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Presenter Disclosure – Prior 12 Months

Speaker (Honoraria):

- Learning Disability Association Annual Conference, Lebanon and Kuwait
- ADHD Workshop, Brooklyn College, NY
- Vera French Mental Health Center, Davenport, Iowa
- Georgetown Pediatrics Annual Conference, Pawleys Island, SC
- Eisenhower Army Medical Center, Fort Gordon, August, GA
- Door County Institute, Medical College of Wisconsin, Milwaukee
- Stixrud Group, Mental Health Services, Rockville, MD
- Philippines ADHD Conference
- University of Alabama Annual ADHD Conference
- Center for Pediatric Excellence 10th Annual ADHD Conference, Ottawa, Canada
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Executive Functioning, Self-Regulation and ADHD
Impact on Understanding and Treatment

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Sources:

Barkley, R. A. (2015). *Attention deficit hyperactivity disorder: A handbook for diagnosis and management (4th ed.).* New York: Guilford Press

Barkley, R. A. (2012). *Executive Functions: What They Are, How They Work, and Why They Evolved.* New York: Guilford Press.

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Objectives

- Discuss the current nature of ADHD as understood in clinical research and how it implies the involvement of the executive functions (EF) and self-regulation (SR)
- Note the serious problems plaguing the concept of EF
- Show how an understanding of the concept of SR can greatly clarify and operationalize the concept of EF and so make the connection between them explicit.
- Show how, despite evidence from neuropsychological testing to the contrary, ADHD must be a disorder of EF/SR given its neuroanatomy, neuropsychology, and impact on EF in everyday life activities (EF rating scales)
- Set forth the numerous implications of the EF/SR theory of ADHD for both a far better understanding and more effective management of the disorder

Executive Functioning:

Nature and Problems

From R. A. Barkley (2012). *The Executive Functions: What They Are, How They Work, and Why They Evolved.* New York: Guilford Press

Current Status of EF

- A term used extensively in education, psychology (especially neuropsychology), psychiatry, neuroscience, and other disciplines
- Typically regarded as *"those cognitive abilities needed for goal-directed action"* but little agreement exists beyond this
- Considered to be an umbrella term (meta-construct) that comprises a set of interacting mental abilities but no consensus exists on why they qualify as EF or on how many Some consensus that EF serves as the basis for self-regulation but little effort has been made to explain the link
- Argued as being humanity's highest faculty, but why?
- Largely mediated by the brain's prefrontal cortex but not exclusively so

Serious Problems with the EF Construct

- Philosophical and scientific problems:
  - Lacking in a consensus theory; no current functioning theory at all – just vague descriptions, component lists, and thematic diagrams
  - Implies a homunculus or “ghost in the machine” that is the central executive
  - Little or no reference to its evolutionary history apart from the PFC neuroanatomy
  - Little or no mention of what adaptive problems the EF system evolved to solve
  - Concepts and assessment tools still wedded to the outdated localization of function view of neuropsychological abilities when neuroanatomy has moved on to identifying functional connectivity networks among brain regions that act in concert
- Lacks any consensus definition
  - More than 20 definitions exist
  - Most emphasize self-regulation, goal directed behavior, and planning and problem-solving
- So why not just abandon the term altogether? (Koziol, 2015)

More Problems with the EF Concept

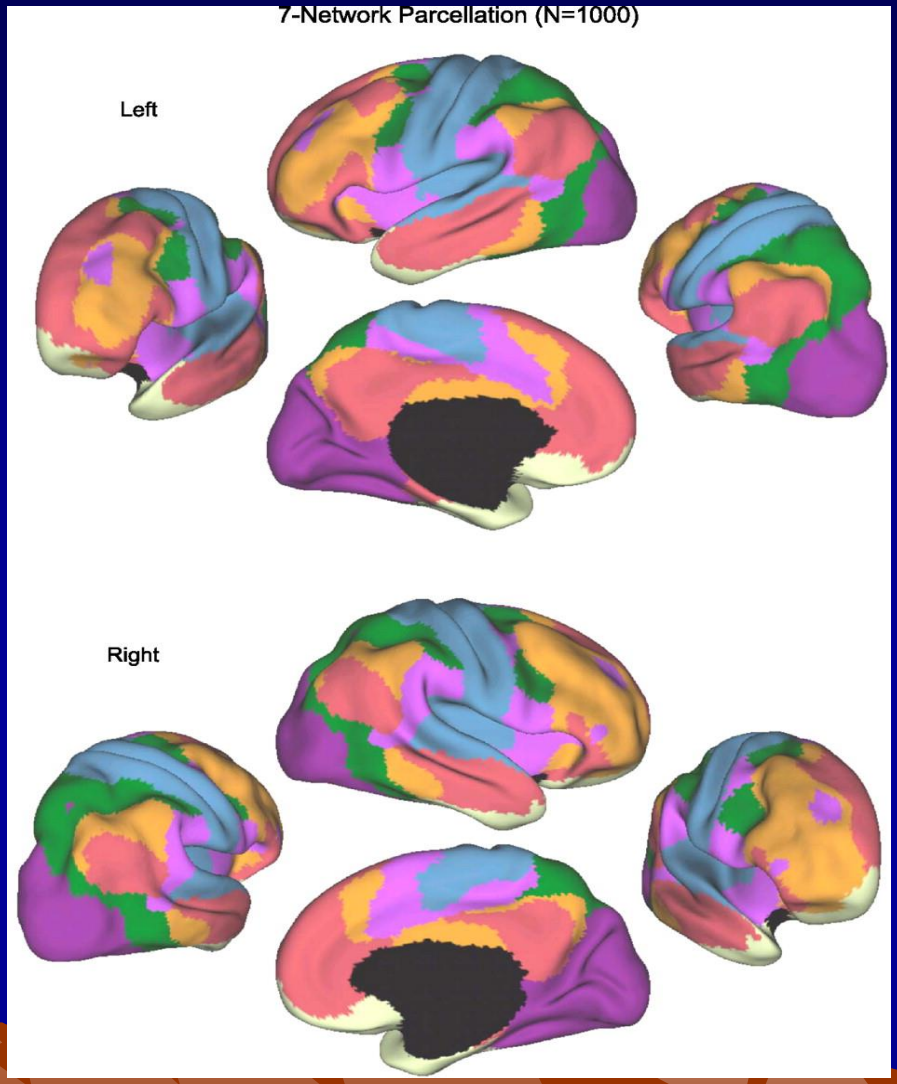
- Avoiding the definitional problem, more recent reviews consider EF to be a "meta"-construct serving as an "umbrella" term for a set of numerous specific components
  - Up to 33 components have been attributed by experts to meta-construct of EF
  - Yet there is no definitional or operational basis for making such a determination – how does an EF and non-EF mental ability differ?
  - And factor analytic studies of EF batteries often reveal a single, large construct with smaller (weaker) dimensions often reflecting method variance (the tests given)
- Assessment of EF usually employs psychometric tests. But:
  - Many tests exist that purport to assess EF but without any clear definition anything goes!
  - They are usually limited to "cold" cognitive abilities (declarative knowledge and thinking) and do not assess some critical EF abilities (divergent thinking, problem-solving and novelty-automaticity, emotion regulation, self-motivation, time binding, social goals)
  - Many are unreliable, do not evaluate unitary abilities, are often poorly normed, and do not evaluate functional networks
    - Moreover, the abilities being tested (and the brain networks involved) change with test version, experience, context, and development yet none of this is incorporated into scoring or interpretation
  - EF tests have no significant correlation with EF ratings and no ecological validity
    - Poor at predicting adaptive functioning and effectiveness in major domains of life activities rife with EF

Does ADHD = EFDD????

(Executive Function Deficit Disorder)

The Neuro-Anatomy and Neuropsychology of ADHD Virtually Guarantee It!

The 7 Functional Brain Networks Based on Connectivity



- Purple (Visual)
- Blue (Somatomotor)
- Green (Dorsal Attention)
- Violet (Ventral Attention)
- Cream (Limbic)
- Orange (Frontoparietal)
- Red (Default)

Yeo, B. T. T. et al., (2011). The organization of the human cerebral cortext estimated by intrinsic functional connectivity. *Journal of Neurophysiology, 106 (3),* 1125-1165.

Neuro-Imaging Findings

All 7 functional networks involve the cortical, basal ganglia, thalamic, and cerebellar regions.

In ADHD we find smaller (3-10%), less activity (10-25%+), leyaed development (2-3 yrs.) in these brain regions:

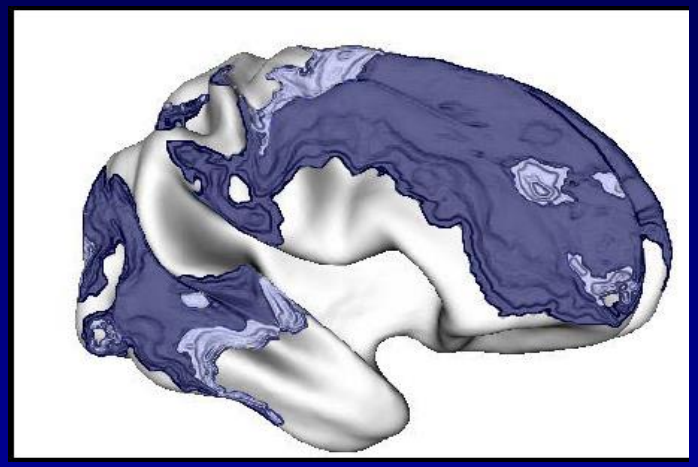
- Orbital-Prefrontal Cortex (primarily right side)
- Basal Ganglia (mainly striatum & globus pallidus)
- Cerebellum (central vermis area, more on right side)
- Anterior cingulate cortex
- Corpus callosum (primarily anterior splenium)
- Thalamus (??)

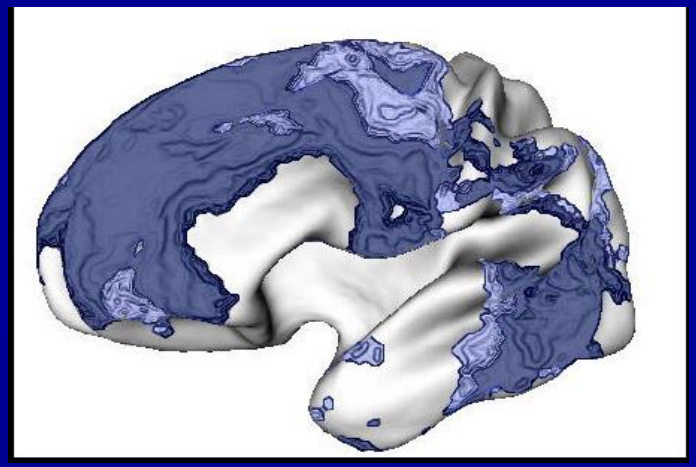
More Neuro-Imaging Results

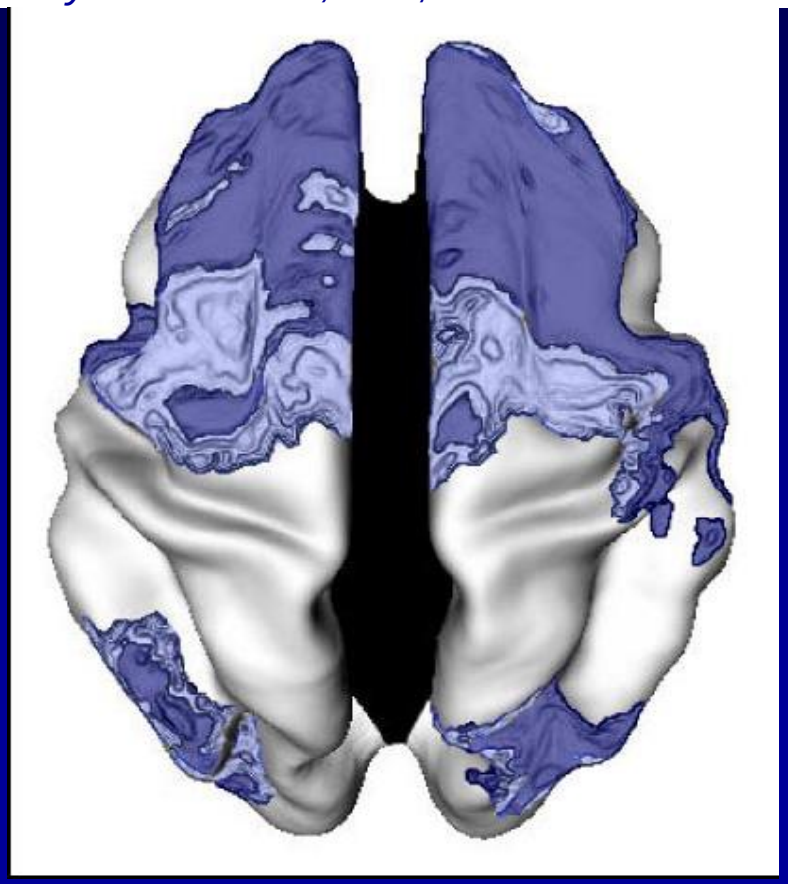
- Size of these regions is correlated with degree of ADHD symptoms, particularly inhibition
- No substantial gender differences
- Structural differences in volume persist to late adolescence then some normalization
- Functional differences may persist into adulthood in most cases, especially in frontal-parietal regions
- Results are not due to taking stimulant medication
- Indeed, longer term use of stimulants has been associated with improved growth in these regions (neuroprotection)

Delayed brain growth in ADHD (3 yrs.)

From Shaw, P. et al. (2007). ADHD is characterized by a delay in cortical maturation. *Proceedings of the National Academy of Sciences, 104*, 19649-19654.







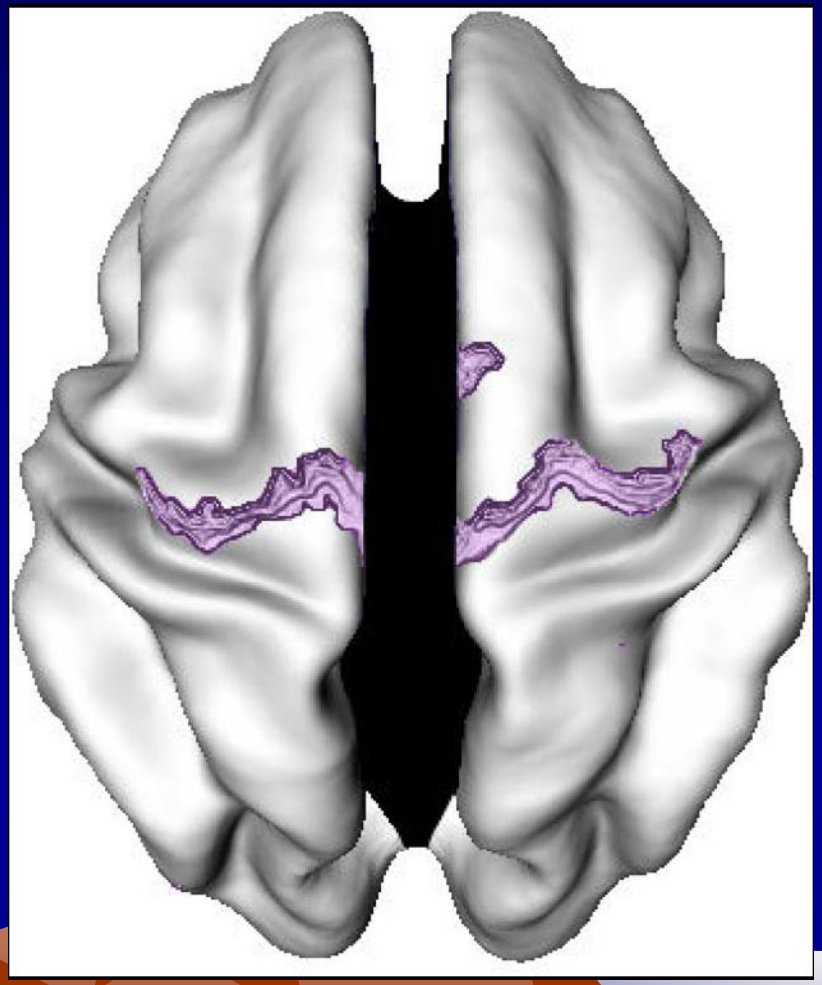
Greater than 2 years' delay
0 to 2 years delay

Ns: ADHD=223; Controls = 223

Early cortical maturation in ADHD children

From Shaw, P. et al. (2007). ADHD is characterized by a delay in cortical maturation. *Proceedings of the National Academy of Sciences, 104*, 19649-19654.

Fig. 4. Regions where the ADHD group had early cortical maturation, as indicated by a younger age of attaining peak cortical thickness.



Basal ganglia abnormalities in ADHD vs Normal

Sobel et al. (2010). *American Journal of Psychiatry, 167*, 977-986

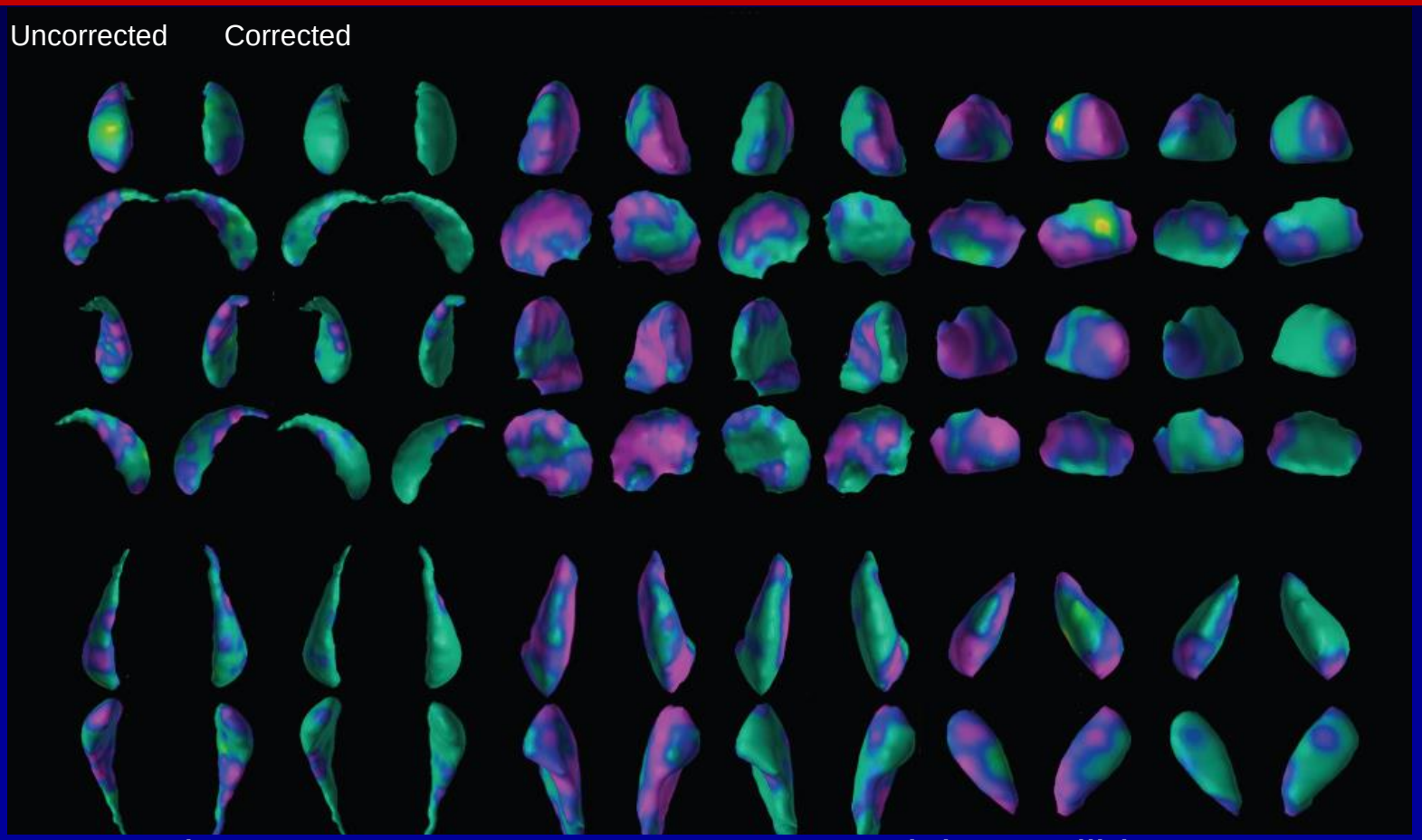
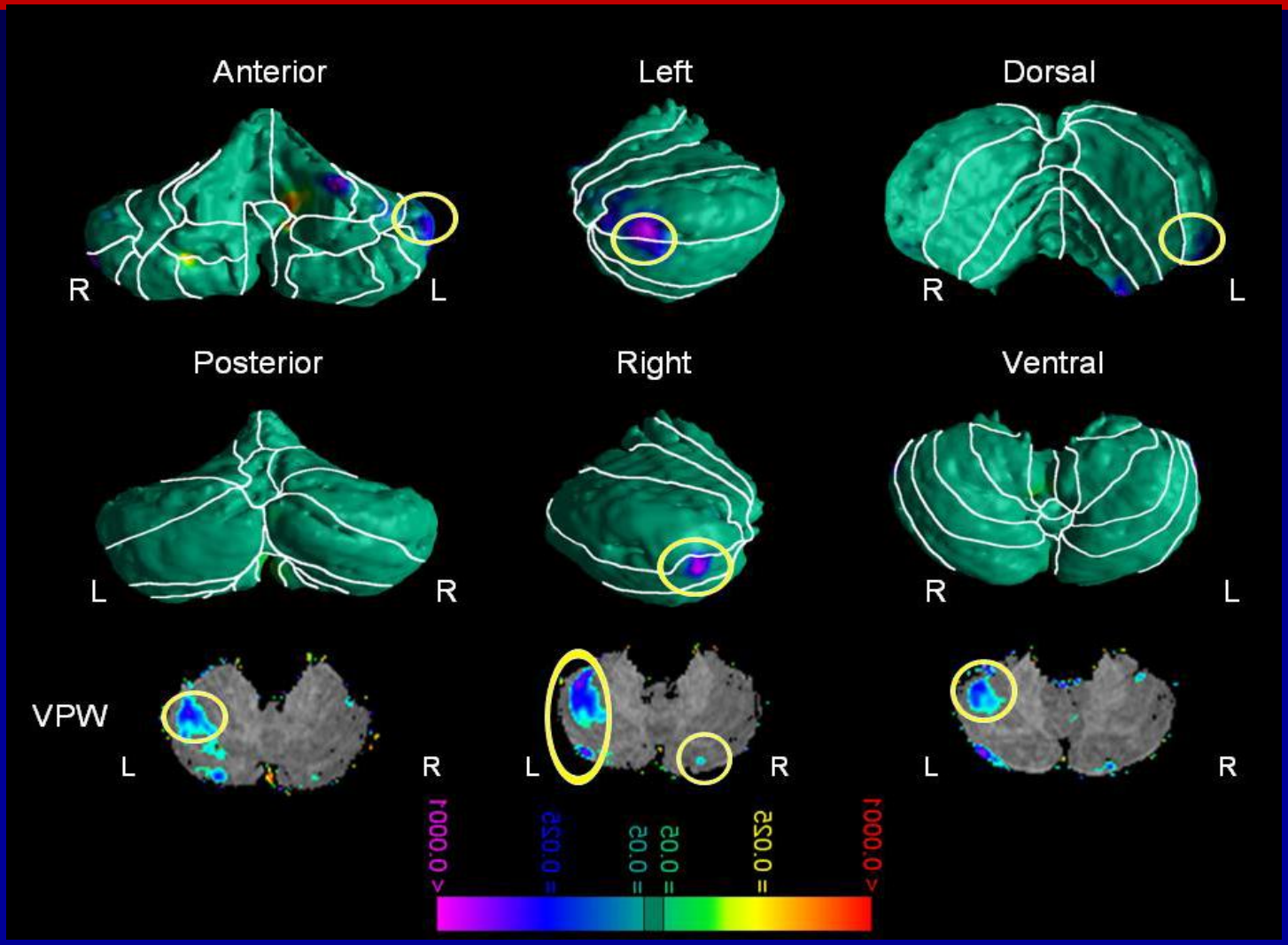


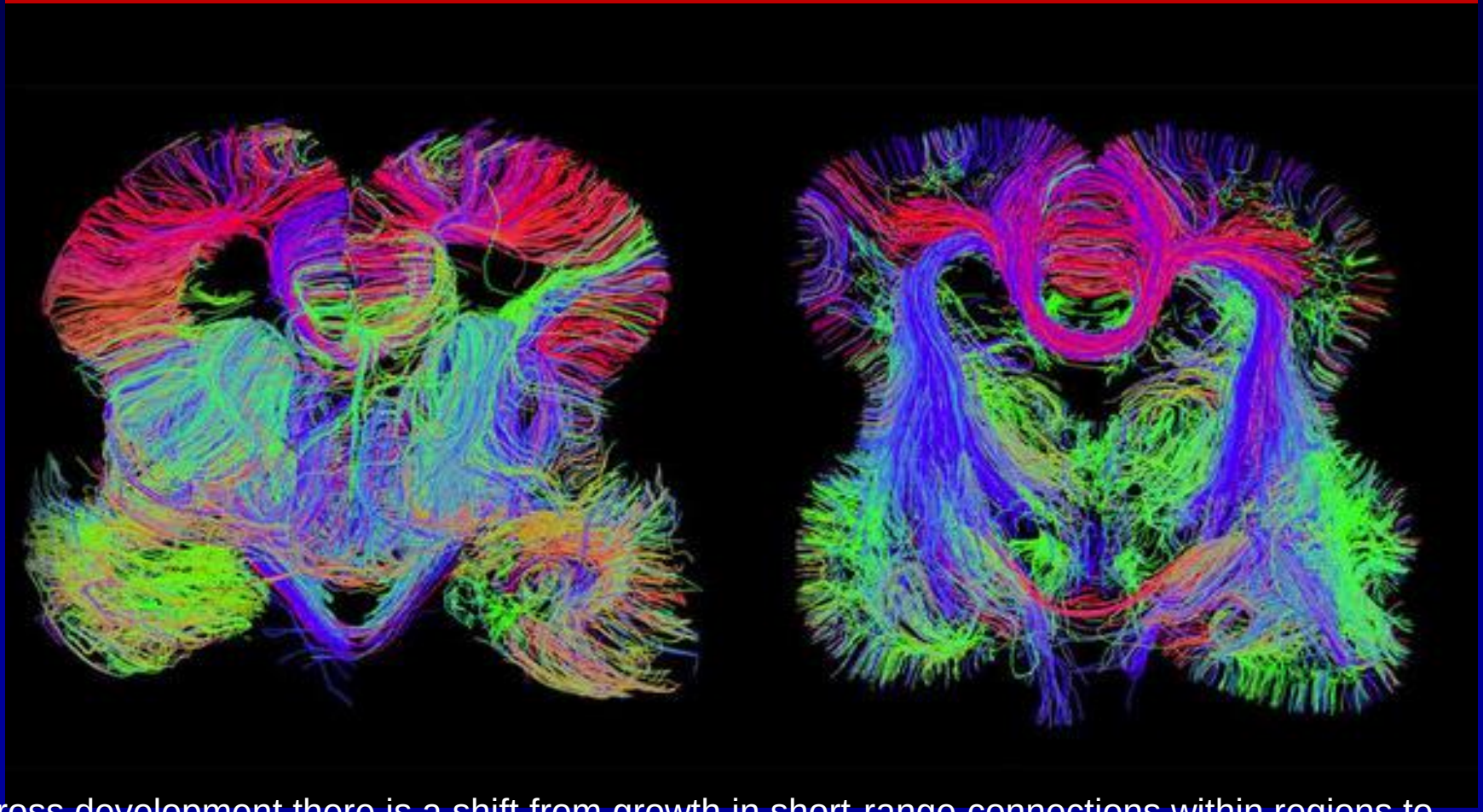
FIGURE 1. Main Effects of Diagnosis on Surface Morphologic Features of Basal Ganglia Nuclei in Youth With ADHD Relative to Healthy Comparison Subjects. The right and left caudate, putamen, and globus pallidus are displayed in rotational views and in their dorsal and ventral perspectives. Anterior (A), posterior (P), lateral (L), and medial (M) views of each nucleus are shown. The color bar indicates the significance value for group comparisons at each point on the surface. Green values represent statistically nonsignificant differences ($p \geq 0.05$) of the surface of the basal ganglia nuclei between groups. Yellow and red values ($p < 0.0001$) represent outward deformations of the surfaces or local volume increases, whereas blue and purple represent inward deformations of the surfaces or local volume reductions ($p < 0.0001$). Ns = 47 ADHD vs 57 controls ages 7-18

Cerebellar Abnormalities in ADHD Diagnosed Children



The figure shows statistical maps in different cerebellum views; the color bar indicates the color coding for p values associated with the main effect of ADHD diagnosis, ranging from p<0.0001 in red (i.e. increased regional volumes) and p<0,0001 in purple (i.e. decreased regional volumes). The theory of Gaussian random field was used to correct for multiple comparisons. The maps show significantly smaller regional volumes in cerebellar lobules I-IV and crus I on the left as well as crus II on the right in youths with ADHD compared to healthy controls. L= left; R= right; VPW = Volume preserve warping.

Typical Brain Network Development

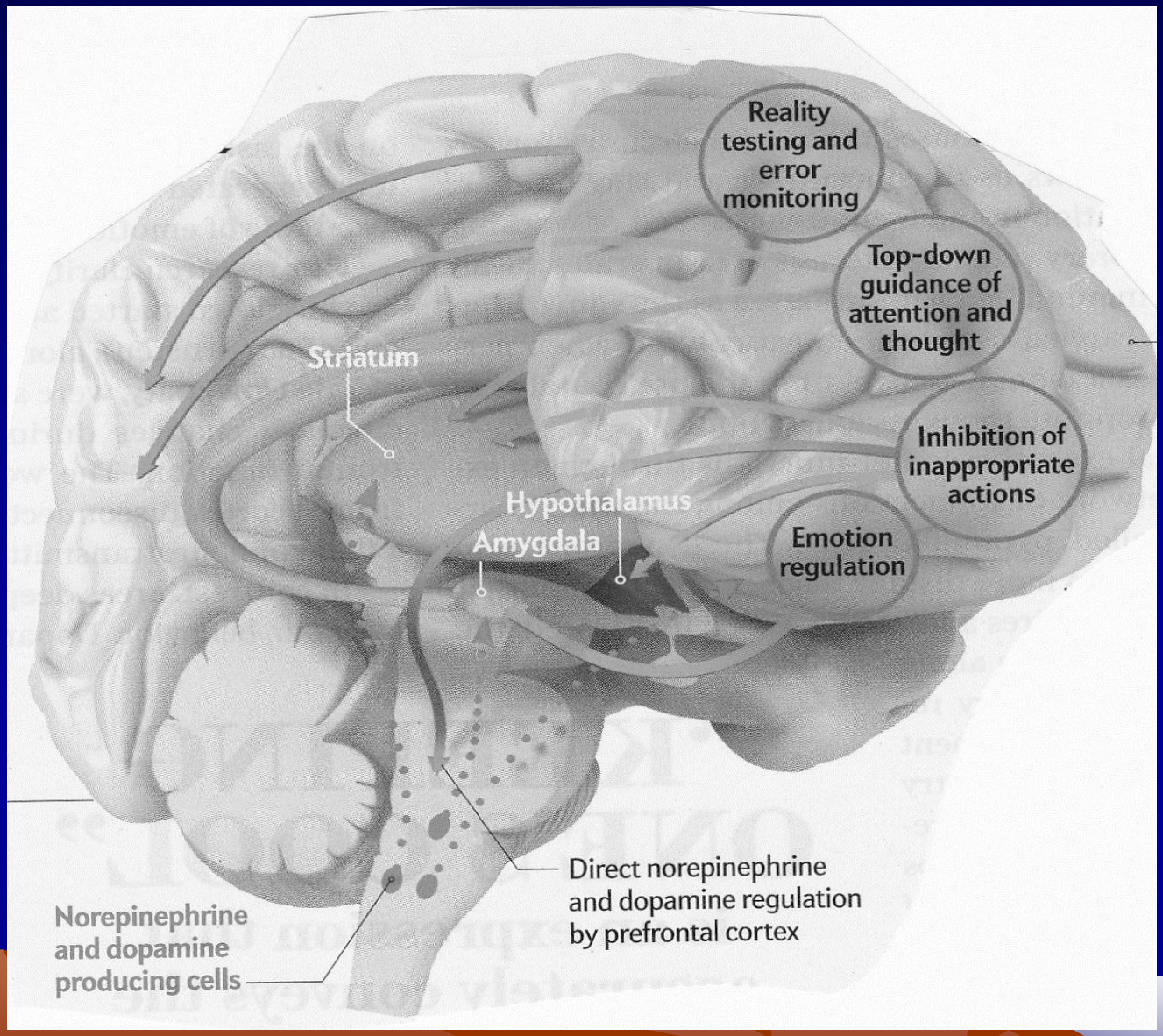


Across development there is a shift from growth in short-range connections within regions to increased long-range connections across regions along with pruning of some connections to form the functional cortical networks – this is delayed and disrupted in many of the networks implicated in ADHD. With maturation, it is mainly the frontal-parietal (executive) network that remains impaired

The Frontal Parietal Cortical Network Can Be Usefully Fractionated into Four EF Reciprocal Sub-networks: All are Implicated in Self-Regulation and in ADHD

- The frontal-striatal-thalamic circuit: Associated with deficits in response suppression, freedom from distraction, mental representations that guide behavior (working memory), manipulation of mentally held information (organization, planning, and problem-solving), and responding to novelty. Typically known as the "cool" or **"what"** EF network
- The frontal-cerebellar circuit: Associated with motor coordination deficits, but also with problems with the automaticity of actions, the anticipation of rewards, and the rate, rhythm, force, and especially timing and timeliness of behavior and thought. I call it the **"when"** EF network.
- The frontal-limbic circuit: Associated with symptoms of emotional self-regulation, motivation deficits, hyperactivity-impulsivity, and proneness to reactive aggression, known as the appraisal, **"hot"** or **"why"** EF network
- The frontal-cingulate-parietal network: Associated with deficits in self-awareness, performance monitoring, and error detection.

Executive Brain Networks



Why the Controversy in ADHD Research about EF?

- ADHD is a disorder of brain networks that contribute to EF/SR
  - So logically ADHD must be a disorder of EF/SR
- But only 35-50% or fewer of ADHD cases are impaired on EF psychometric tests ($\geq 93^{rd}$ %)
  - So ADHD cannot be a disorder of EF in half or more cases
- Yet 86-98% of clinical-referred adults with ADHD are impaired on rating scales of EF in daily life as are 65-75% of ADHD children followed to adulthood with persistent ADHD.
  - So ADHD must be primarily a disorder of EF in daily life
- Which Approach is Right??

More on the Controversy

- EF tests have little or no significant correlations with EF or ADHD ratings in daily life;
  - so they are not measuring the same construct (only share 0-10% of their variance – trivial!)
- EF tests poorly predict impairments in major life domains
  - So why are they stilled viewed as the “gold” standard for assessing EF?
- EF ratings are stronger predictors of such impairments
- Yet EF tests are used in the vast majority of research to build theories of EF and to make claims about the development of EF, differentiation among disorders in their impact on EF, and whether early EF deficits predict outcomes later in life
  - EF ratings would likely have shown entirely different results
- And EF ratings and ADHD symptom ratings share 50-70% of their variance reflecting near co-linearity (a single dimension)

How to Resolve the Problem? With an Explicit Theory of EF as SR

- Most common construct assigned to EF by expert neuropsychologists is self-regulation
- So make self-regulation the core of EF
  - A self-directed action
  - Intended to alter subsequent behavior
  - So as to change the probability of a future (delayed) event or consequence (improve one's longer term welfare)
- Each EF is a self-directed action (a type of SR)
- EFs (and SR) are always future directed (intentional)
- Humans use at least 7 different self-directed actions (EFs), usually in concert, for self-regulation to strive to achieve delayed goals and maximize their longer-term welfare

More on the Theory of EF as SR

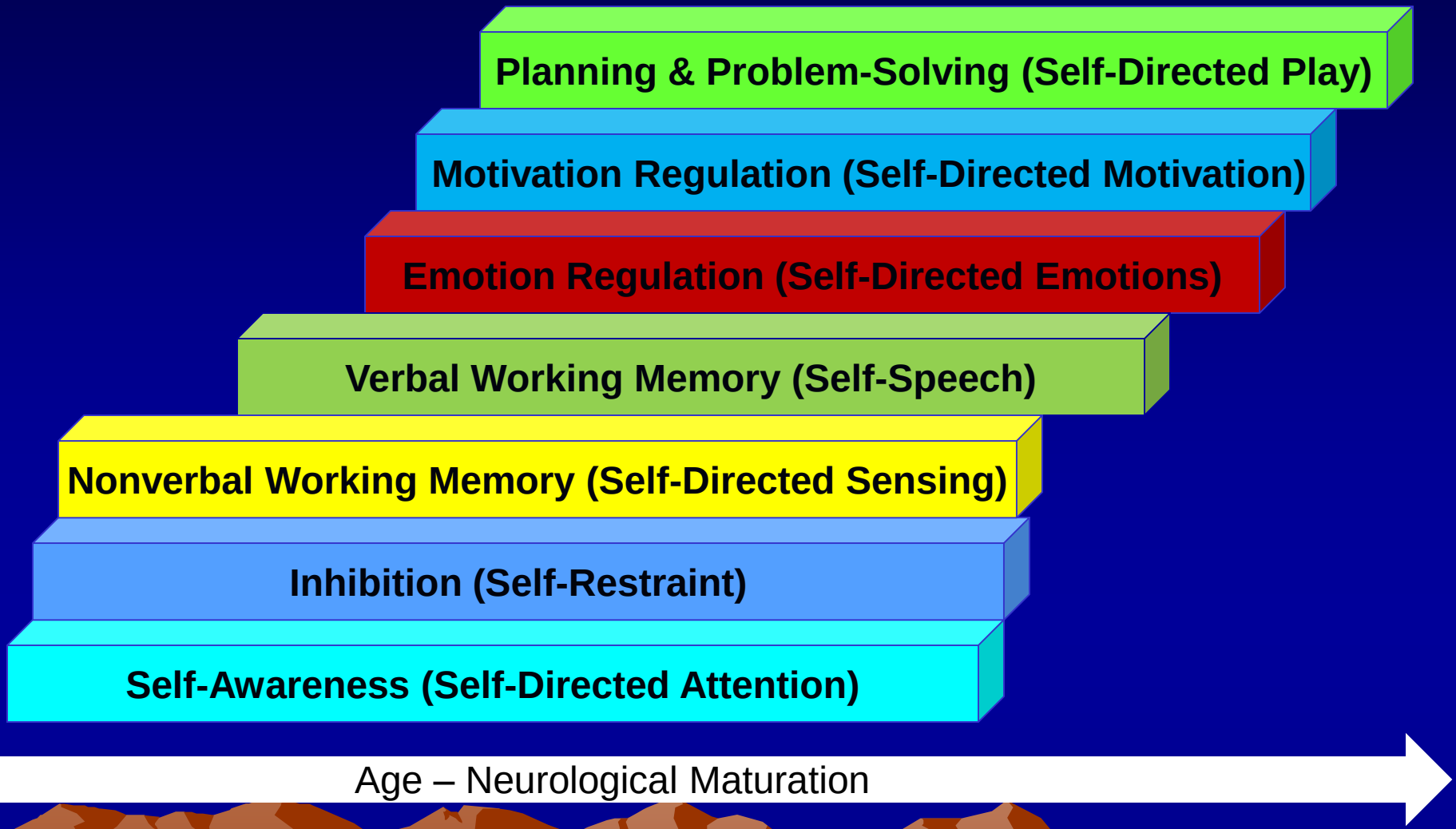
- These EFs develop in a step-wise sequence and so are hierarchically organized
  - Self-awareness, inhibition, and visual imagery appear to be the base or core EFs and so emerge first
- They exist to address the problems and opportunities involved in social (group) living
- They produce effects at a considerable distance from the genes that control them and so can be usefully viewed as an extended phenotype

Building a Theory of EF: Linking Inhibition, Self-Control, and the Executive Functions

What is EF?

- An executive function can be defined as a major type of action-to-the-self (a type of self-regulation)
- There are 7 major types of EFs:
  - Self-Awareness (meta-cognition)
  - Inhibition and interference control
  - Nonverbal working memory
  - Verbal working memory
  - Emotional
  - Self-Motivation
  - Planning and problem-solving
- Each likely develops as a behavior initially directed at interacting with and controlling the environment that is then turned on the self (for self-control) and then internalized (privatized, inhibited)
- They likely develop in a step-wise hierarchy - Each needs the earlier ones to function well

Sequential Development of the EFs



The EFs Create Four Developmental Transitions in What is Controlling Behavior

- External → Mental (private or internal)
- Others → Self
- Temporal now → Anticipated future
- Immediate → Delayed gratification

  (Decreased Temporal Discounting of Delayed Consequences)

Michon's Model of Driving

Level IV: Strategic Abilities

i.e., Purpose or goals for using the car, best routes through traffic to attain the goals, time likely needed to attain each goal, knowledge needed to enact the plan effectively (weather, traffic, construction, known accidents, etc.)

Level III: Tactical Abilities

i.e., abilities required to operate the vehicle on roadways in the presence of and interactions/conflicts with other drivers and their vehicles, such as driving laws, knowledge of safe driving tactics, etc.

Level II: Operational Abilities

i.e., familiarity with and sound management of the vehicle and its components such as steering, braking, acceleration, signaling, mirrors, seat belts, other safety equipment [ex. Driving a car in an empty parking lot]

Level I: Basic Cognitive Abilities Required to Drive

i.e., normal reaction time; visual field perception; motor speed, agility, coordination, and range of motion; visuo-spatial reasoning; hearing; language and reading abilities, etc.

Barkley's Model of EF

Level IV: Strategic – Cooperative Abilities

i.e., Underlies human coordinated group activities in which goals can be attained that are not possible for any individual. Underlies cooperative ventures, division of labor, formation of communities and governments

Level III: Tactical – Reciprocal Abilities

i.e., Underlies human social exchange, turn taking, reciprocity, promise keeping. Basis of economic behavior (trading); Underlies ethics, social skills and etiquette; Basis for legal contracts

Level II: Methodical – Self-Reliant Abilities

Essential for daily adaptive functioning, self-care, and social self-defense

i.e., Self-Organization and Problem-Solving, Self-Management to Time, Self-Restraint, Self-Motivation, Self-Regulation of Emotions

Level I: Instrumental – Self-Directed Abilities

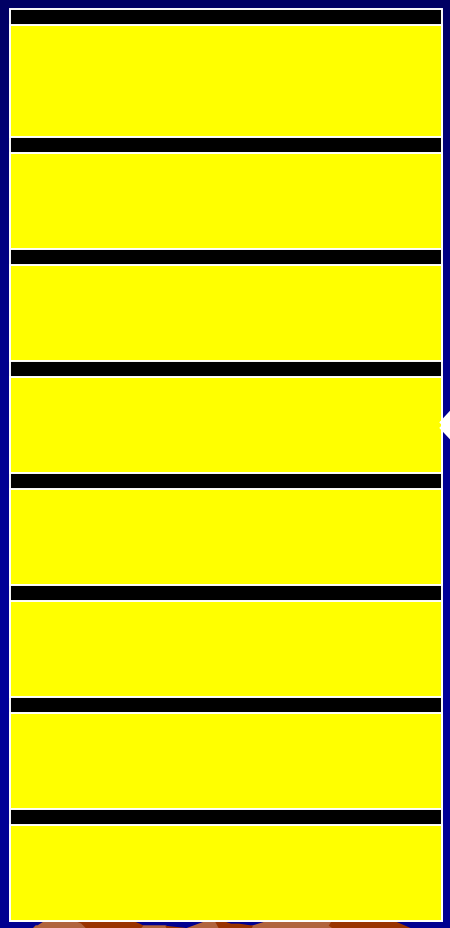
i.e., self-awareness, executive inhibition and interference control, nonverbal and verbal working memory, planning, problem-solving, self-motivation, emotion regulation

Executive Functioning - Defined

EF is the use of self-directed actions (forms of self-regulation) to choose goals, and to select, enact, and sustain actions across time toward those goals, usually in the context of others and often relying on social and cultural means. This is done for the maximization of one's longer-term welfare as the person defines that to be.

(Barkley, 2012)

Self-Regulatory Strength May Be a Limited Resource Pool



- Inhibition & Self-Restraint
- Self-Management to Time (NV-WM)
- Self-Organization & Problem-Solving (V-WM)
- Emotional Self-Regulation
- Self-Motivation

The pool increases in capacity with maturation.

Using EF/SR reduces the pool. temporarily

So Does:
Stress, Alcohol, Drug Use, & Illness

6 Level Hierarchy of EF

PFC Disorders like ADHD

Extended Utilitarian

Strategic - Cooperative

Severe PFC Injury

Tactical - Reciprocal

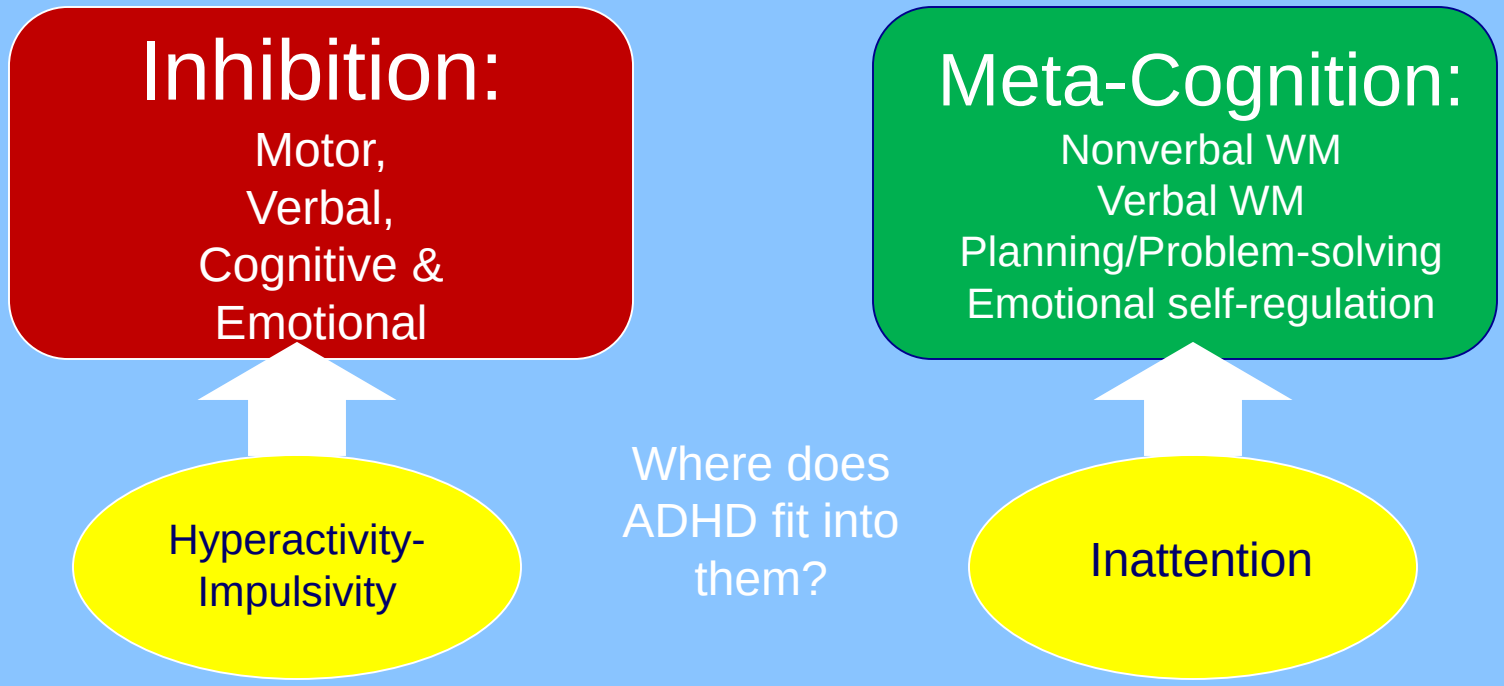
Methodical – Self-Reliant

Instrumental – Self-Directed

Pre-Executive (non-EF)

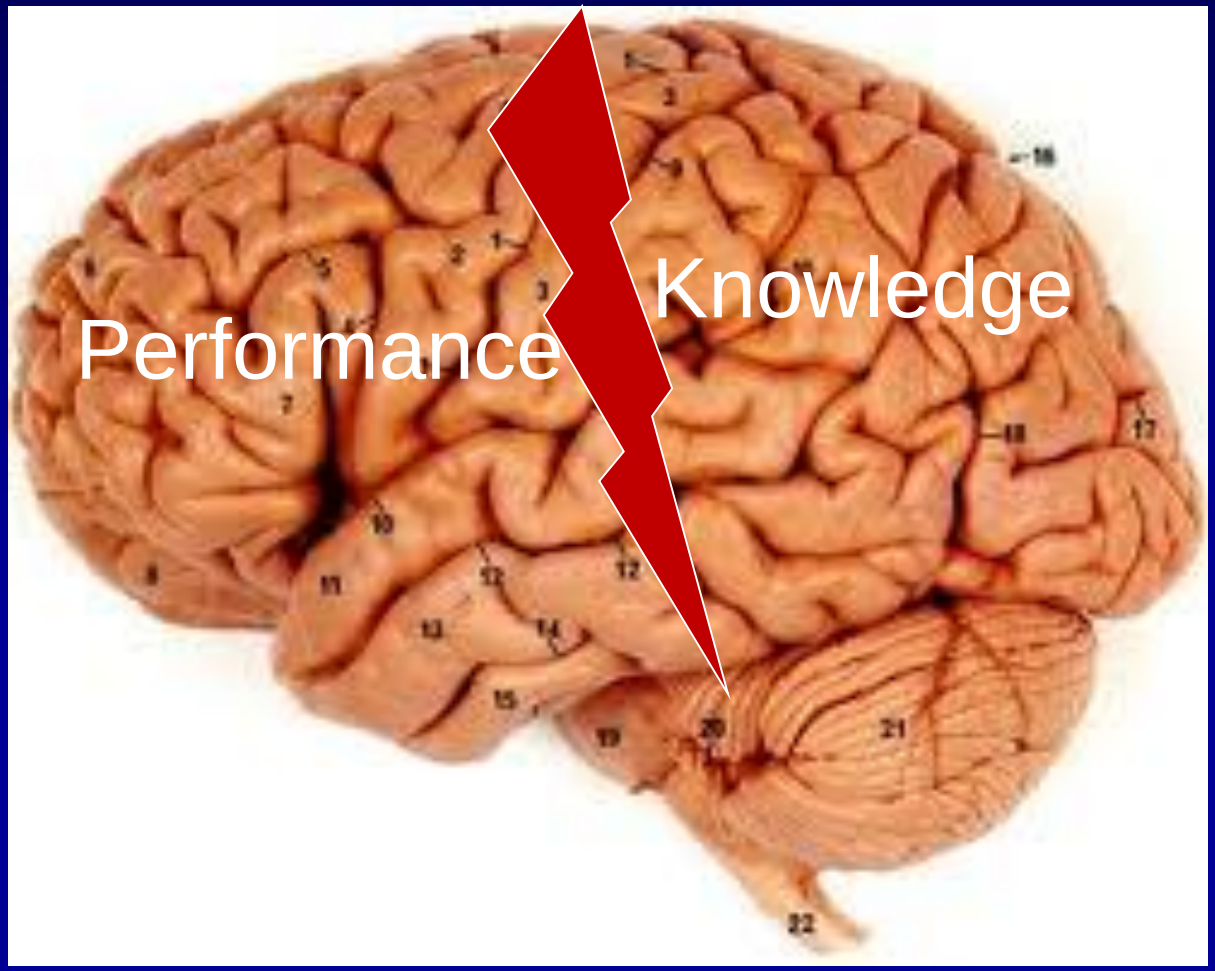
How Does ADHD Fit Into EF?

EF Comprises a Single Domain that Can Be Usefully Subdivided into two Broad Dimensions



The Brain as a Knowledge vs. Performance Device

ADHD



Understanding ADHD

- ADHD disrupts the 7 forms of EF/SR and most upper levels of its extended phenotype but especially the tactical and higher levels thereby creating a disorder of self-regulation across time
- ADHD can be considered as “Time Blindness” or a “Temporal Neglect Syndrome” (Myopia to the Future)
- It adversely affects the capacity to hierarchically organize behavior across time to anticipate the future and to pursue one’s long-term goals and self-interests (welfare and happiness)
- It’s not an Attention Deficit but an Intention Deficit (Inattention to mental events & the future)

Understanding ADHD

It's a Disorder of:

- Performance, not skill
- Doing what you know, not knowing what to do
- The when and where, not the how or what
- Using your past at the "point of performance"

The point of performance is the place and time in your natural settings where you should use what you know (but may not)

The Value of the Concept of Delayed Executive Age in ADHD

- ADHD appears to delay EF development by 25-40%, or an average of 30%
- Use this estimate to understand a child's executive age or EA (chronological age minus 30%)
- Adjust expectations to match this EA
- Determine new responsibilities and freedoms based on their EA not their CA
- Provide accommodations or scaffolding to support the child at this EA

Implications for Treatment

- Teaching skills is inadequate
- The key is to design prosthetic environments around the individual to compensate for their EF deficits
- Therefore, effective treatments are always those at the “point-of-performance”
- The EF deficits are neuro-genetic in origin
- Therefore, medications may be essential for most (but not all) cases – meds are neuro-genetic therapies
  - They are also associated with neuro-protective effects (normalizing effects) on brain structure and functioning as well as on EF tasks
- Is EF responsive to direct training?
  - Preschool play-based EF training (maybe – 2 promising pilot studies focusing on “at risk” children)
  - EEG Neurofeedback (questionable effectiveness; placebo controlled, blinded studies find no effects)
  - Cognitive training technology (doubtful – no far transfer to functioning in natural settings)
  - fMRI Neurofeedback training (1 promising pilot study by Katya Rubia)

More Treatment Implications

- Behavioral treatment (BT) is essential for restructuring natural settings to assist the EFs – think of it as the external scaffolding needed to support the EF/SR system (externalizing the prefrontal lobes)
  - BT provides artificial prosthetic informational cues to substitute for the working memory deficits (signs, lists, cards, charts, posters)
  - BT provides artificial prosthetic consequences placed in the large time gaps between consequences thus increasing accountability and motivation (i.e., tokens, points, etc.)
- But BT serves two different purposes depending upon the nature of the problem/disorder being treated
  - Informational - knowledge and skill building
  - Motivational - knowledge and skill performance
- The effects of BT do not generalize or endure after removal because they primarily address the motivational deficits in ADHD and so must be sustained if gains are to be maintained

More Treatment Implications

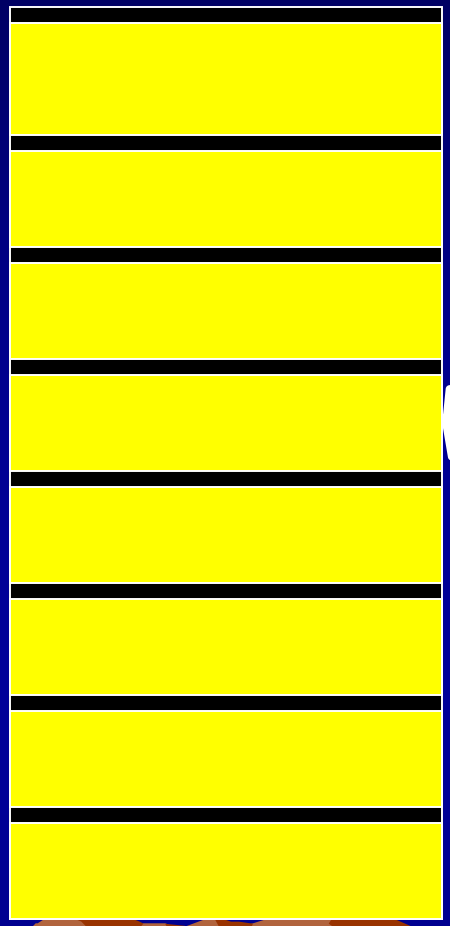
- Treatments that might be promising but remain largely untested in EF/SR disorders like ADHD
  - Over-learning and repeated rehearsal (moving from novelty and the EF "slow" system to automaticity/routinization in the non-EF "fast" brain
  - Mental simulation of "if-then" situations to facilitate acquisition and practice of EF even in the absence of that situation
  - Observational learning – like mental simulation, video modeling or video self-modeling may be useful in promoting acquisition and practice of self-regulation and EF even in the absence of such direct learning events (being used in ASD research now)
- The compassion and willingness of others to make accommodations are vital to success
- A chronic disability perspective is most useful
- While ADHD creates a diminished capacity: Does this excuse accountability?
  - (No! The problem is with time and timing, not with consequences)

How can we compensate for EF deficits? By reverse engineering the EF system

- Externalize important information at key points of performance (off-load working memory demands onto external storage devices)
- Externalize time and time periods related to tasks and important deadlines
- Break up lengthy long-term tasks spanning long periods of time into many smaller steps
- Externalize sources of motivation
- Externalize and manualize mental problem-solving
- Replenish the SR resource pool (willpower)

Replenishing the EF/SR Resource Pool

S-R Fuel Tank
(Willpower)



- Greater Rewards and Positive Emotions
- Statements of Self-Efficacy and Encouragement
- 10 minute breaks between EF/SR tasks
- 3+ minutes of relaxation or meditation
- Visualizing and talking about future rewards before and during SR demanding tasks
- Routine physical exercise; Also Glucose ingestion

Regular limited practice using EF/SR and the Willpower Pool can increase later pool capacity. However, the capacity may eventually diminish once practice is terminated.

Adapted from Bauer, I. M. & Baumeister, R. F. (2011). Self-regulatory strength. In K. Vohs & R. Baumeister (Eds.), *Handbook of Self-Regulation (2nd ed.) (pp. 64-82).* New York: Guilford Press

Conclusions

- The concept of EF can be salvaged by equating it with the more precise definition of SR and realizing that humans use at least 7 types of SR (each being an EF) to modify their behavior so as to improve their future welfare
- EF/SR system is multi-leveled and arranged in a hierarchy over maturation
- EF/SR likely evolved to solve problems in social living among large numbers of non-kin.
- EF/SR radiates effects outward (upward) into expanding zones of influence and functioning in the larger social environment

Conclusions

- ADHD delays and disrupts behavioral inhibition and the internalization of the instrumental level of self-directed EFs producing a cascading of deficits into all 7 components of EF
- In essence, ADHD produces a time or future blindness causing the individual to live more in “the now” and so be a less future-directed individual
- By disrupting EF/SR, ADHD affects the 5 major EFs seen in daily life activities:
  - Self-restrain or inhibit behavior, thoughts, words, emotions
  - Self-manage to time; anticipate and prepare for the future
  - Self-organize and problem solve across time
  - Self-motivate across time
  - Self-regulate emotions across time

Conclusions

- Behavior in people with ADHD cannot be hierarchically organized and sustained in support of longer term goals and welfare
- This results in a serious and pervasive disorder of self-regulation across time and settings and impaired social functioning (reciprocity, cooperation, and mutualism)
- Preventing them from dealing effectively with the probable future and pursuing one's long-term goals and welfare
- Thereby requiring the design of prosthetic environments that compensate for EF/SR deficits while using neuro-genetic medicines to temporarily improve or normalize the instrumental self-directed EFs