Executive Function – Critical Networks, Development

11/19/24

The Gom Jabbar (*Dune*)

“I hold at your neck the gom jabbar,” she said. … “the gom jabbar. It kills only animals.”

…

“You will feel pain in this hand within the box. Pain. But! Withdraw the hand and I'll touch your neck with my gom jabbar - the death so swift it's like the fall of the headsman's axe. Withdraw your hand and the gom jabbar takes you. Understand?”

“What's in the box?”

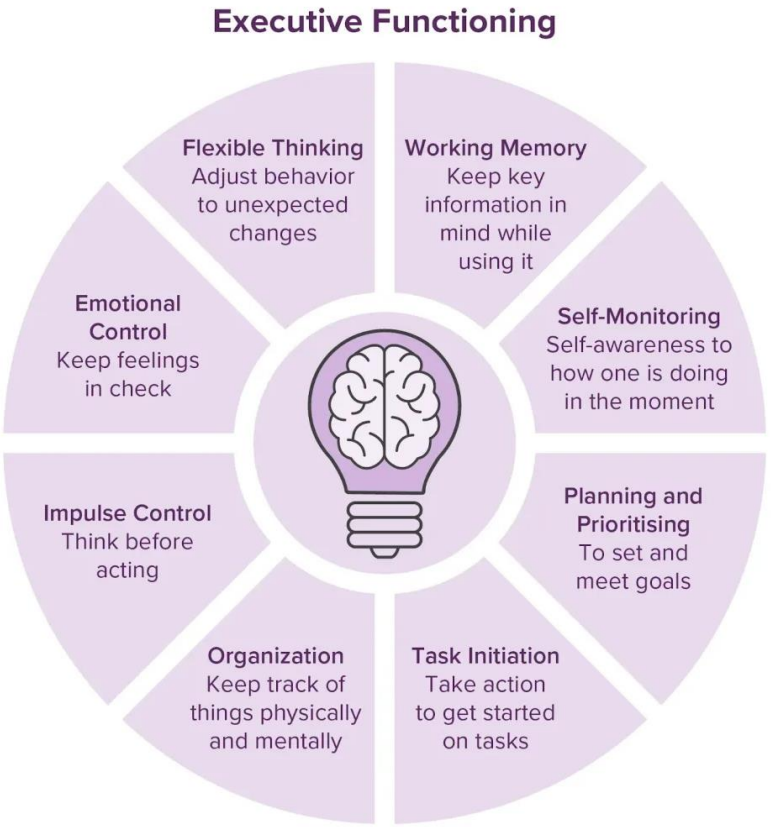
“Pain.”

…

The old woman said; “You've heard of animals chewing off a leg to escape a trap? There's an animal kind of trick. A human would remain in the trap, endure the pain, feigning death that he might kill the trapper and remove a threat to his kind.”

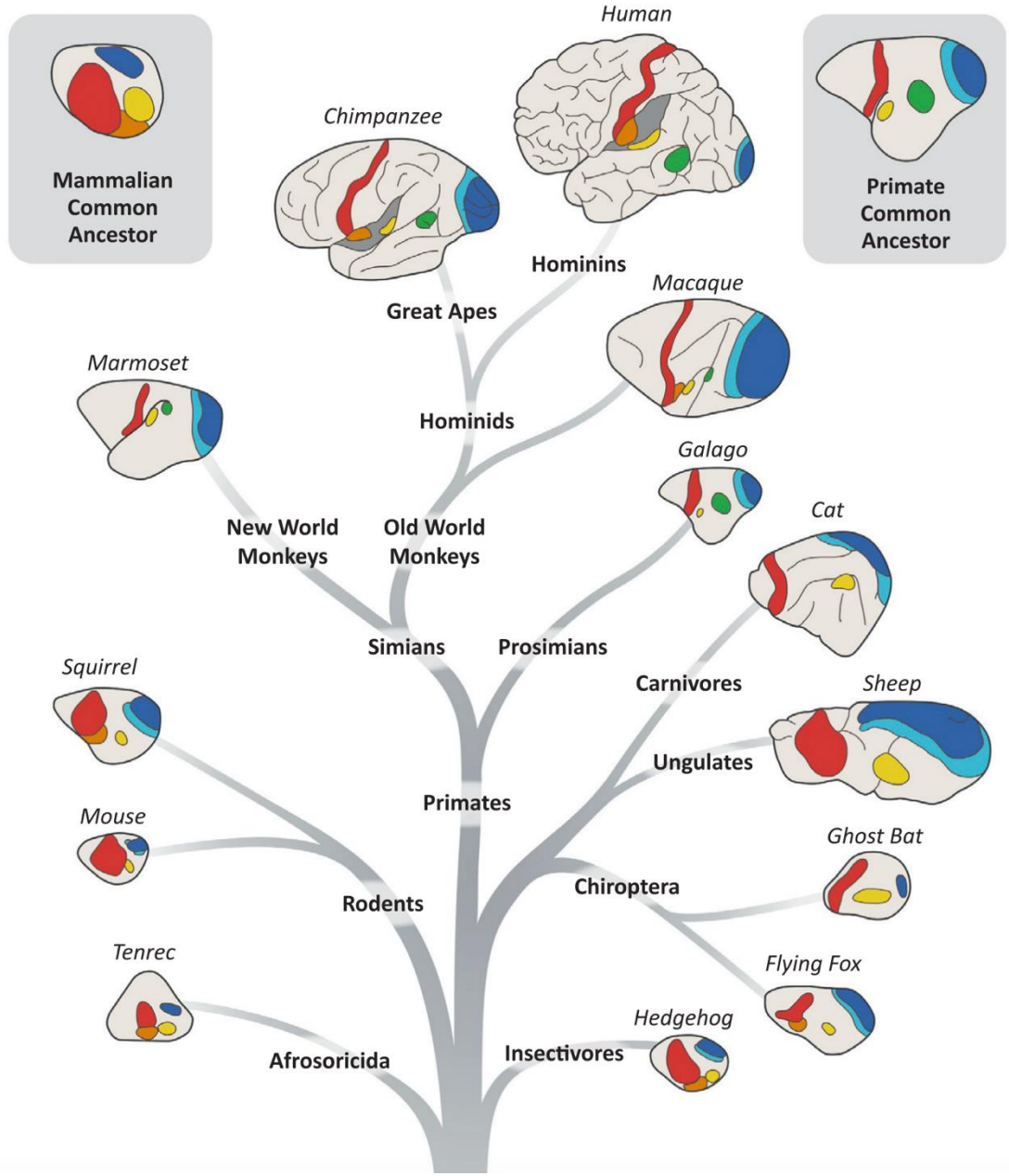
What is executive function?

- An umbrella term for a set of higher-order cognitive processes and skills that enable goal-directed behavior, decision making, and self-regulation
- Three key components:
  - **Inhibition**: suppress impulses, resist distractions, delay gratification to maintain orientation towards a goal
  - **Working memory**: hold and manipulate relevant information
  - **Flexibility**: shift attention or strategies in response to changing environments or other constraints



Brain size has increased in human evolution

- The human is brain is 5x larger than would be expected for a mammal of the same body weight
- The proportion of cortex devoted to sensory processing decreases in primate and human evolution



Somatosensory Cortex

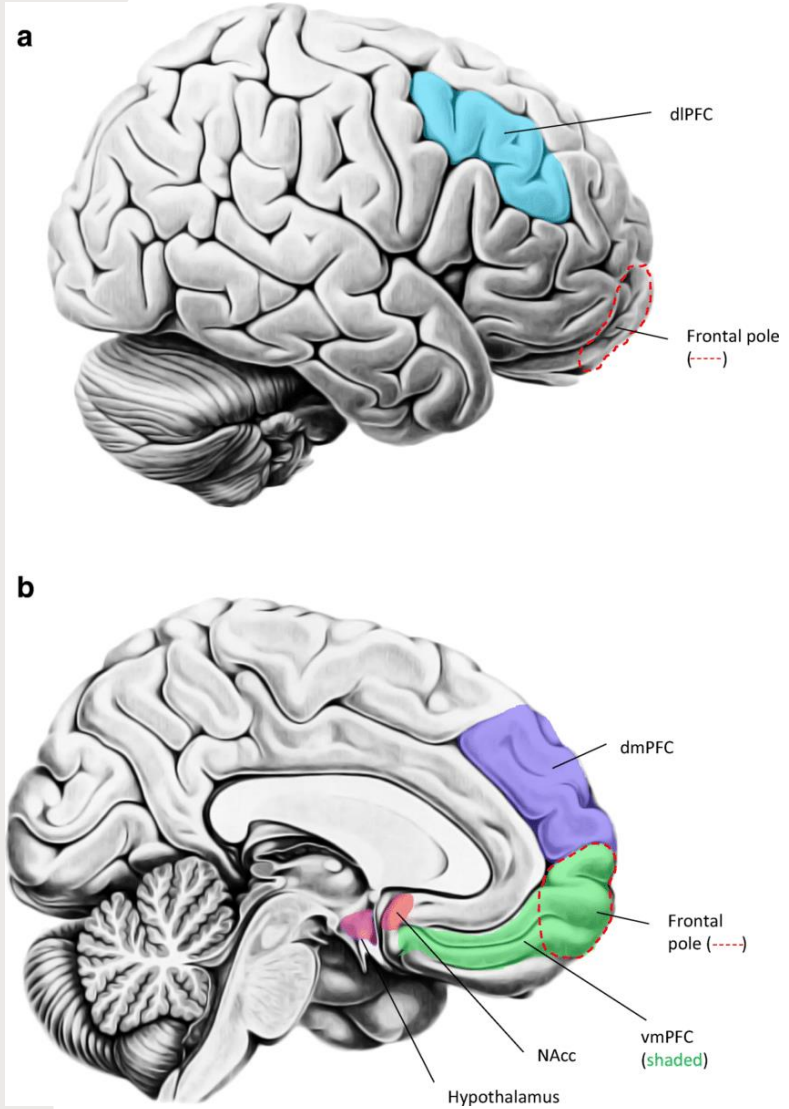
Primary / Secondary Visual Cortex

Primary Auditory Cortex

MT (motion)

Frontal lobe expansion

- **Prefrontal cortex (PFC)** experienced most significant growth
- Complex problem-solving, empathy, theory of mind, moral reasoning
  - **Dorsolateral Prefrontal Cortex (dlPFC):** executive function, working memory, planning, cognitive flexibility
  - **Ventromedial Prefrontal Cortex (vmPFC):** decision-making, emotional regulation, social behavior



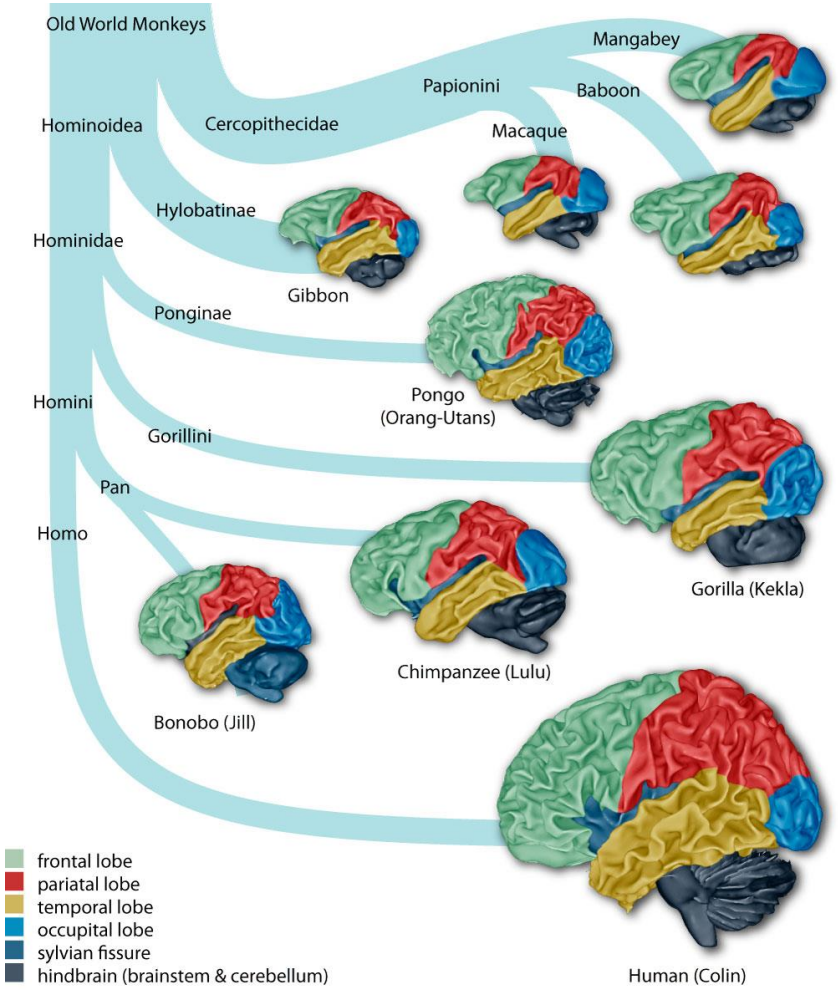
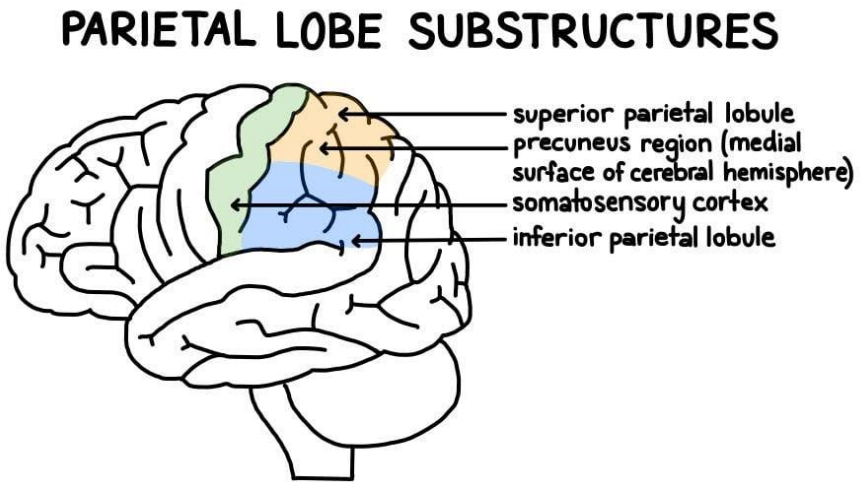
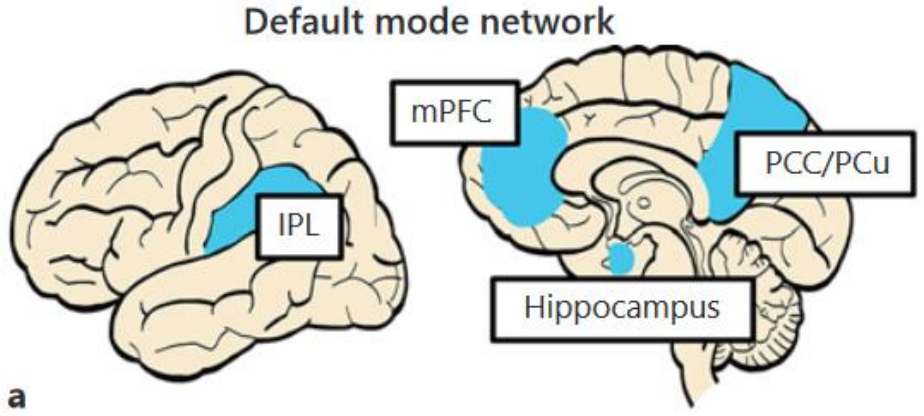


Fig. HE: Visualization of evolution of brains in primates based on the inner surface. The lobes, the sylvian fissure and the hindbrain (brainstem and cerebellum) are colorized for better orientation.

Parietal lobe expansion

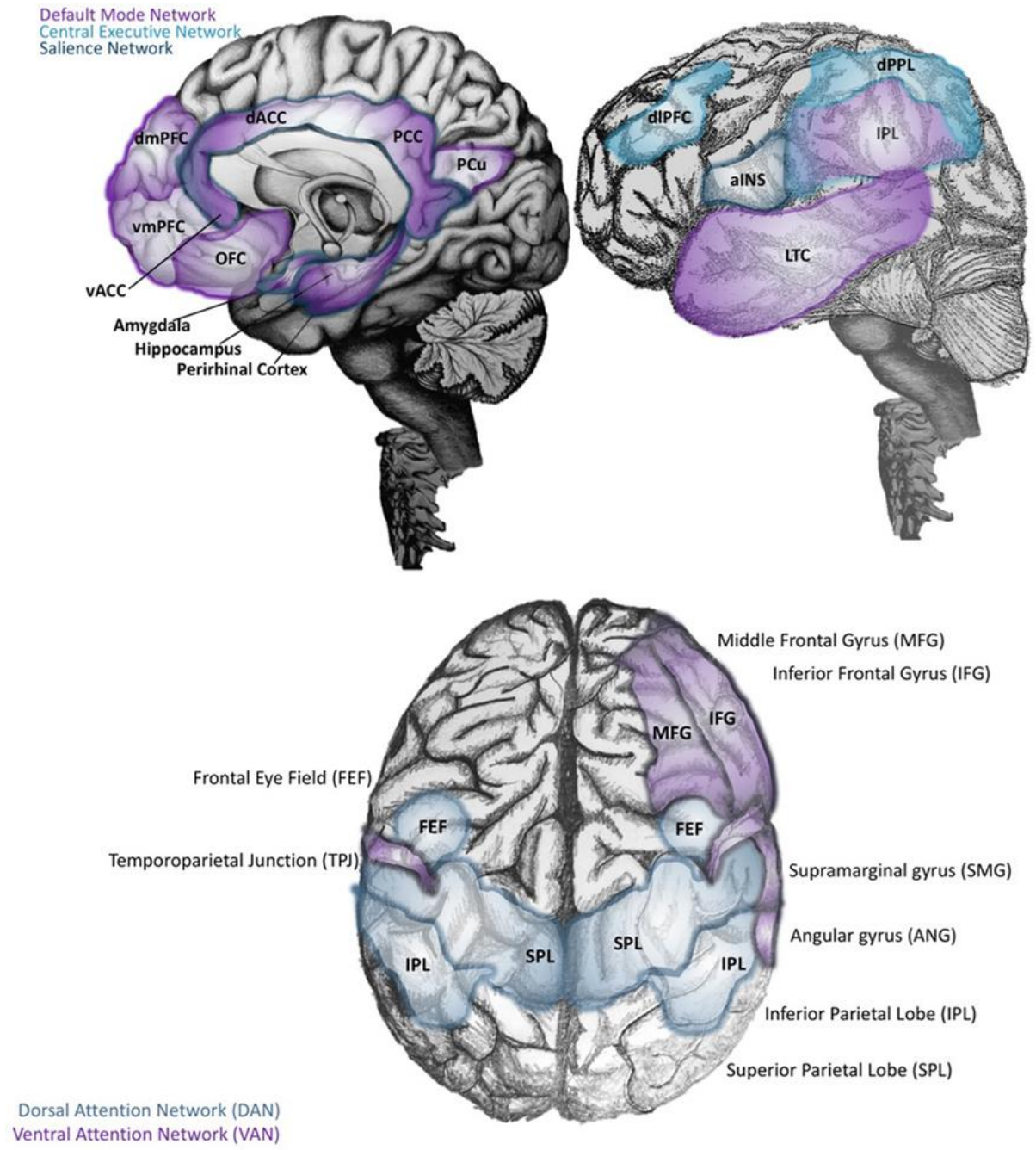
- **Inferior parietal lobule (IPL)** performs multimodal integration (sensory information + motor planning), allowing for more sophisticated cognition and abstraction
  - spatial awareness, tool use, symbolic thought, action sequencing
- **Precuneus** associated with self-awareness, episodic memory, and visuospatial processing
- Both areas are critical components of the **default mode network (DMN)**





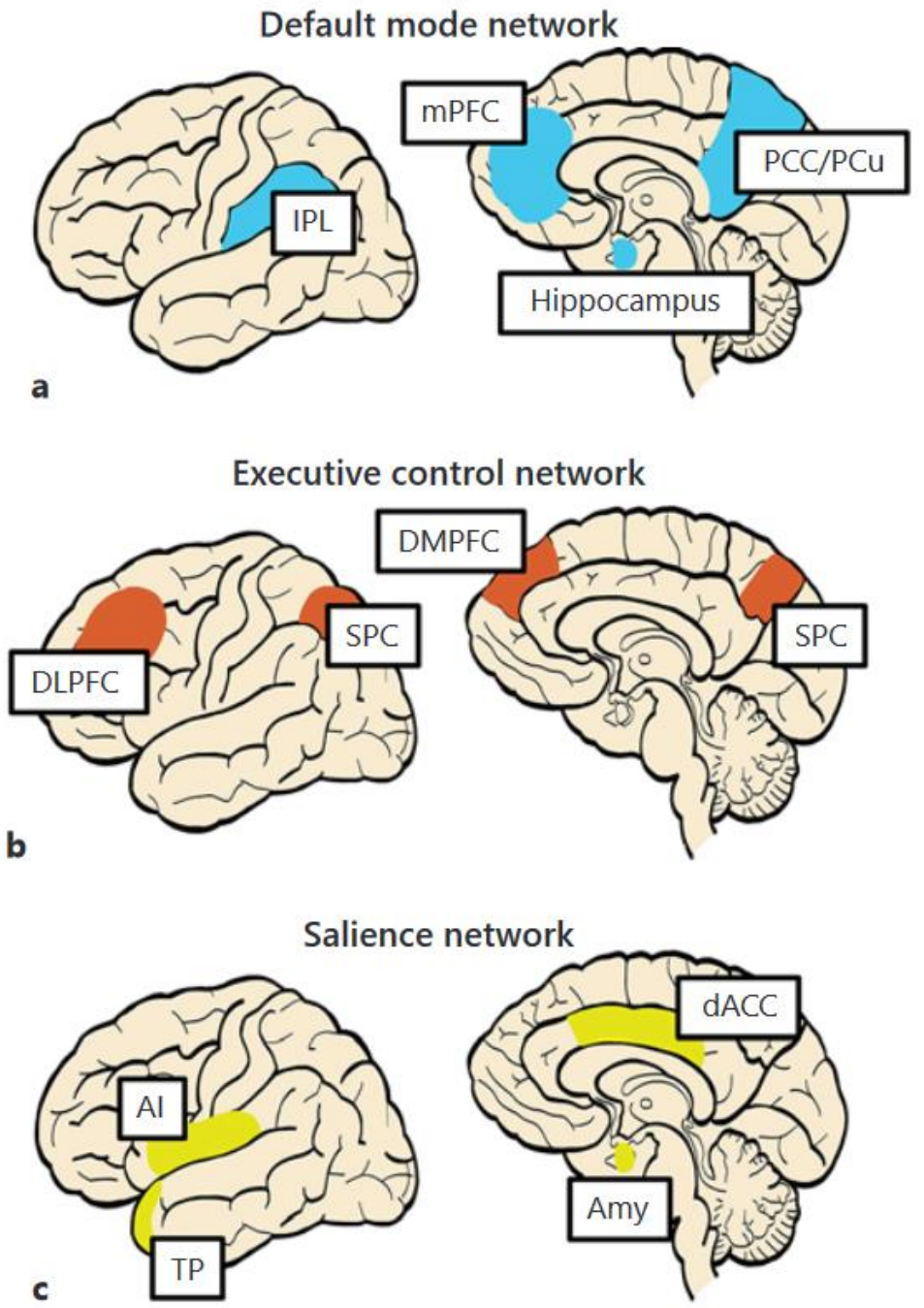
These expansions were critical for coordinating networks

- Emergence of networks that regulate the sensorimotor loop
- **Frontoparietal control network (FPCN) = Central executive network (CEN)**
  - The main network for executive functioning
- Attentional networks benefited from this expansion, too



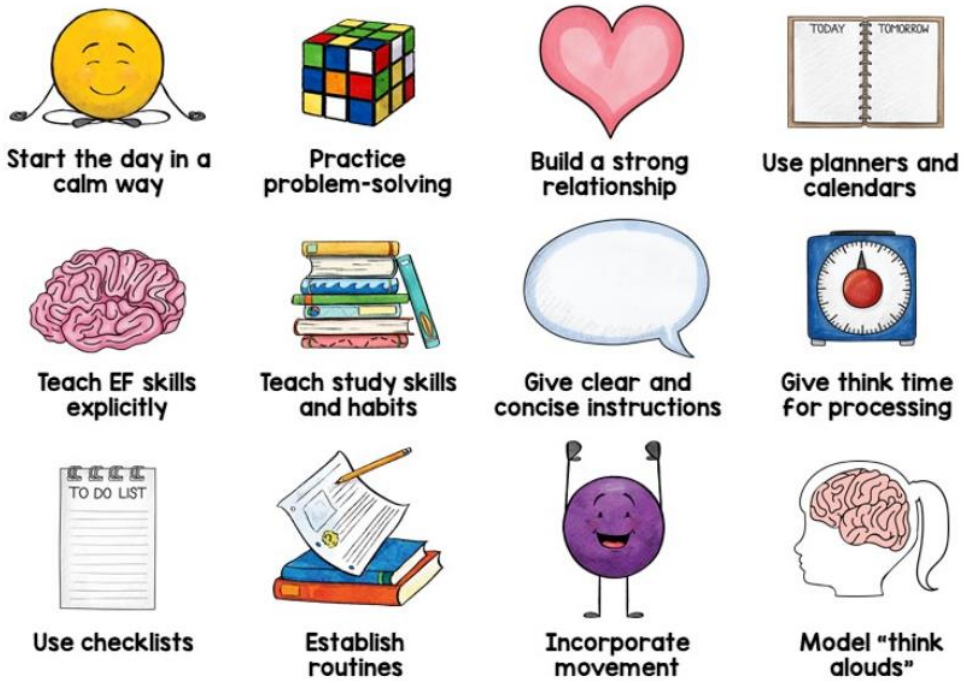
Triple Network System

- Highest level governing system that regulates cognitive, emotional, attentional processes
- **Default Mode Network (DMN)**
  - Introspection, self-referential thinking, mind-wandering, memory retrieval, narrative formation, social cognition
- **Central Executive Network (CEN)**
  - Goal-directed behavior, working memory, decision-making, cognitive control, task orientation
- **Salience Network (SN)**
  - Detection and prioritization of relevant stimuli, network switching, allocation of attentional and cognitive resources



Most task prioritization is inhibition

- “You” don’t really “come up” with any of your ideas of what to do
- They emerge from subconscious activity as a smattering of impulses, desires, and abstract plans
- You inhibit the undesired impulses and automatic responses to allow the chosen one to flourish
- This ability to self-regulate is perhaps the most important factor to success and wellbeing in life
  - Short and long-term goal achievement, conflict resolution, task management, effective communication, physical health maintenance, financial stability, resilience, emotional regulation

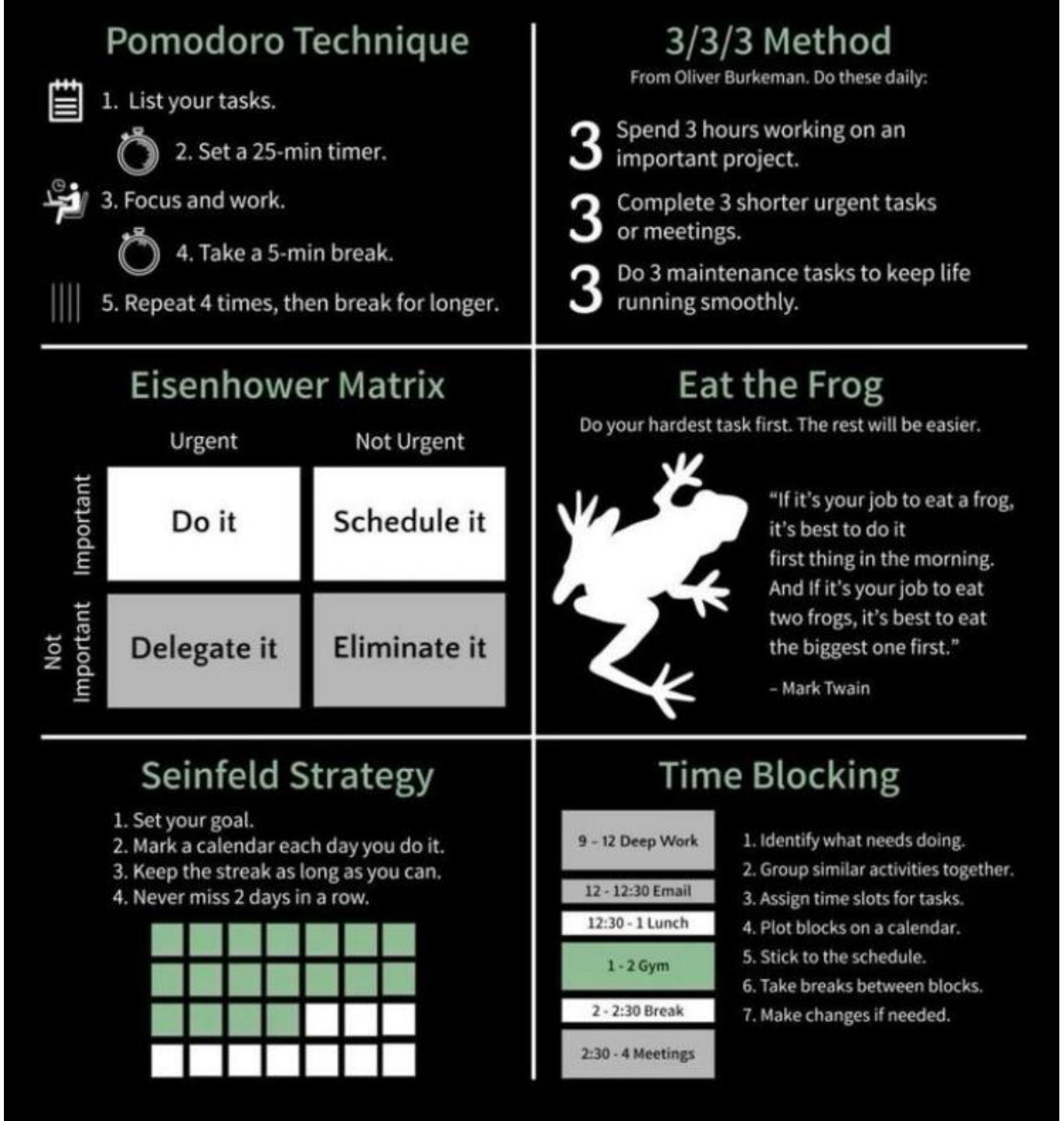


Stroop Task

- Easy to read the word because reading happens mostly automatically
- Difficult to say the color of an incongruent word, because you must inhibit the automatic reading function

Productivity strategies

- It is important to develop personal strategies for how to get work done
- For most things in life, as long as you pass the basic competence threshold for the task, the rest of your success relies on self-regulation strategies



Cognitive flexibility

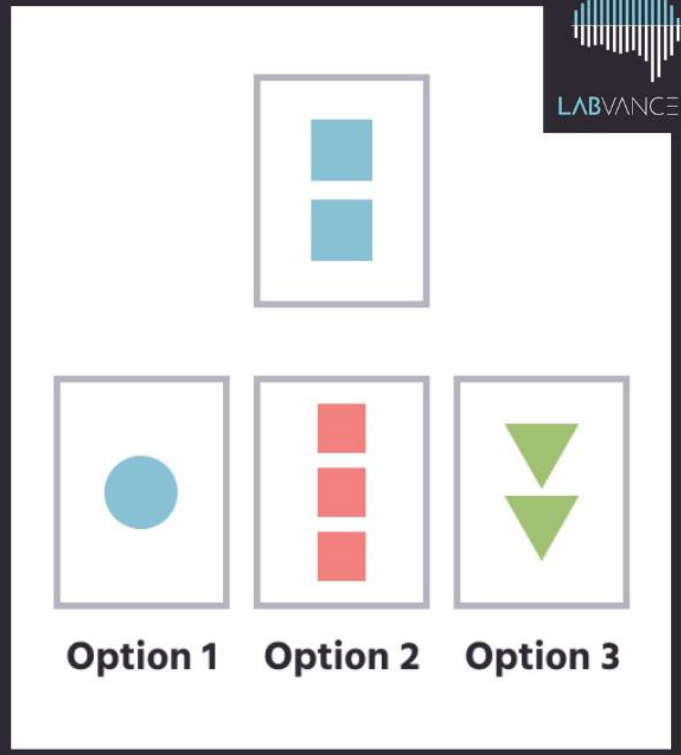
- The mental ability to switch between thought processes, to update an understanding of rules and constraints, to adapt behavior to changing context
- **SN** detects relevant stimuli – especially unexpected stimuli – and signals a need to make adjustments
  - **Anterior Insula (AI)**: environment or internal changes, more general
  - **Anterior Cingulate Cortex (ACC)**: conflict and error adaptation, more specific to goal-orientation
- **CEN** implements goal-oriented adjustments
  - May couple with **DAN** to reorient attention for external planning
  - May couple with **DMN** for introspection, autobiographical planning

Wisconsin Card Sorting Test (WCST)

- The rule will randomly change as the participant performs the task
- Tests the ability to learn what the new rule is and adapt to it
- **Perseveration**: impairment in ability to cognitively switch

The sample card is at the top and below it are three options

The participant must investigate what the rule is based on the changing feedback upon the response and adapt their choices accordingly:

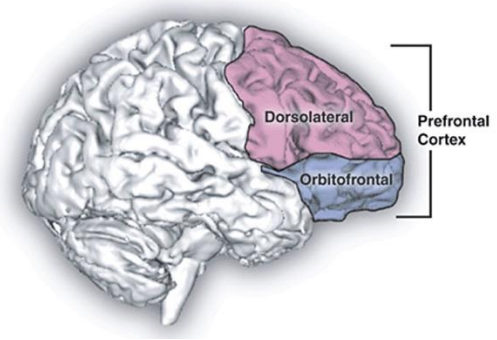


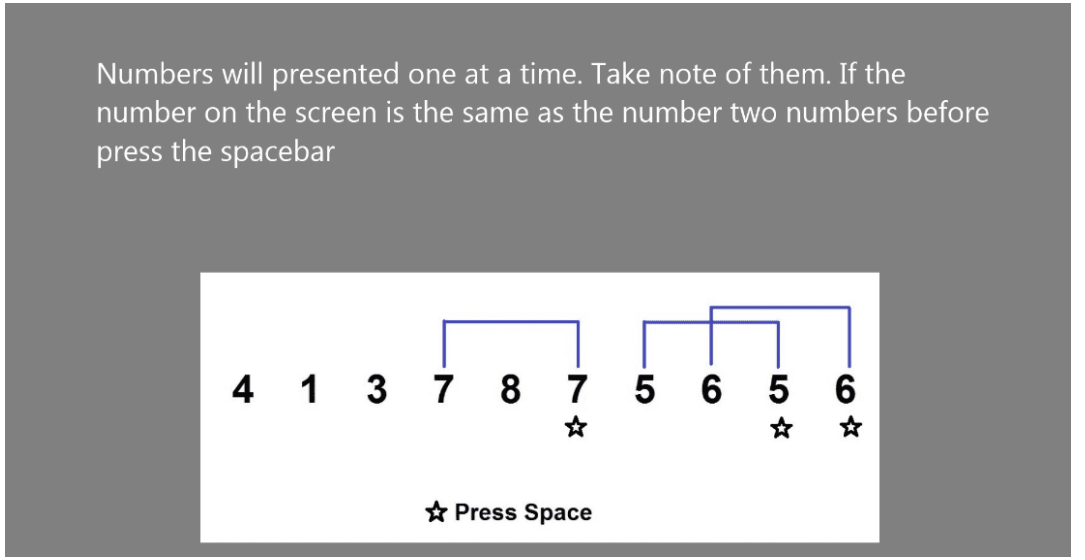
- If the rule is **color**, then option 1 is correct
- If the rule is **shape**, then option 2 is correct
- if the rule is **number**, then option 3 is correct

The participant does not know the rule explicitly, but must work to find out and remember the response feedback!

N-Back Task

- Maintenance of working memory is critical skill for EF
- Ability to hold and manipulate information in the mind + the ability to selectively drop information as needed in order to replace with what is newly relevant
- **N-** refers to how many items back one must recall (**1, 2, 3-back**)
- **dlPFC** critical region for performance





Executive Function Development

Development Stage	Emerging Abilities	Key Brain Networks	Milestones
Infancy & Toddlerhood (0–3 years)	- Basic self-regulation (e.g., impulse control). - Simple working memory (e.g., finding a hidden toy).	- **Salience Network (SN)**: Early development of **anterior insula (AI)** and **ACC**. - **Subcortical structures** (e.g., **basal ganglia**).	- Briefly delay gratification. - Early planning and impulse inhibition emerge by age 2.
Preschool Years (3–5 years)	- Improved inhibitory control (e.g., resisting impulses in structured tasks). - Beginning cognitive flexibility. - Enhanced working memory.	- **Central Executive Network (CEN)**: Emerges to support goal-directed behavior. - **Default Mode Network (DMN)**: Early connections between **mPFC** and **PCC**.	- Improved performance on tasks like **Stroop Task**. - Early multi-step instruction-following.
Early School Years (6–12 years)	- Significant gains in EF domains: inhibition, working memory, and cognitive flexibility. - Development of metacognition (e.g., thinking about thinking).	- **CEN**: Strengthens **DLPFC** and **PPC** connections. - **SN**: Refined for attention management. - **DMN**: Further integration.	- Handle more complex EF tasks like **Wisconsin Card Sorting Task** and **1-** and **2-Back Task**. - Manage long-term goals (e.g., homework).
Adolescence (13–18 years)	- Advanced cognitive flexibility (e.g., abstract thinking). - Greater emotional regulation (still maturing). - Improved long-term planning.	- **CEN** & **SN**: Increased efficiency between **DLPFC**, **ACC**, and **AI**. - **Dopaminergic pathways**: High reward sensitivity.	- Manage multitasking and moral reasoning. - Can perform **3-back task** and up - Increased capacity for abstract and complex problem-solving.
Adulthood (18–25 years)	- Full maturation of EF (e.g., advanced planning, emotion regulation). - Coordination of emotions, cognition, and actions.	- **CEN**: Peak efficiency. - **SN**: Optimal switching between **DMN** (introspection) and **CEN** (goal-oriented tasks).	- Fully developed EF abilities like sustained attention, multitasking, and long-term goal management.