

Foundations of executive functions

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Agenda

- definition of executive functions
- brief anatomy of the executive functions
- unity and diversity of executive functions
- shifting
- updating
- inhibition
- some executive function tasks

What are executive functions?

Set of higher order functions that control all cognitive processes

Like the director of an orchestra executive functions control:

- which cognitive functions are silenced/heightened at a certain time
- How cognitive functions are coordinated

Executive functions enable behavioural and cognitive control

What cortical regions are fundamental to executive functions?

Executive functions rely on a *distributed network*, involving several cortical and subcortical regions involved. But traditionally, the **prefrontal cortex** (often shortened as PFC) is attributed a key role within this network.

Key cortical regions involved:

- dorsolateral prefrontal cortex (DLPFC). Some functions: working memory, goal maintenance, planning and top-down control.
- ventrolateral prefrontal cortex (VLPFC). Some functions: response selection, inhibition, and controlled retrieval.
- orbitofrontal cortex (OFC). Some functions: value representation, reward-guided decision making and impulse control
- anterior cingulate cortex (ACC) Note: this is structurally just outside the prefrontal cortex but it works in synergy with it [Some functions: conflict monitoring, error detection, and performance adjustment].{fragment}
- parietal cortex. Some functions: attentional reorienting, representation updating and integration with sensory information.

- Premotor cortex / supplementary motor area (SMA).
Some functions: action selection and motor planning.

Key subcortical regions are basal ganglia, thalamus, cerebellum

Evolutionary note: inter-species differences in the mass of the PFC relative to the whole cerebral cortex

Prefrontal cortex (PFC) is disproportionately large, relative to total brain mass, in primates (and especially in humans).

Humans have especially massive dorsolateral and orbitofrontal regions.

This may be the neural substrate to the greater executive function skills in humans compared with non-human primates and other mammals.

Function comes from structure. But structure is not just the mass of a region (this is not true: bigger = better). Structure involves also connectivity patterns (networks)

How do we know so much? Progress was/is made through lesion studies and functional neuroimaging.

Frenology

The tragic story of Phineas Gage. A selective prefrontal-cortex lesion

The first well documented case of selective lesion to the PFC.

A railroad worker at the time. In an accident, a metal rod passed through his skull. He survived. But he became a different person.

Before the accident: responsible and smart.

Anecdote: post-mortem exams on the brain of Albert Einstein, widely considered person of greater than average intelligence, was smaller than the average brain.
https://en.wikipedia.org/wiki/Brain_of_Albert_Einstein

After the accident: Able to walk and talk. But unable to *control* himself, impatient, impulsive, showing socially inappropriate behaviour, and *no inhibition*.

Unity and diversity of executive functions: Miyake et al. (2000)

Seminal study evaluating quantitatively the commonalities and differences among several multiple executive-function tasks.

Key conclusions: executive function tasks show **unity** (shared variance among tasks) and **diversity** (distinct variance-based components among tasks). Namely, there were three separable but moderately correlated factors:

- Shifting (task-set switching)
- Updating (working-memory updating)
- Inhibition (suppressing prepotent responses)

Executive functions components:

- Shifting
- Updating
- Inhibition

Implications: Executive functions share some underlying mechanisms (unity). Executive functions form a multi-component system (diversity).

Shifting

Updating

Inhibition

Measuring updating through the n-back task

n-back task demo

<https://www.psychtoolkit.org/experiment-library/nback2.html>

Measuring shifting through the digit-letter task

digit-letter task demo

Measuring shifting through the global-local task

Measuring inhibition through the Flanker task

Flanker task demo

Measuring inhibition through the Stroop task

Based on the conflict between two pieces of information:

- the meaning of the word
- the color of the ink

Stroop task demo

Beyond the core executive functions

The three core executive functions identified by Miyake et al. (2000) are important because they can be considered building blocks for higher-order functions, but they are *not exhaustive*.

Some additional processes commonly treated as executive functions include:

- Planning and problem solving
- Goal setting and maintenance
- Performance monitoring and error detection
- Cognitive flexibility beyond simple shifting (e.g., creativity)
- Decision-making and value-based control in some models