The Developing Brain: Advanced Executive Functioning in Children and Adolescents

Dr. Carissa Muth

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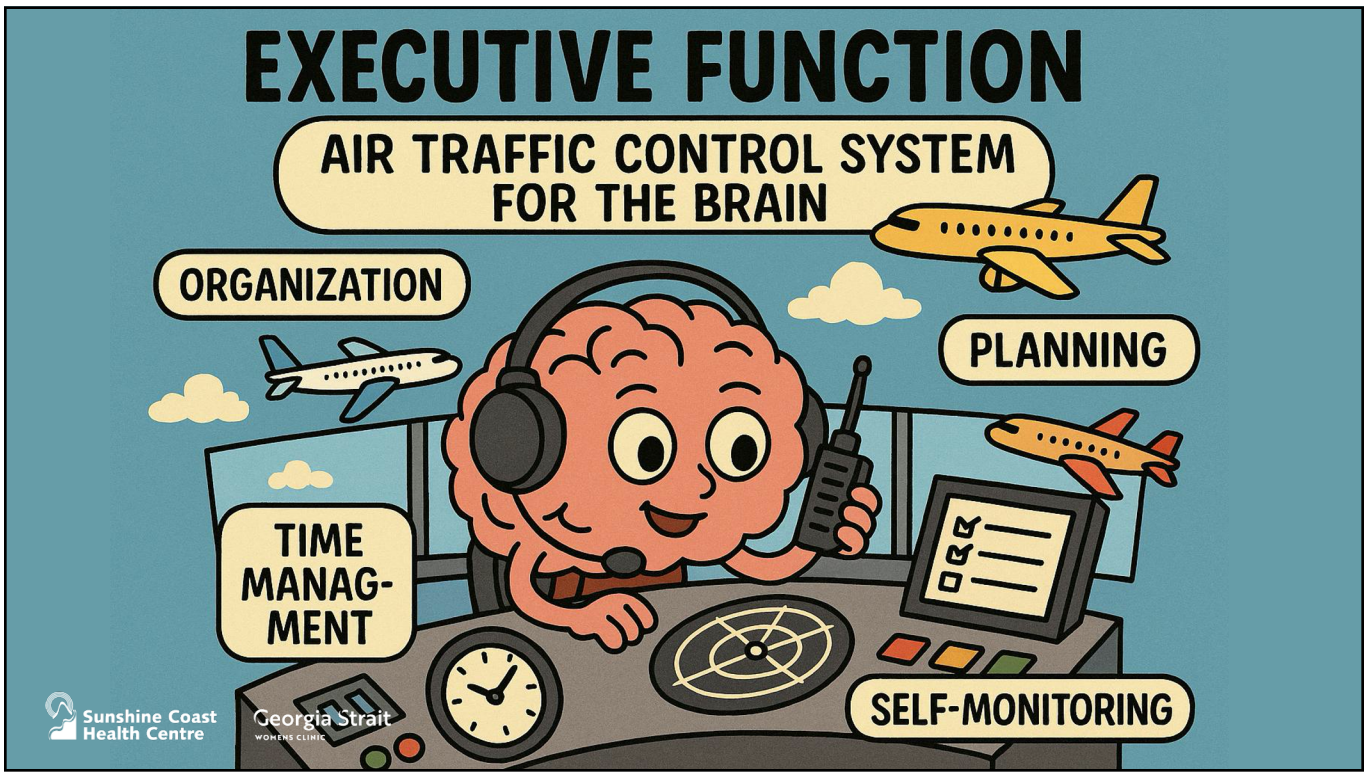

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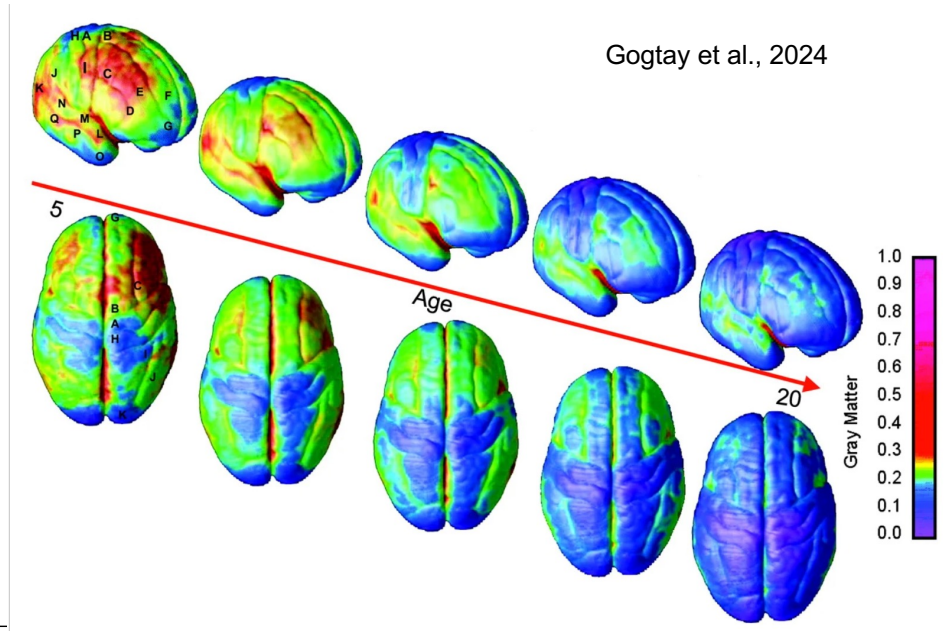

Right lateral and top views of the dynamic sequence of GM maturation over the cortical surface. The side bar shows a color representation in units of GM volume. The initial frames depict regions of interest in the cortex as described for Fig. 1. This sequence is available in Movies 1–4 in the supporting information.

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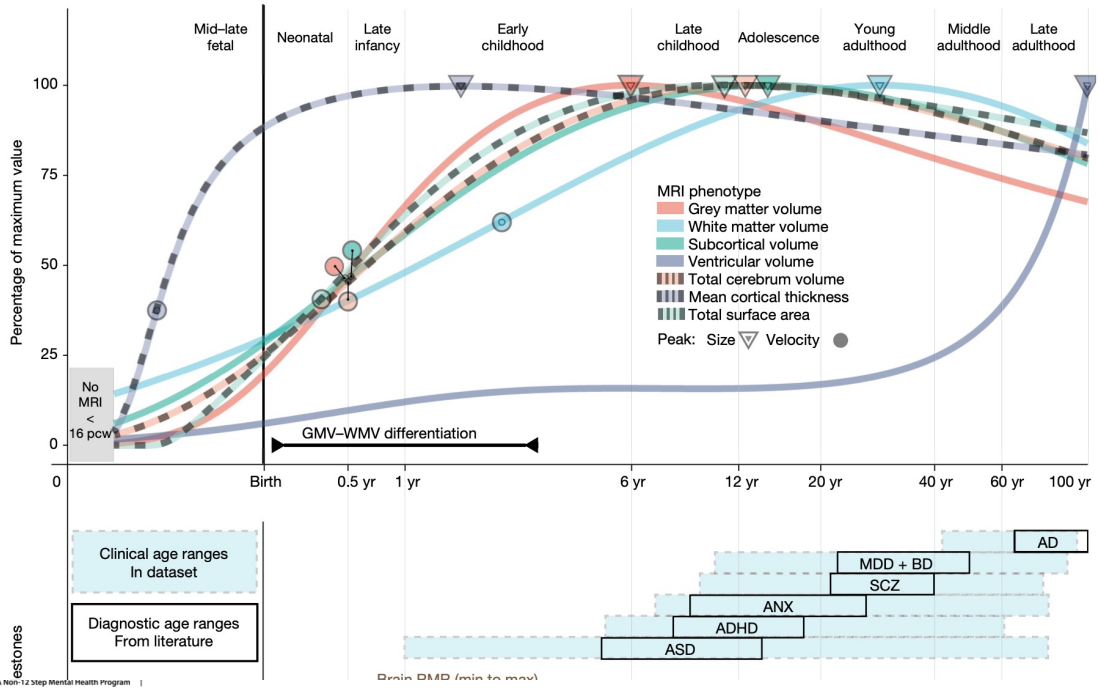

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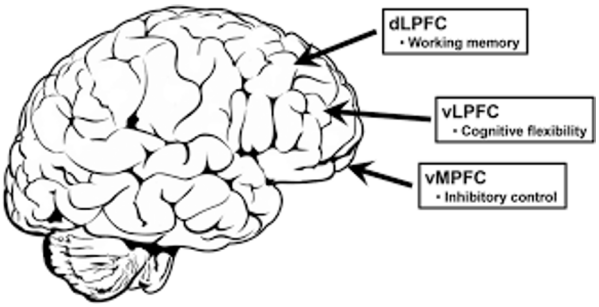
Executive Functioning

- Processes of the brain that drive goal-oriented behaviour
- Often broken down into working memory, inhibitory control, and cognitive flexibility.
- Mainly occurs in the prefrontal cortex
- Variance in adolescence accounted for 90-100% by genetics



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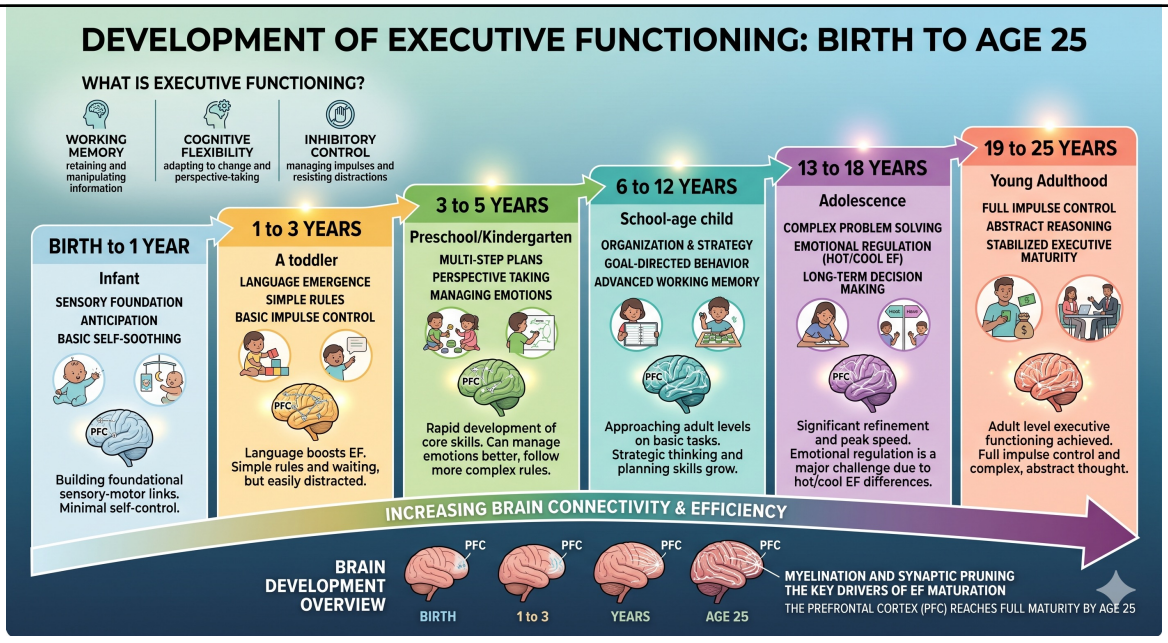

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Development of EF

- Dynamic, might be best explained by gene-by- environment mechanisms
- Exposure to prenatal deprivation and substances of abuse can reduce cognitive ability
- Violence, abuse and environmental deprivation can all contribute to worsening EF
- Environmental differences explain variance in adulthood EF

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Executive Gap

- Research and clinical observation show that many students—especially neurodivergent learners—have an executive function delay of about **3 to 5 years**
- Different brain systems, different timelines
- The executive gap often creates a negative cycle:
  - Child struggles to meet expectations
  - Adults interpret as lack of effort
  - Expectations increase (“You can do better”)
  - Stress increases
  - Executive function decreases
  - Performance worsens

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State Dependent

- **Adaptive**
- **Context dependent**

Niebaum, J. C., Zengilowski, A., Katz, B., Shah, P., & Munakata, Y. (2025). Adaptive habits: understanding executive function and its development. *Trends in Cognitive Sciences*, S1364-6613.

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Executive functions (EFs) are important to just about every aspect of life

Aspects of life	The ways in which EFs are relevant to that aspect of life	References
Mental health	EFs are impaired in many mental disorders, including:	
	- Addictions	Baler & Volkow 2006
	- Attention deficit hyperactivity (ADHD)	Diamond 2005, Lui & Tannock 2007
	- Conduct disorder	Fairchild et al. 2009
	- Depression	Taylor-Tavares et al. 2007
	- Obsessive compulsive disorder (OCD)	Penadés et al. 2007
	- Schizophrenia	Barch 2005

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	Schizophrenia	Barch 2003
Physical health	Poorer EFs are associated with obesity, overeating, substance abuse, and poor treatment adherence	Crescioni et al. 2011, Miller et al. 2011, Riggs et al. 2010
Quality of life	People with better EFs enjoy a better quality of life	Brown & Landgraf 2010, Davis et al. 2010
School readiness	EFs are more important for school readiness than are IQ or entry-level reading or math	Blair & Razza 2007, Morrison et al. 2010
School success	EFs predict both math and reading competence throughout the school years	Borella et al. 2010, Duncan et al. 2007, Gathercole et al. 2004
Job success	Poor EFs lead to poor productivity and difficulty finding and keeping a job	Bailey 2007

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Marital harmony	A partner with poor EFs can be more difficult to get along with, less dependable, and/or more likely to act on impulse	Eakin et al. 2004
Public safety	Poor EFs lead to social problems (including crime, reckless behavior, violence, and emotional outbursts)	Broidy et al. 2003, Denson et al. 2011

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Diamond A. (2013). Executive functions. *Annual review of psychology*, *64*, 135–168. https://doi.org/10.1146/annurev-psych-113011-143750

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Working Memory

- Where thoughts are held and manipulated
  - Working (central executive/ active processing)
  - Memory (temporary storage/ rehearsal)
- We can choose what to think about and how to think about it (i.e. under top-down control)
- Bouts of spiking versus little or no spiking
- Brain uses multiple mechanisms to maintain information in working memory
- Memory struggles versus concentration
- Many describe attentional control as a core component of WM

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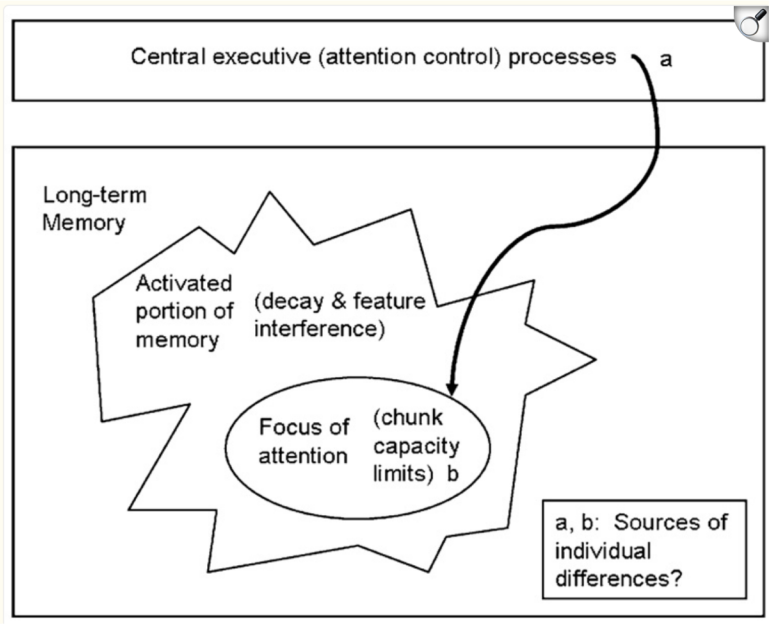

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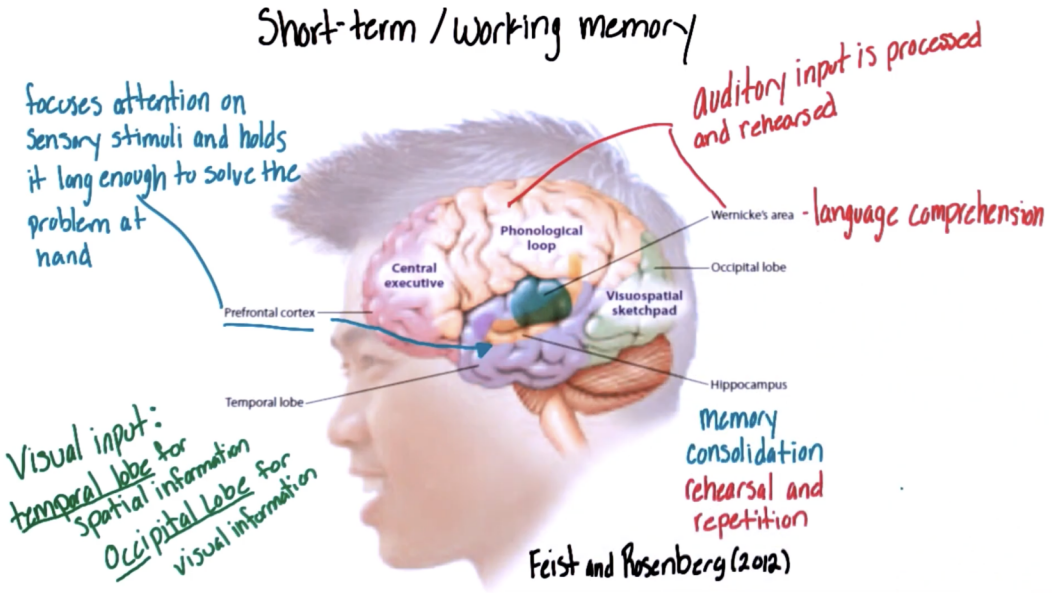

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https://www.youtube.com/watch?v=Ep25ntXtClg

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Improving Working Memory

- Researchers disagree over benefit of WM training
- [Computerized] Training short-term memory improves short-term memory moderately (Rapport et al., 2013)
- No effect of WM training on typically developing children (Sala & Gobet, 2020)

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Category	Technique	Description & How It Works
Cognitive Strategies (Managing Information)	1. Chunking	Grouping small, individual pieces of data (like numbers or letters) into larger, more manageable, meaningful units or "chunks" to reduce the strain on working memory capacity.
	2. Creating Associations (Mnemonics)	Linking new information to things already known. This includes using vivid visualization, rhymes, songs, or the Memory Palace (Method of Loci) technique to encode data more strongly.
	3. Active Rehearsal	Teaching the concept to someone else or self-quizzing. This forces the brain to actively retrieve and organize the information, strengthening the pathways for retrieval.
	4. Spaced Repetition	Reviewing information in short, increasing intervals over days or weeks rather than cramming it all at once. This aids the transfer of data from temporary working memory to long-term memory storage.

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Cognitive Exercises (Direct Practice)	N-Back Tasks	A challenging digital exercise that requires you to recall a stimulus that occurred n steps back (e.g., the letter shown two steps ago), directly training the maintenance and updating of information.
	Mental Math & Sequencing	Performing calculations without aids, or tasks like spelling words backward or reciting sequences backward (e.g., the months of the year). This actively forces the brain to hold and manipulate data.
	Strategy Games	Engaging in games like Chess, Sudoku, or complex card games (e.g., Bridge) that require planning several steps ahead and holding conditional scenarios in mind.

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Lifestyle Factors (Optimal Brain Environment)	Quality Sleep	Essential for memory consolidation, allowing the transfer of data from working memory into long-term storage.
	Regular Exercise	Increases blood flow and oxygen to the brain, supporting the neural growth necessary for improved memory function.
	Mindfulness & Focus	Practices like meditation improve the ability to limit cognitive distractions and better allocate attention resources to the information held in working memory.
	Limit Multitasking	Concentrating on one task at a time prevents the working memory system from being overloaded and fragmented.

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Cognitive Flexibility

- The ability to shift and update actions in conjunction with task, goal, and environment
- Dopaminergic signaling in striatum is strongly implicated in executive functions including cognitive flexibility
- Dopamine plays an important role in adapting to new information and switching between mental strategies (Miederer et al., 2025)
- Higher cortical dopamine levels means lower striatal dopamine levels
- Links to increased self-harm in adolescence

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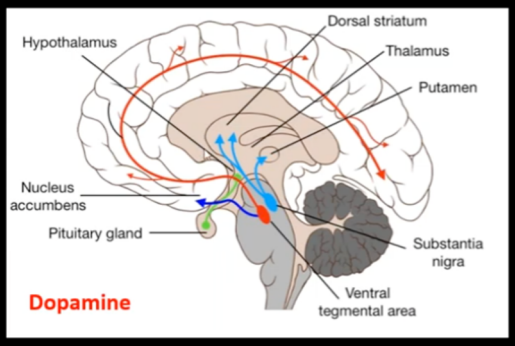
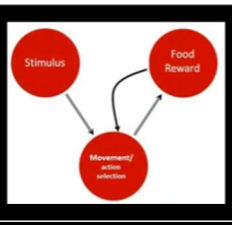
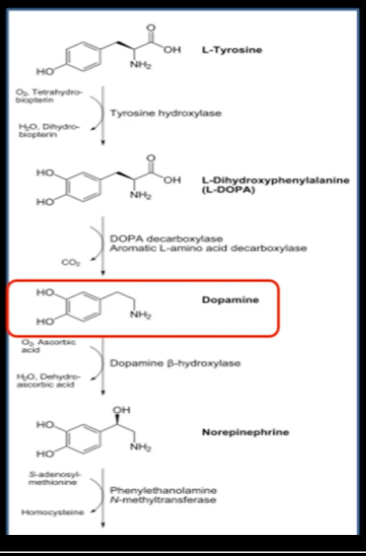
Dopamine Neurotransmission







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Improving Cognitive Flexibility

TABLE 1 | Comparison of noninvasive neuromodulatory techniques in improving cognitive flexibility (CF).

Technique	Modality	Mechanism of action	Effects on CF
transcranial Direct Current Stimulation (tDCS)	Noninvasive stimulation by direct electrical current	Modulates cortical excitability by altering the membrane potential	Promising improvements: studies show enhanced CF, especially in prefrontal tasks, but some show no effect
repetitive Transcranial Magnetic Stimulation (rTMS)	Magnetic stimulation via repetitive pulses	Induction of neuroplastic changes by modulating synaptic plasticity and membrane potential	Positive effects on CF, particularly with DLPFC targeting, but some interventions show no effect
Photobiomodulation (PBM)	Low-level near-infrared light therapy	Improves mitochondrial function and cortical blood flow	Positive effects on CF, particularly in neurological conditions with cognitive deficiencies
Virtual reality (VR)	Computer-simulated interactive and dynamic environments	Provides immersive nature and ecologically valid cognitive tasks	Effective in improving CF via real-life simulation
Neurofeedback (NF)	Real-time EEG-based self-regulation	Voluntary modulation of brainwave activity	Generally positive effects on CF, especially in ADHD and ASD children

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https://www.sciencedirect.com/science/article/abs/pii/S2352154625000038

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Inhibitory Control

- The behavioural developmental trajectory of IC begins towards the end of the first year of life
- IC shows a prominent and rapid improvement during the toddler and preschool years
- Highly sensitive to emotion and stress

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Feature	Cold Executive Function	Hot Executive Function
Trigger	Logic, data, and neutral tasks.	Emotion, social status, and rewards.
Brain Region	Dorsolateral Prefrontal Cortex.	Ventromedial Prefrontal Cortex / Limbic System.
Peak Difficulty	Low (tasks are straightforward).	High (requires resisting intense feelings).
Adolescent Ability	Often adult-like by mid-teens.	Significantly underdeveloped until mid-20s.
Example	Knowing that speeding is dangerous.	Speeding because your friends are cheering.

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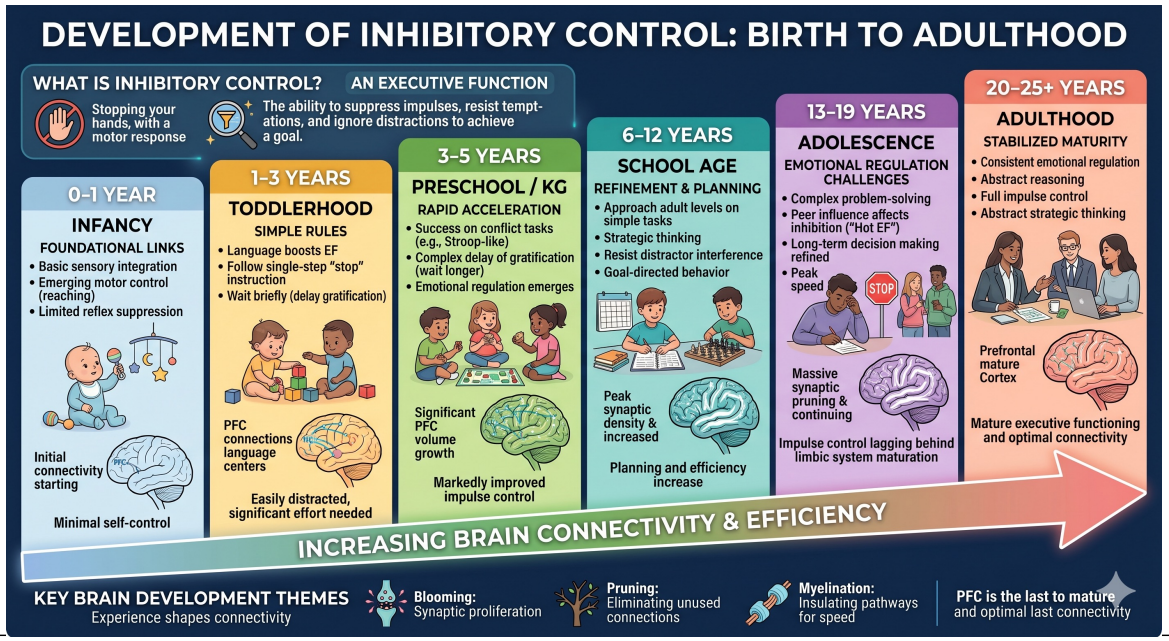

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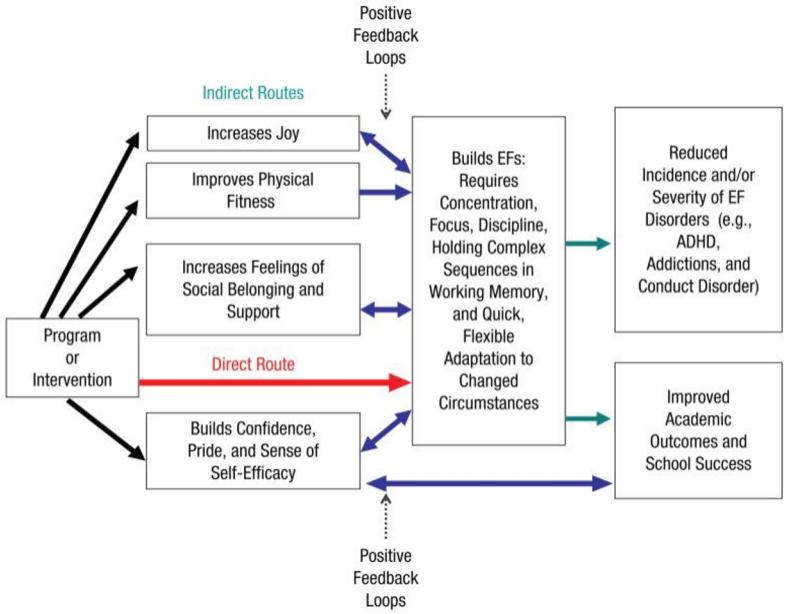

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Environment

Type of Modification	Example	Why it helps
Visual Externalization	Using a physical countdown timer (like a Time Timer).	You don't have to "calculate" time in your head; you can just see it.
Structural Quiet	Using noise-canceling headphones or "privacy carrels."	The brain doesn't have to work to filter out background noise.
Cognitive Offloading	Putting a "To-Do" list exactly where the work happens.	It saves the brain from having to "remember the plan" using working memory.
Environmental Priming	Setting out your gym clothes the night before.	It removes the "deciding" step in the morning, which preserves mental energy.

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Barriers

- Sensory processing
- Autonomic Arousal
- Stress

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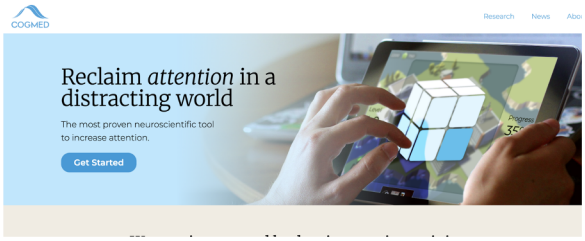
Interventions

- **CogMed and other computer practice**
  - Improves specific skills practiced
  - No evidenced it transfers to other untrained EF domains
  - Questionable whether learned skills can be applied to real world situations



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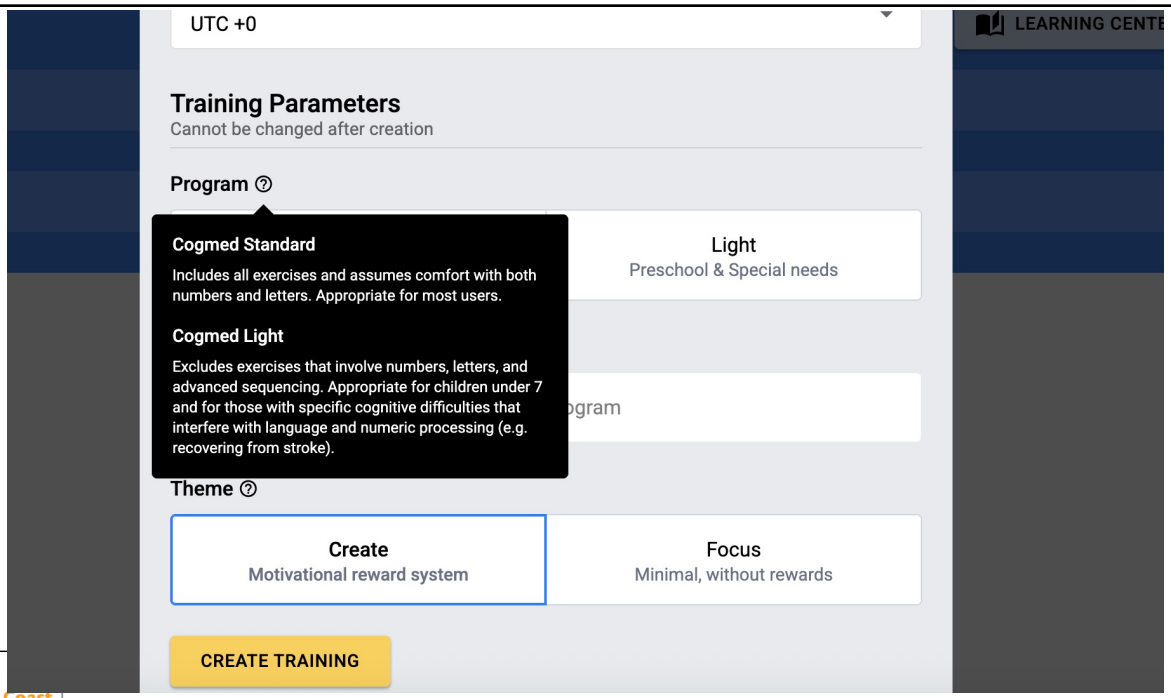

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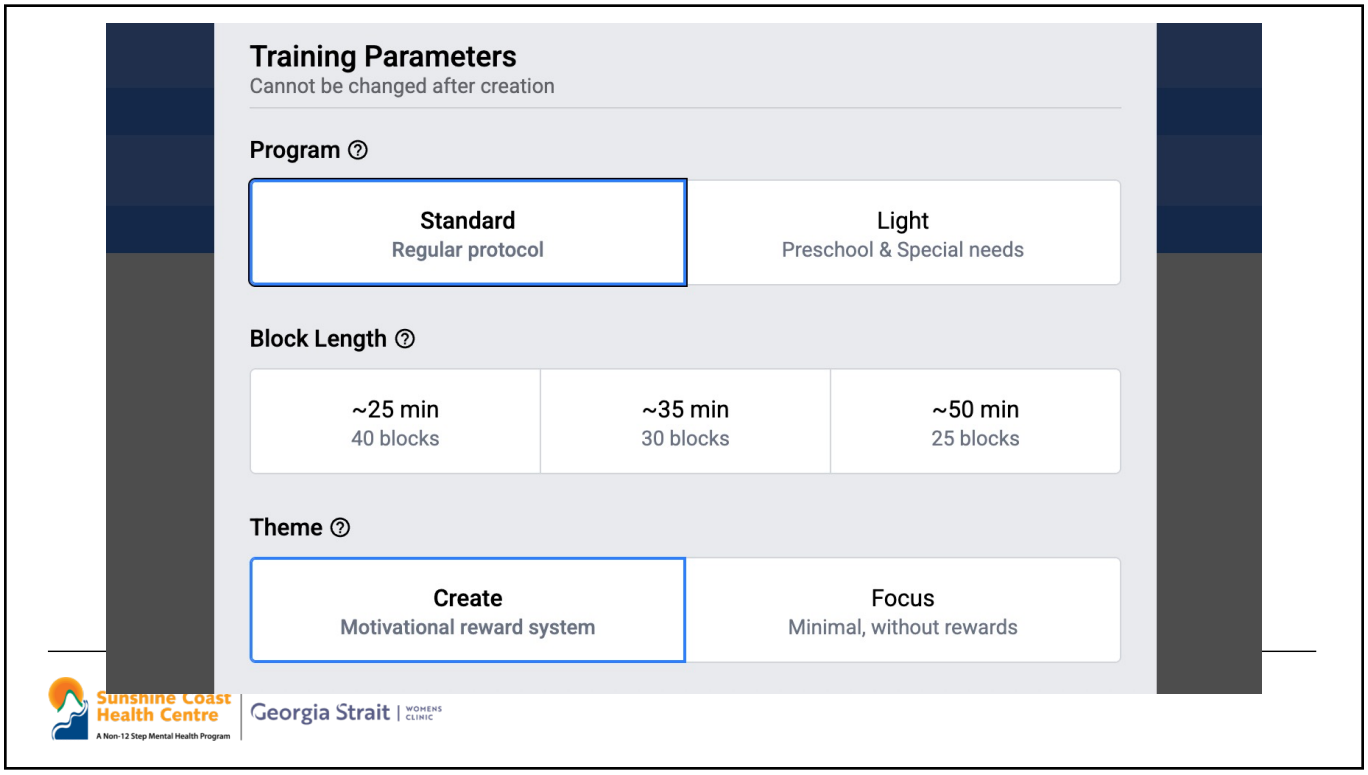
Training Parameters
Cannot be changed after creation
Program
Standard
Regular protocol
Light
Preschool & Special needs
Block Length
~25 min
40 blocks
~35 min
30 blocks
~50 min
25 blocks
Theme
Create
Motivational reward system
Focus
Minimal, without rewards
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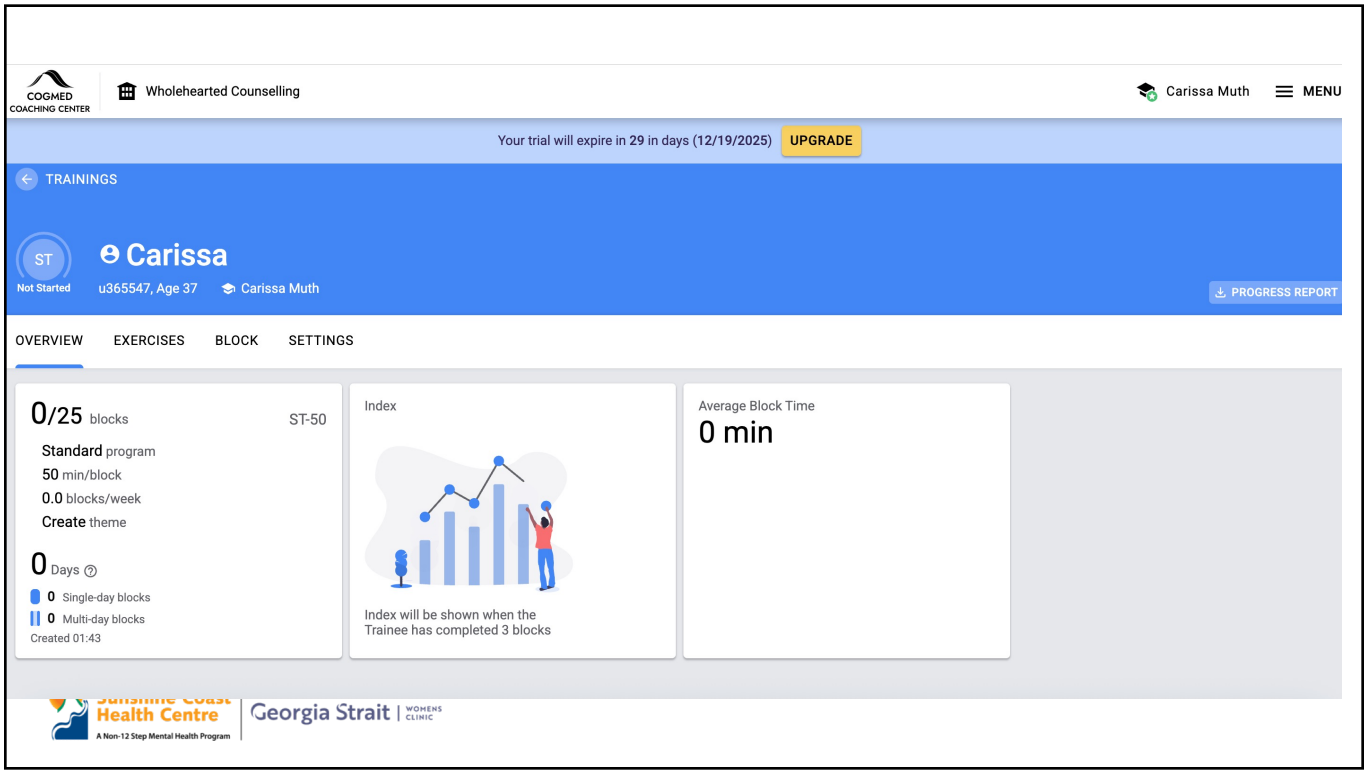
COGMED COACHING CENTER
Wholehearted Counselling
Carissa Muth
MENU
Your trial will expire in 29 in days (12/19/2025)
UPGRADE
TRAININGS
ST
Not Started
Carissa
u365547, Age 37
Carissa Muth
PROGRESS REPORT
OVERVIEW
EXERCISES
BLOCK
SETTINGS
0/25 blocks
ST-50
Standard program
50 min/block
0.0 blocks/week
Create theme
0 Days
0 Single-day blocks
0 Multi-day blocks
Created 01:43
Index
Index will be shown when the Trainee has completed 3 blocks
Average Block Time
0 min
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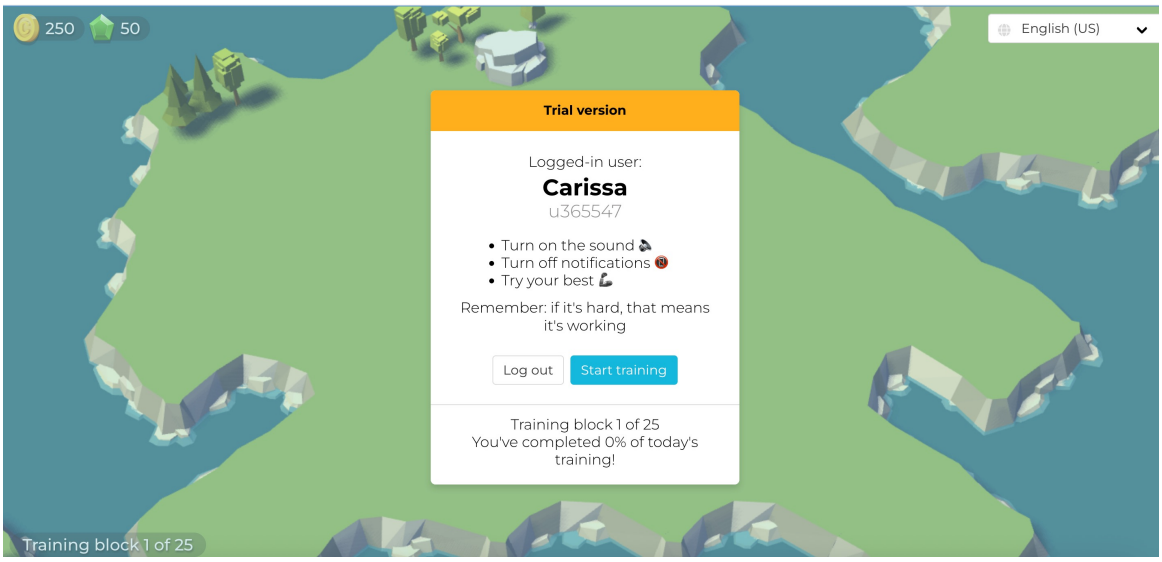

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Interventions

- **Environmental Training**
  - Ex. Circle time games such as “freezing” when music stops
  - Found to enhance inhibition only in preschoolers who entered the study with lower inhibition control than average
  - Chronic physical activity (such as sports) has been shown to help improve aspects of EF
  - Cognitively challenging activities, such as team sports, more helpful than non-engaging aerobic exercise

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Interventions

- **Tools of the Mind and Montessori**
  - Include activities that foster EF, such as pretend play, waiting your turn for a certain material
  - Activities such as theatre, orchestra and choir may help with EF skills

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EF Skill Targeted	Section from Previous Response	Examples of Tools & Activities	Key Mechanism/Goal
1. Inhibition	Stopping a Response (Reactive Inhibition)	Simon Says/Red Light, Green Light, Freeze Dance, Traditional Martial Arts, or simple tasks requiring precision (e.g., carrying a full tray).	Requires the child to override a strong, dominant impulse to move or act in favor of a rule-based or more appropriate action.
2. Working Memory	Holding and Manipulating Information	Memory/Concentration Games, Go Fish, Uno, Checkers, "I Went to a Picnic..." verbal games, and copying a sequence of sounds or actions.	Forces the child to hold information (rules, previous moves, item lists) in mind while simultaneously performing a task.
3. Cognitive Flexibility	Shifting Focus and Adapting	Sorting Games with Changing Rules, Improvisational Play/Theater, and "Think Outside the Box" challenges (e.g., finding new uses for an ordinary object).	Challenges the child to switch mental sets quickly and adapt their thinking or behavior when the rules or context change.
4. General EF Skills	Professional and Therapeutic Support	Executive Function Coaching, Cognitive Behavioral Therapy (CBT), and Mindfulness Practices (e.g., deep breathing).	Provides structured, targeted training for organization and study skills, and helps improve self-awareness and emotional regulation, which underpins all other EF skills.

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EF Skill Targeted	Tool/Strategy	Description and Goal
Planning & Organization	Digital Organization & Habit Stacking	Using apps (e.g., Google Calendar, Trello, Evernote) for long-range planning (multi-step projects, exams) and note-taking. Habit Stacking (e.g., "After I finish dinner, I immediately check my planner") links new desired behaviors to existing routines.
Time Management	Time-Tracking/Estimation & The Pomodoro Technique	Time-Tracking: Having the teen estimate how long a task will take, and then tracking the actual time. This builds metacognition about time. Pomodoro: Using focused work intervals (25 min) followed by short breaks to combat procrastination and maintain focus.
Working Memory	Active Study Strategies (Self-Quizzing, Summarization)	Moving beyond simple rereading. Strategies like generating questions from notes, writing summaries without looking at the text, or teaching the material to someone else forces them to actively retrieve and manipulate information in working memory.
Inhibition & Self-Control	"Pause & Plan" Techniques (e.g., STOPP method)	In social or emotional situations, practicing a strategy like STOPP (Stop, Take a breath, Observe, Pull back, Proceed) helps inhibit impulsive reactions. Also, designating "no-phone" work zones to reduce distraction inhibition failure.
Cognitive Flexibility	Debate & Perspective-Taking Activities	Engaging in formal or informal debate where they must research and argue a position they disagree with. This forces them to switch perspectives and consider multiple viewpoints.
Goal-Directed Persistence	S.M.A.R.T. Goal Setting	Teaching them to set goals that are Specific, Measurable, Achievable, Relevant, and Time-bound. This structures the motivation needed for long-term projects and academic success.
Emotional Regulation	Journaling & Mindfulness/Meditation	Journaling to process and label strong emotions, moving from reactive feeling to reflective thought. Mindfulness strengthens the PFC's ability to observe emotional states without immediately acting on them.

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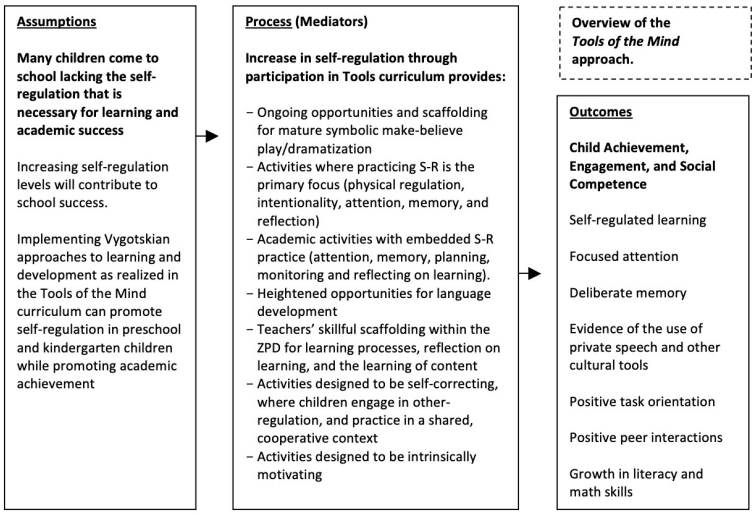

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https://bostonchildrensmuseum.org/sites/default/files/pdfs/5-Tools-of-the-Mind-Curriculum.pdf

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- The Freeze game
  - Gain experience in inhibition control and self monitoring
  - Children dance to music, teacher shows picture of stick figure in particular position, when music stops, children stop in a position that matches stick figure
- Buddy Reading
  - Taking turns one child is reader and other is listener

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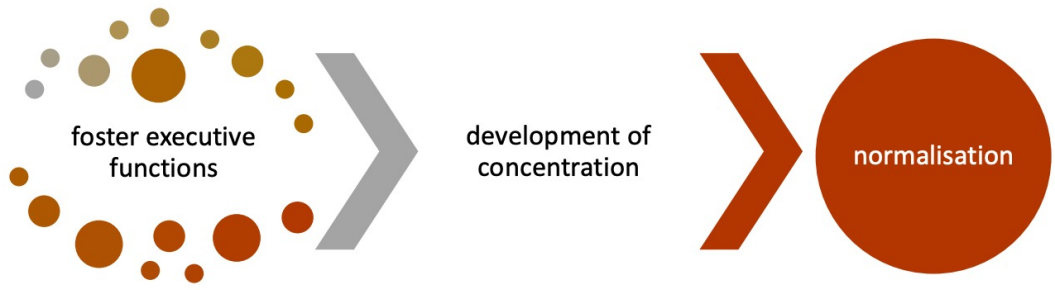

Fostering executive functions are a crucial precondition for the development of concentration. Concentration leads to normalised children.

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https://montessori-group.com/wp-content/uploads/2022/01/De-Brouwer_Fostering-Executive-Functions-the-Montessori-Way.pdf

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- Walk the Line
  - While holding an object in one hand, children carefully walk on an oval line and they respond to music by going one way or the other. Properly walking the line requires children to maintain focus, ignore distractions, control and resist impulses, and to sustain attention when walking the line.

- Silent Game
  - While sitting in one room, the children together make silence. The teacher stands in the hallway, calling children by name, one by one. The children should not respond to other names, stay fully silenced, and control their bodies so they don't make any sound. Only when called by their own name, children respond to their teacher by quietly walking out the classroom, without disturbing other's. Children need to control their movement, suppress irrelevant impulses and stay focussed. Looking at activities like walking the line and the silent game in more detail, we learn that these types of activities are not only fun to do, they also help children to train their executive functions.

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Strategies For Kids With Executive Functioning Challenges

www.thepathway2success.com

Start the day in a calm way

Practice problem-solving

Build a strong relationship

Use planners and calendars

Teach EF skills explicitly

Teach study skills and habits

Give clear and concise instructions

Give think time for processing

Use checklists

Establish routines

Incorporate movement

Model "think alouds"

Clipart by Kate Hadfield, Sarah Pecorino, & Whimsy Workshop Teaching

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Interventions

- **Self-regulation Skills**
  - Mindfulness meditation
    - Observing sensations and thoughts without judgement
    - Teaches sustained focus, task switching
  - Teaching skills
    - Planning before acting

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Interventions

- Neurofeedback
- Training the brain activity (measured by EEG) in brain regions crucial for complex thinking
- EEG reading reflects into a game that the child plays to train their brain
- Over many sessions, the brain learns, unconsciously, how to reproduce the rewarded electrical patterns

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How NeurOptimal® works

NeurOptimal® is a software-based neurofeedback system that monitors electrical activity from both sides of the brain in real time. When the software detects that the brain is about to shift, it introduces tiny interruptions in the audio or media the person is listening to, giving the central nervous system immediate information about its own activity.

Because NeurOptimal® processes information at millisecond speed, it interacts with the brain in its own language of pure information. It behaves more like a real-time partner than a simple tool, noticing and mirroring shifts so the brain can self-adjust with precision.

- Non-directive. The system does not tell the brain what to do. It simply reflects information.
- High-precision and fully automated. No protocol selection or EEG interpretation.
- Moment-to-moment feedback. Timing is central, not only amplitude at isolated sites.
- Designed as a wellness and brain-training tool that supports flexibility, resilience, and self-regulation.

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Member Lo

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Canada

License/Registration

Canada and the US enjoy a similar pathway to legislate health care. Canada uses registrations within the province to regulate those who can independently treat diagnosed disorders such as psychology, medicine, counseling, etc. The requirements for certification in Canada are exactly the same as for the US including a Technician Certification level in both biofeedback and neurofeedback.

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PEMF

- Emit magnetic fields that induce weak electrical currents in the brain tissue
- Theorized to influence synaptic plasticity (brains ability to reorganize and form new connections)
- Some studies suggest it can improve blood flow and improvement in executive functioning
- May influence the balance of key neurotransmitters
- Target Dorsolateral PFC- which is the primary brain region responsible for working memory and impulse control

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