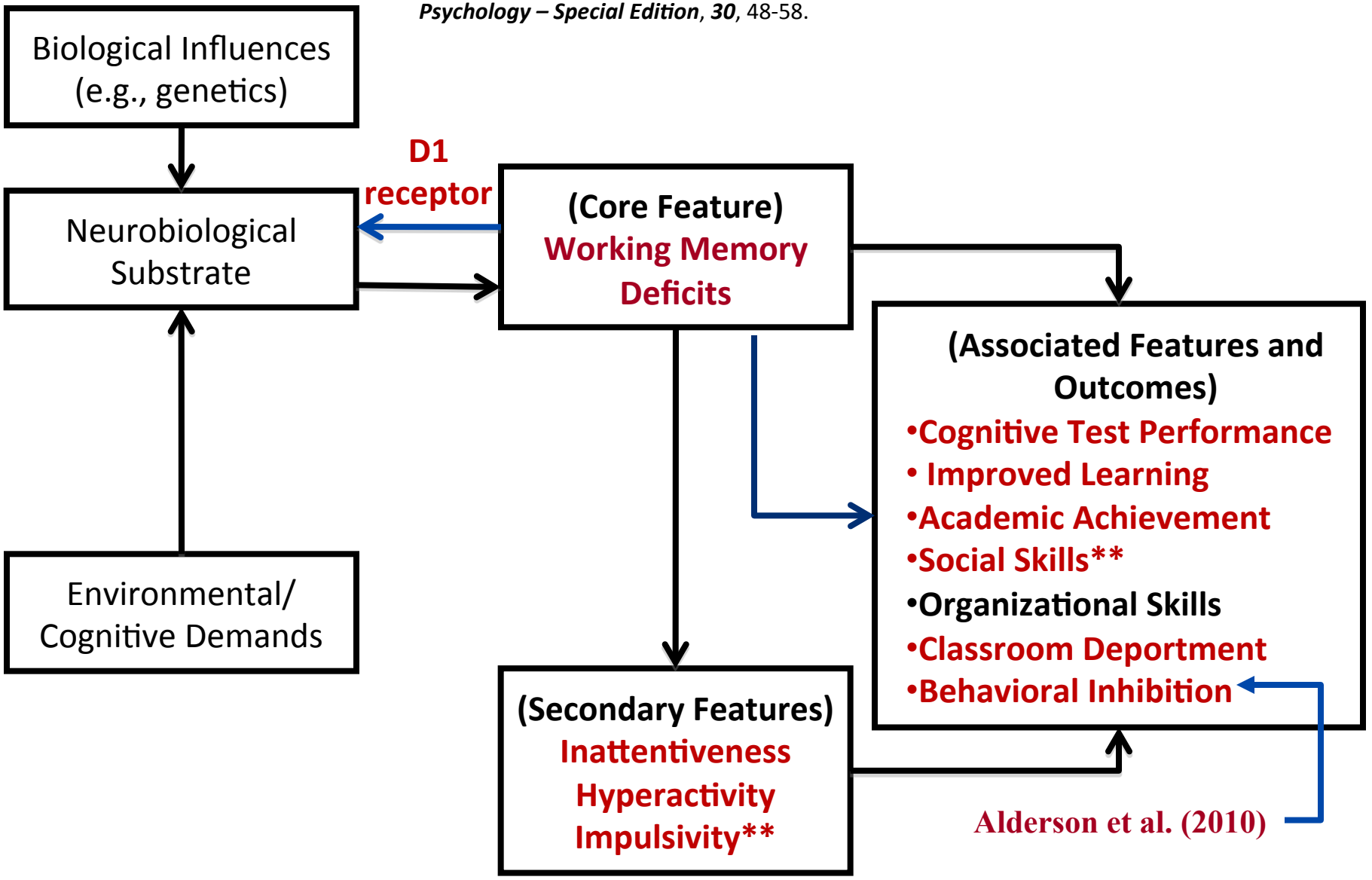
Summary

- 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


Internal Focus ??
LTM interaction ??
Divided attention no
ES=2.76
Central Executive
Auditory Input yes
Visual Input yes
Visual Input yes
Deficient WM systems/ subsidiary systems & processes
Phonological Analysis
??
Visuospatial Analysis ??
Visual analysis & STS
Phonological
ES=.55
STS
Inferior parietal lobe
??
Orthographic to phonological recoding
Visuospatial
ES=.89
STS
Right hemisphere
yes
Rehearsal Process
Rehearsal Process
??
Phonological output buffer
Broca's area-premotor cortex
Visuospatial output buffer
Right premotor cortex
Spoken Output
Motor Output

Functional Working Memory Model of ADHD

Rapport, M.D., Chung, K.M., Shore, G., & Isaacs, P. (2001). *Journal of Clinical Child Psychology – Special Edition*, ***30***, 48-58.



Insert PP slides of Impulsivity and Social Skill Deficits

Consolidation – the process by which short-term memories become long-term memories

Hippocampus: central to the consolidation of declarative memories based on the seminal studies by Scoville and Miller (1957; J Neurochem) following the bilateral medial temporal lobotomies that removed the 'H.M.'s" hippocampi, the parahippocampal cortex, and parts of his amygdala.

- **H.M. lost the ability to form new declarative memories**

- **Consolidation requires 3 interrelated processes:**
  1. **Stimulation of glutamate receptors [note: which can be blocked by infusing glutamate receptor antagonists into the hippocampus]**
  2. **Protein synthesis**
  3. **Gene transcription – process of transferring DNA sequence information into RNA information**

  [note: protein synthesis & gene transcription are not needed for STM]

- **LTM process can be tested at a 3-hour interval to ensure consolidation [Lombroso & Ogren, 2008; J Am Acad Child Adolescent Psychiatry, 47]**

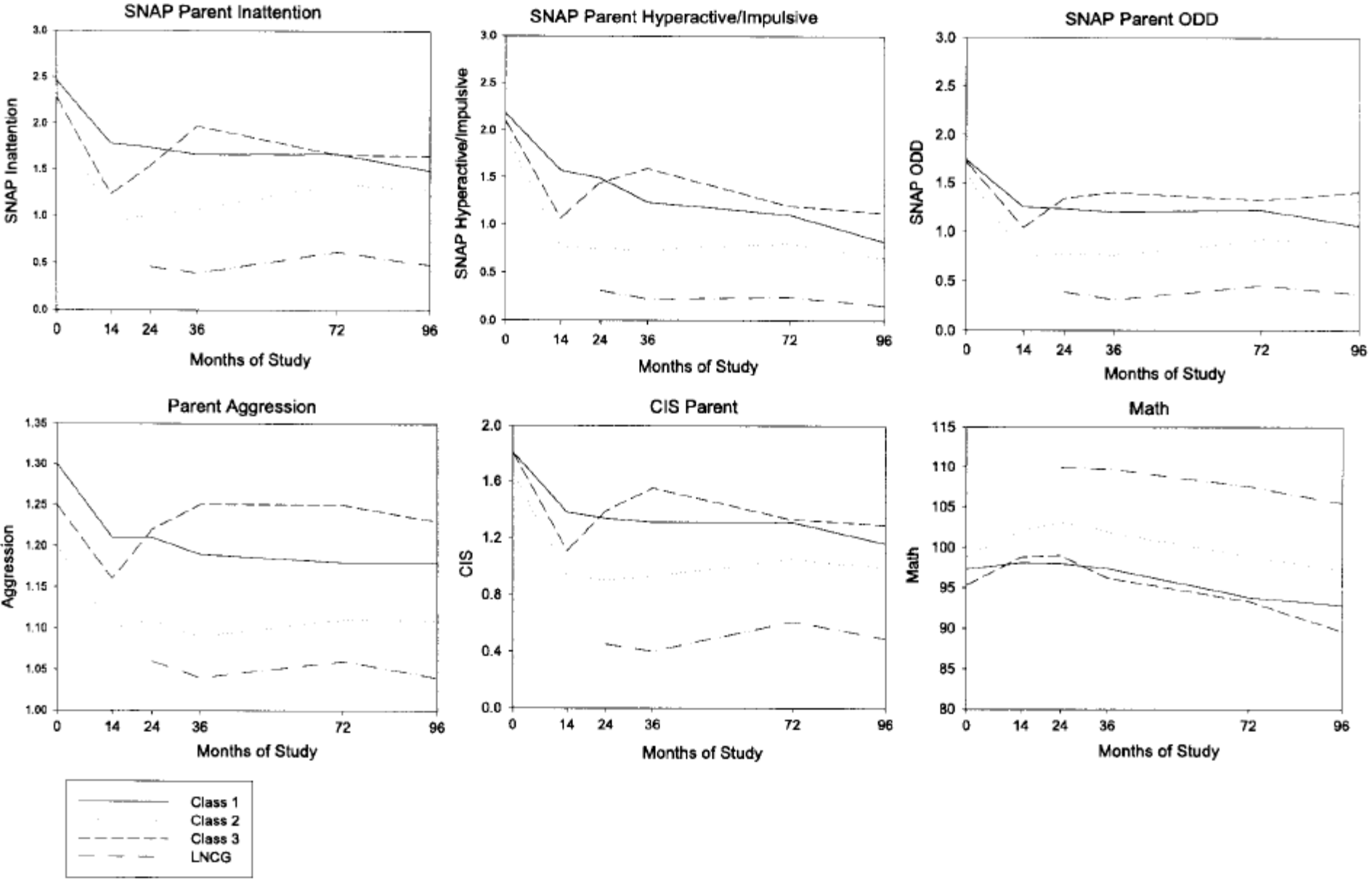
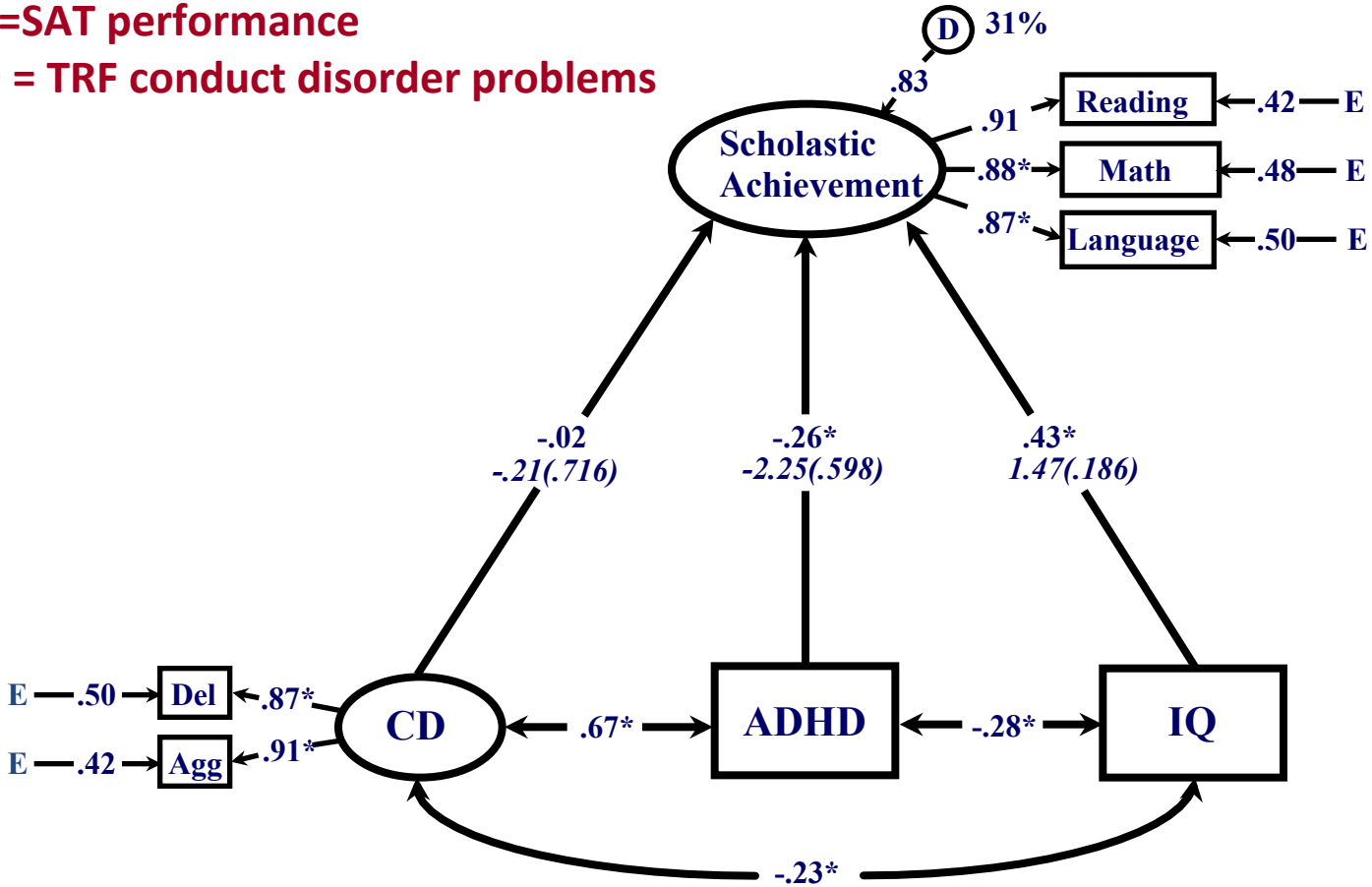
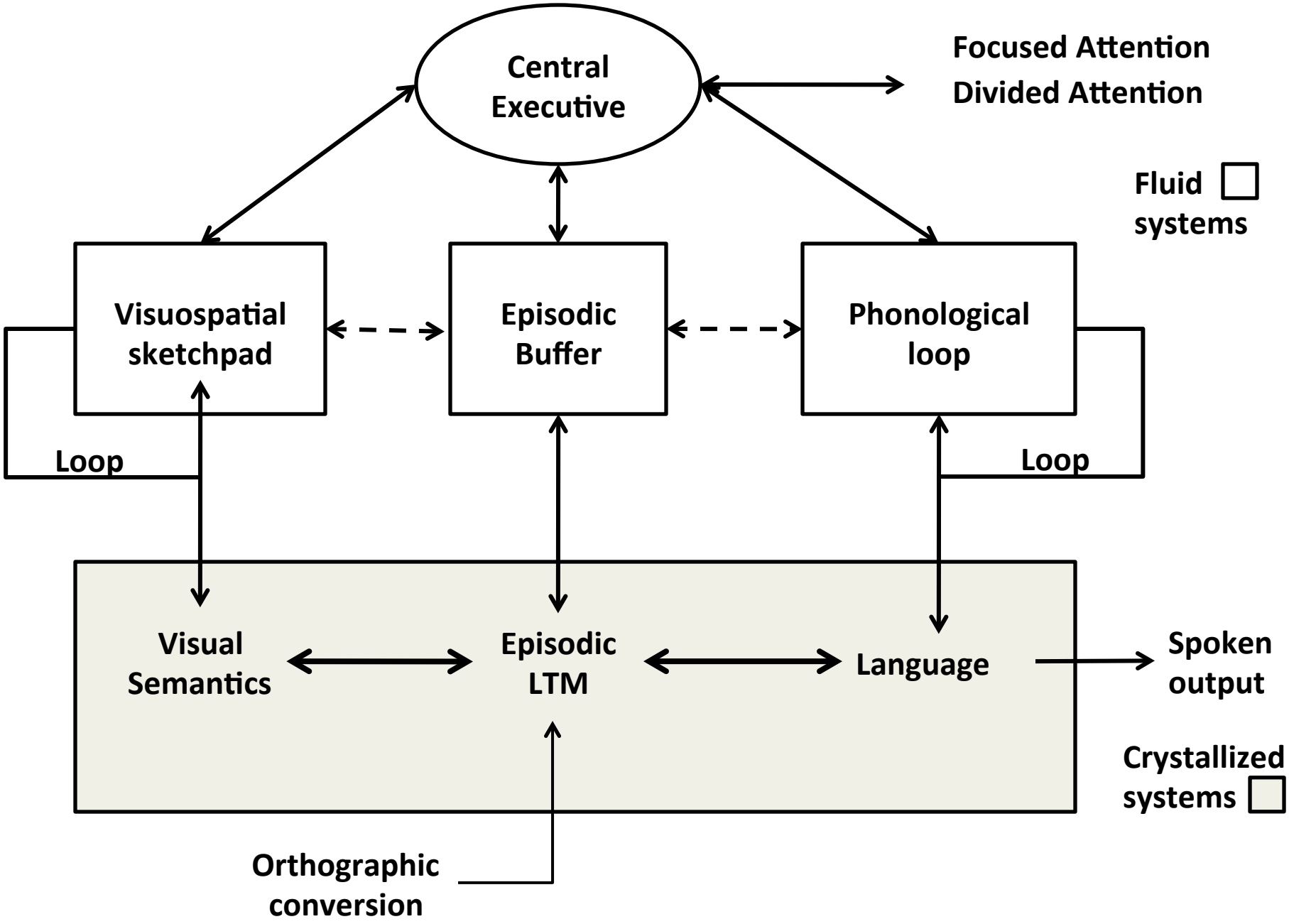


Fig. 3 Selected outcome variables for MTA children, graphed by 36-month ADHD symptom latent class and LNCG. CIS = Columbia Impairment Rating Scale; LNCG = local normative comparison group; ODD = oppositional defiant disorder; SNAP = Swanson, Nolan, Pelham Rating Scale.

N = 325 children
SA=SAT performance
CD = TRF conduct disorder problems



Rapport, Scanlan & Denney (1999) *J. of Child Psychiatry and Psychology*


Central Executive
Focused Attention
Divided Attention
Fluid systems
Visuospatial sketchpad
Episodic Buffer
Phonological loop
Loop
Loop
Visual Semantics
Episodic LTM
Language
Spoken output
Crystallized systems
Orthographic conversion

Childhood Academic Impairments

Evaluated using teacher reports, academic achievement tests (e.g., WRAT, Woodcock), and IQ tests (WISC, Woodcock, Peabody)

- **Poor School Performance (90%+)**
  - **(reduced productivity is greatest problem)**
- **Low Academic Achievement (10-15 pt. deficit)**
- **Low Average Intelligence (7-10 point deficit)**
- **Learning Disabilities (24-70%)**
  - **Reading (15-30%; 21% in Barkley, 1990)**
  - **Spelling (26% in Barkley, 1990)**
  - **Math (10-60%; 28% in Barkley, 1990)**
  - **Handwriting (common but % unspecified)**

Characteristics of Reliable Tests, Tasks, and Paradigms Used to Differentiate Children with ADHD from Normal Controls [n= 439 task comparisons in 142 studies]

Rapport, M.D., Chung, K.M., Shore, G., Denney, C.B., & Isaacs, P. (2000). ***Journal of Clinical Child Psychology – Special Edition, 29***, 555-568.

			Working Memory					
Task	Recognition	Recall	Time Parameter	Subvocal Speech	Buffer	Response Stimulus Present	Self- (S)/ Other- (O) Paced	Effect Size
Reliable Tasks:								
CPT	yes	no	s or msec	yes	yes	no	O	0.85
Go/No-Go	yes	no	msec	yes	yes	no	O	0.31
Stop Signal	yes	no	msec	yes	yes	no	O	1.03
Vis Mem (recall)	no	yes	s	yes	yes	no	S/O	0.78
Unreliable Tasks:								
Boston Naming	no	yes	s-min	no	no	yes	S	0.65
Finger tapping	no	no	s-min	no	no	yes	S	0.27
Language	no	yes	min	no	no	no	S	0.47
Pegboard	yes	no	s-min	no	no	yes	S	0.37
Rey AVLT	no	yes	s-min	yes	no	no	S	n/a
Tower of London	no	yes	s-min	no	no	yes	S	n/a
Trail making	yes	no	min	no	no	yes	S	0.55
Visual motor	no	no	min	no	no	yes	S	0.30
WRAML	yes	yes	s-min	yes	no	no	S	0.35

Note: AVLT = Auditory Verbal Learning Test; CPT = Continuous Performance Test; WRAML = Wide Range Assessment for Memory and Learning; n/a = unable to calculate effect size owing to insufficient statistical information.

Rapport, M.D., Chung, K., & Shore, C. (2000). *Journal of Clinical Child Psychology, 29*, 555-568.
[based on 439 task comparisons reported in 142 independent studies]

Educational Outcomes

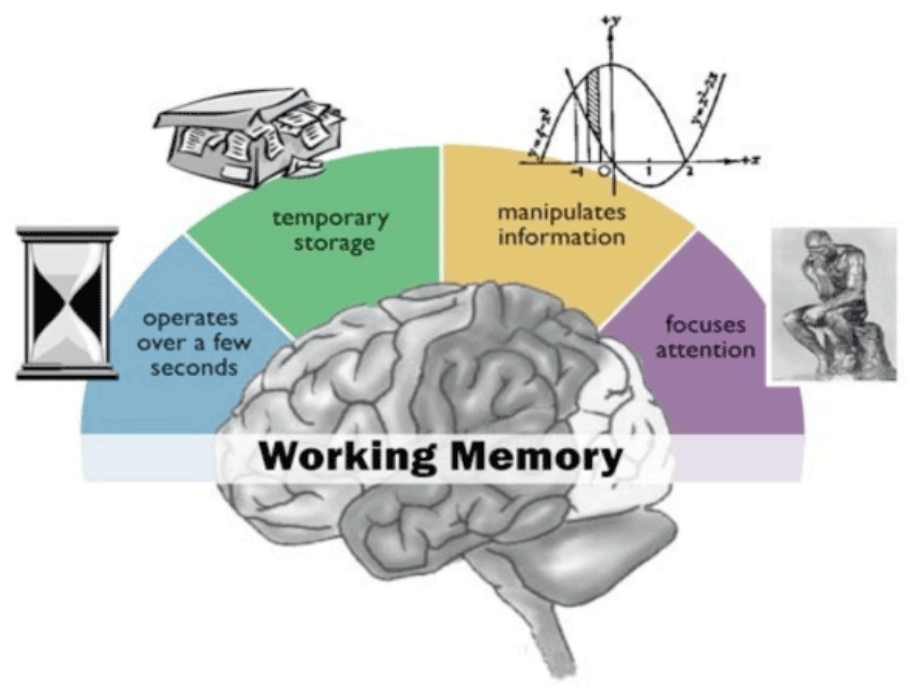
Assessed by school data, self-report, & high school transcripts:

- **Lower Class Ranking (MKE: 69% vs. 50%)**
- **Lower GPA (MKE: 1.7 vs. 2.6)**
- **Poorer school performance—reduced productivity (+90%)**
- **Low academic achievement (10-15 point deficit)**
- **Higher rate of LD: reading, spelling, math, writing (24%-70%)**
- **More grade retention (25-45%; MKE: 42 vs. 13)**
- **More are suspended (40-60%; MKE: 60 vs. 19)**
- **Greater expulsion rate (10-18%; MKE: 14 vs. 6)**
- **Higher drop out rate (23-40%; MKE 32 vs 0)**
- **Fewer enter college (MKE: 22% vs. 77%)**
- **Lower college graduate rate (5% vs. 35%)**

MKE = Milwaukee Young Adult Outcome Study

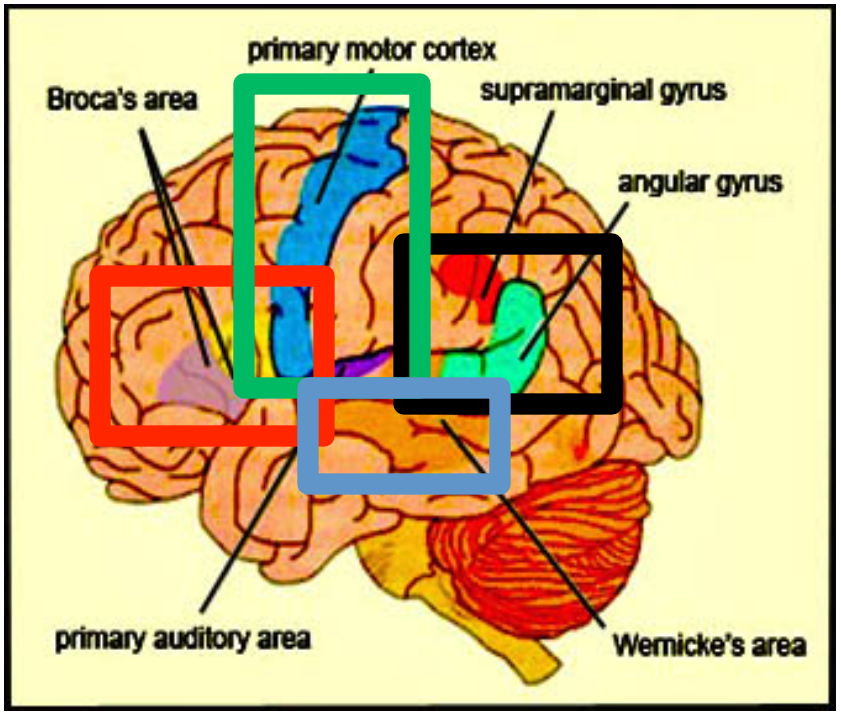
What is Working Memory?

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

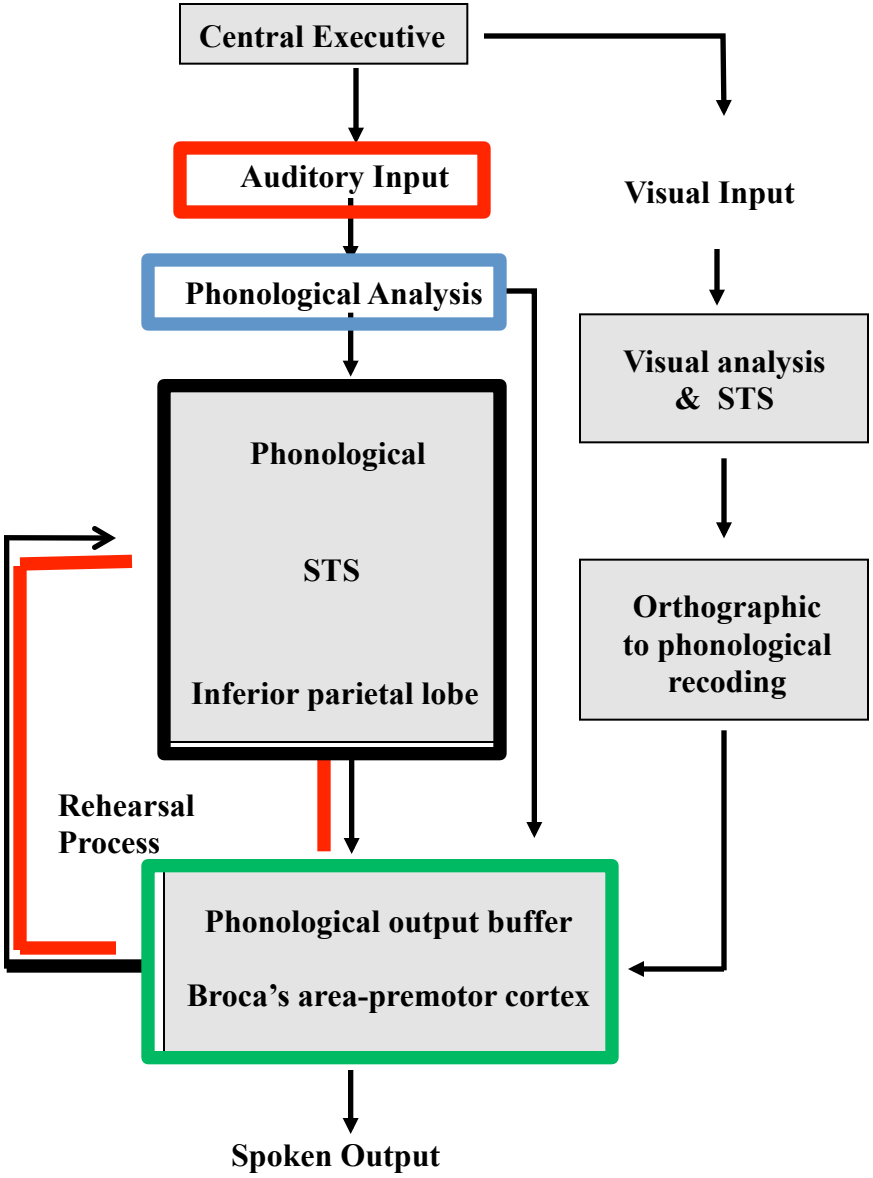


http://usablealgebra.landmark.edu/wp-content/uploads/2008/12/working-memory-2.gif

Phonological Working Memory

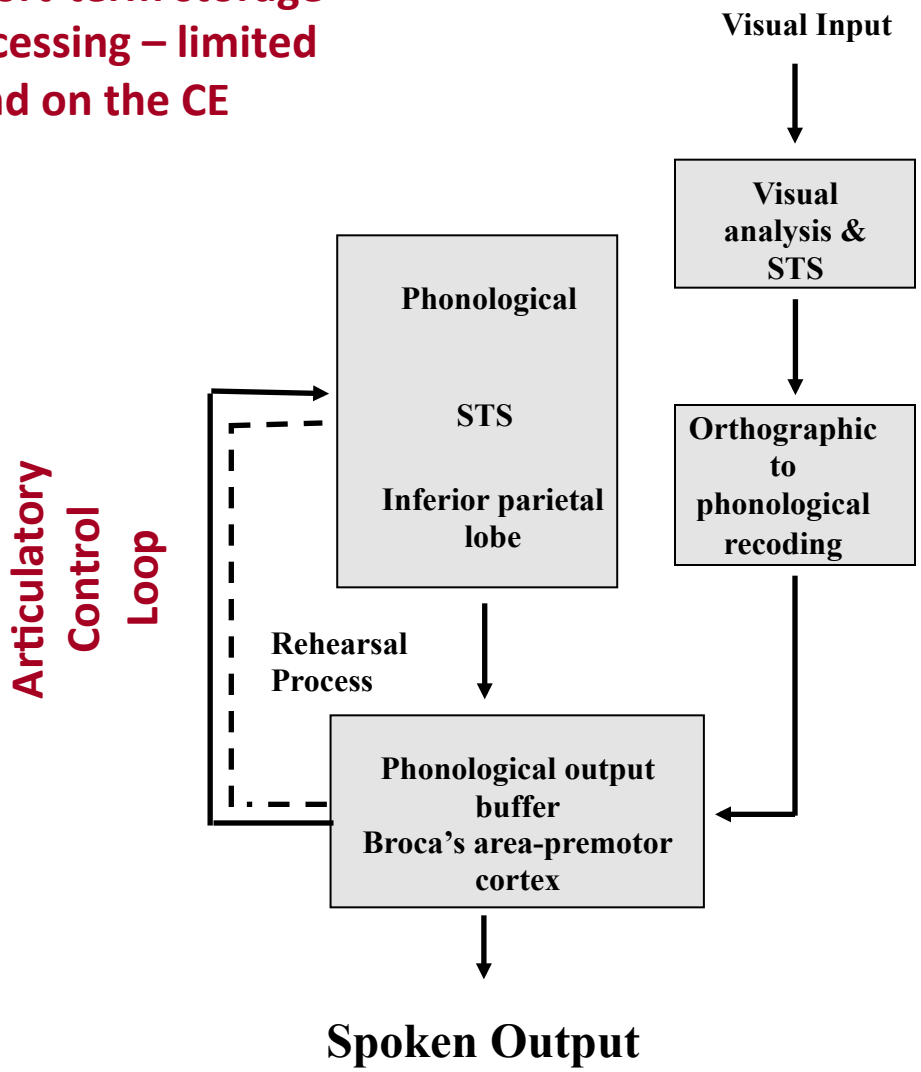


http://docsbrainblocks.com/images/dyslexia_1.jpg



Baddeley, 2007

Requires short-term storage but no processing – limited demand on the CE



What components of the WM Phonological Store are deficient?

Child must hold 2, 4, or 6 single syllable words under 3 distinct recall conditions:

Recall conditions:	**3-seconds**	**12-seconds**	**21-seconds**
	2 words	**2 words**	**2 words**
	4 words	**4 words**	**4 words**
	6 words	**6 words**	**6 words**

[Word lists and recall conditions completely counterbalanced over 4 sessions 1-week apart]

What components of the WM Phonological Store are deficient?

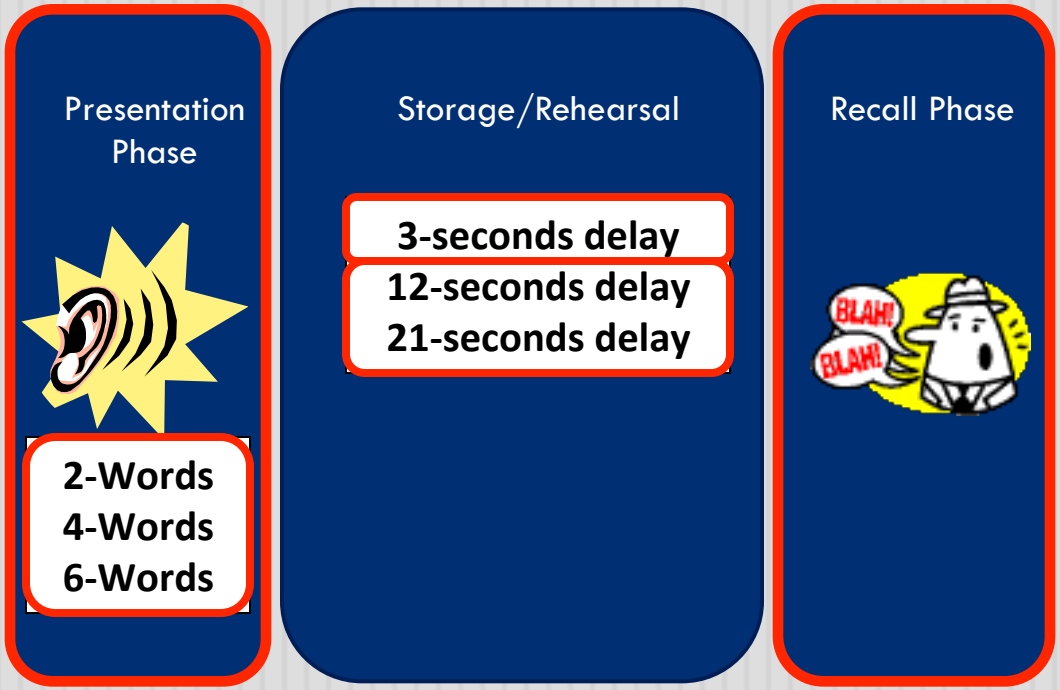
Analyses:

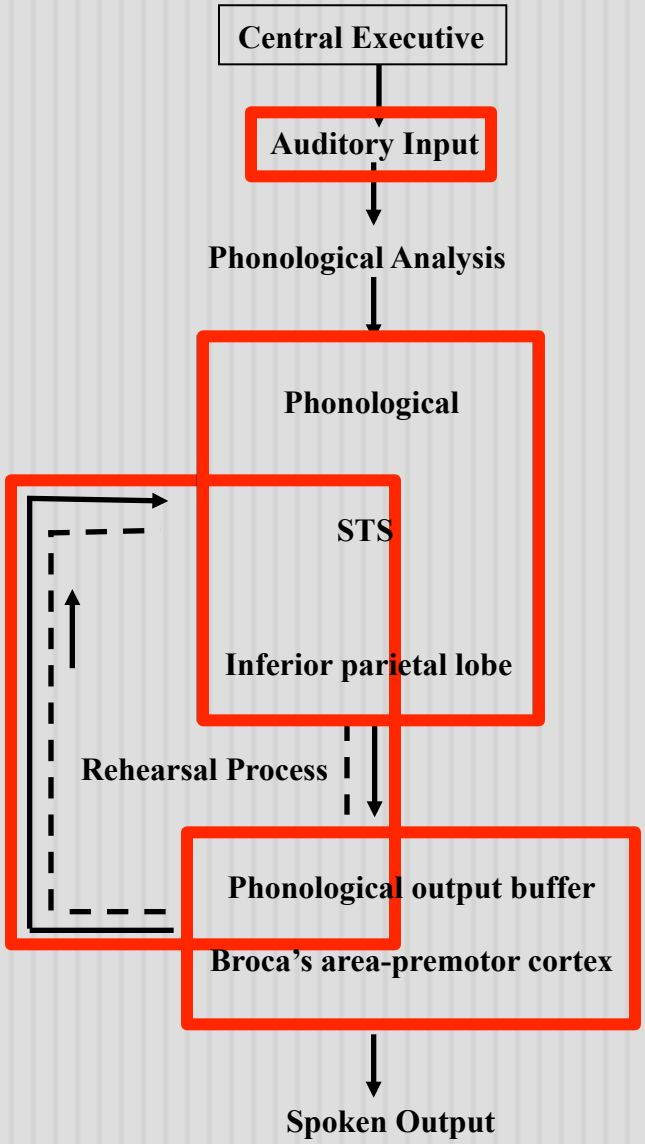
- ✓ **Examine word list effect for ADHD & TD children under 3-sec [minimal delay condition – WM store can hold information for 2-3-s without invoking the rehearsal mechanism] – results indicate whether storage capacity is limited in children with ADHD.**

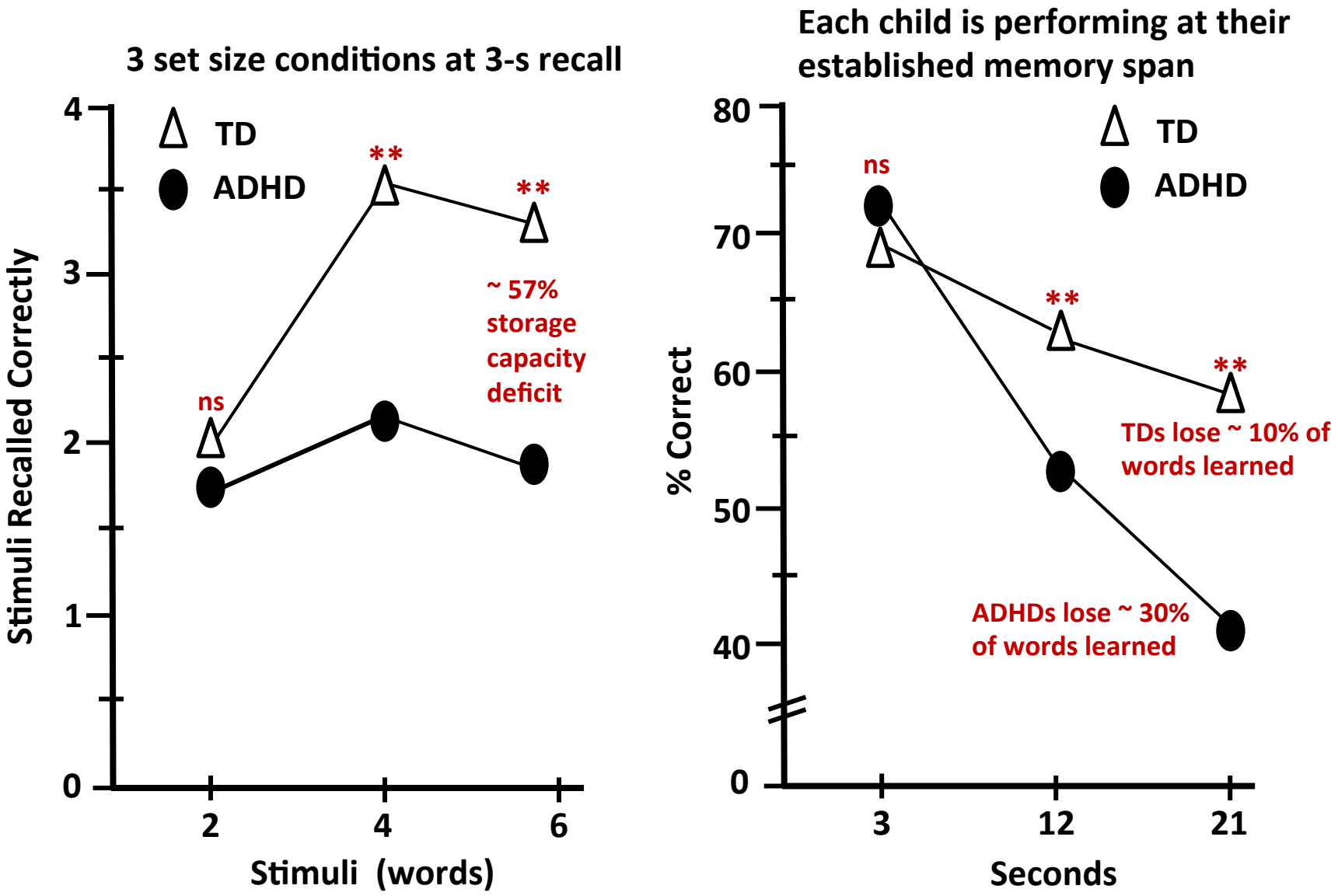
- ✓ **Select the longest word list a child can successfully recall at 50% or greater to establish individual word span (Conway et al., 2005).**

- ✓ **Examine potential rehearsal mechanism deficiencies by comparing each child at his established span across the 3 recall (3-s, 12-s, 24-s) conditions.**

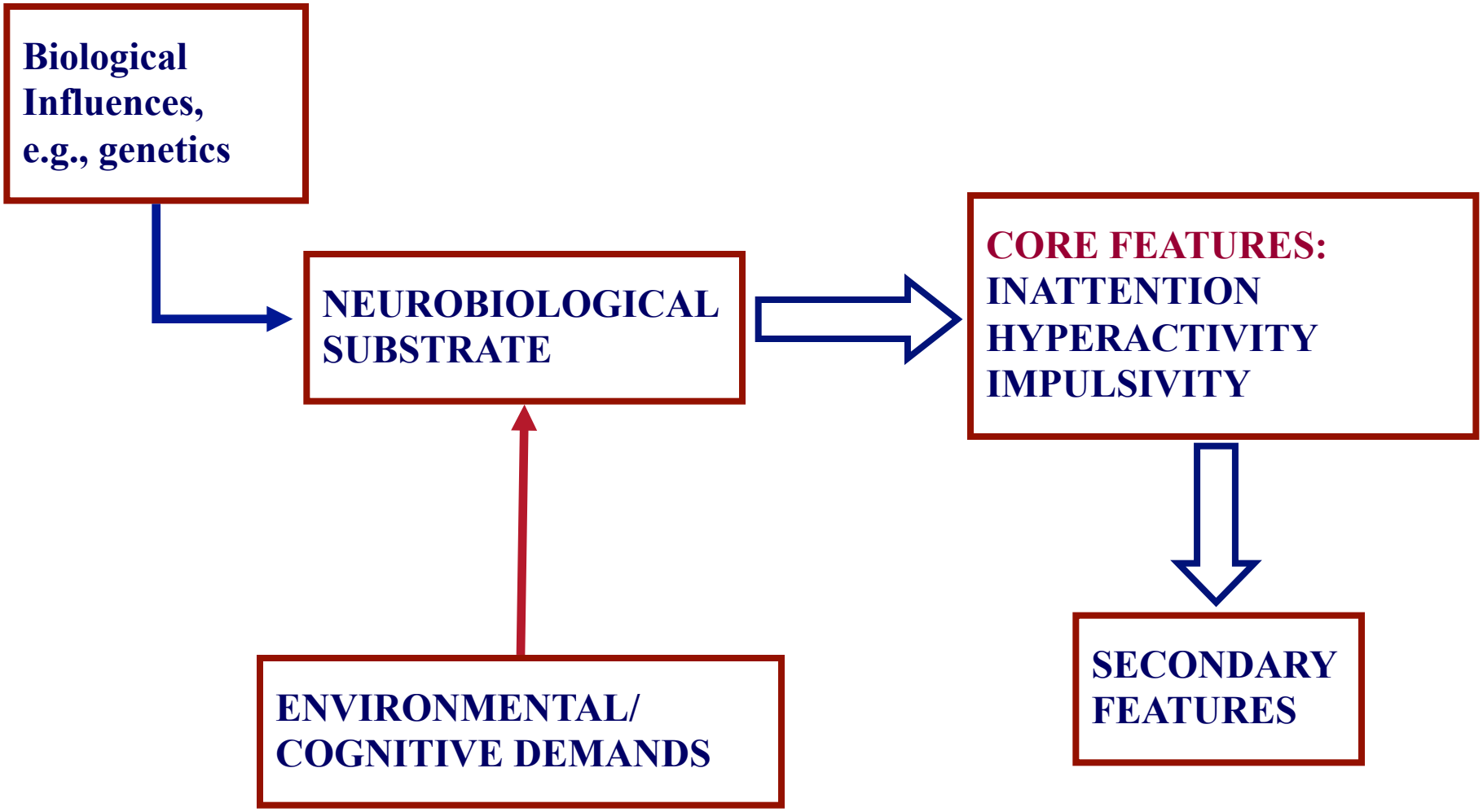
Phonological Memory Task






3 set size conditions at 3-s recall
Stimuli Recalled Correctly
4
3
2
1
0
TD
ADHD
**
**
ns
~ 57%
storage
capacity
deficit
2
4
6
Stimuli (words)
Each child is performing at their
established memory span
% Correct
80
70
60
50
40
0
TD
ADHD
ns
**
**
TDs lose ~ 10% of
words learned
ADHDs lose ~ 30%
of words learned
3
12
21
Seconds

WORKING MEMORY MODEL OF ADHD



Functional Working Memory Model of ADHD

Rapport, M.D., Chung, K.M., Shore, G., & Isaacs, P. (2001). *Journal of Clinical Child Psychology – Special Edition*, ***30***, 48-58.