Intro to Behavioral Neuroscience (B)
Lecture 6: Executive Function

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https://youtu.be/e4Edfj9tdbs

Lecture video at above link.

Today: Executive Function

<u>Executive Functions and Planning</u>

1) What are executive functions?
2) Delay of gratification
3) Impairment of executive functions after brain damage and neuropsychological tests
    - Stroop test
    - Wisconsin card sorting test
    - Iowa gambling task
4) Model of frontal lobe functions (Miller/Cohen)
5) Adolescence and cognitive control
6) Experiments by Benjamin Libet on movement decisions

What is executive function?

Imagine you want to organize a spontaneous party for the next day:
You need to :

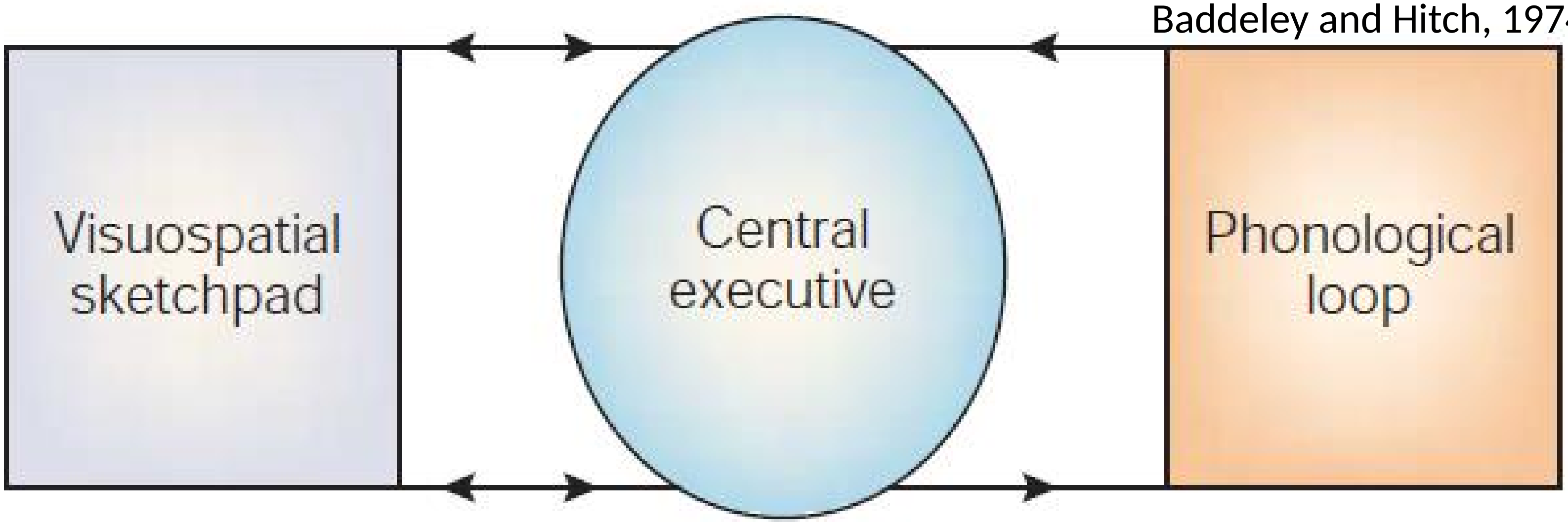
- decide what to cook and what not to cook
- go shopping (probably different stores)
- decorate the party room
- fix the heater
  - → get spare parts from hardware store
  - → look up instructions how to fix it (DIY web site?)
  - → fix it
- invite some people
- tell your neighbors
- You should not get distracted by TV or chatty neighbors

The tasks in abstract terms:

- **Plan** and **choose** from many options
- **Ignore** distracting stimuli and **persist** in the task
- **Keep track** of what has been done and still needs to be done

Executive Control and Working Memory

Baddeley and Hitch, 1974



short-term (seconds) store for visuospatial content

short-term (seconds) store for verbal content

Division of visuospatial sketchpad and phonological loop reflects experimental results that show independence of memory systems for visuospatial versus verbal contents.

Central executive: controls cognitive functions, guides attention, i.e., can divide and switch attentional resources.

What is executive function?

<u>Supervisory attentional system</u> (Norman and Shallice, 1980)

According to this model, control of behavior is either guided by:

- automatic schemata, habits, routines

- the supervisory attentional system (SAS) that controls behaviors for which no routine exists.

Sometimes, routines can take over behavior and show that the SAS is needed. For example, say you want to go to the supermarket on a Sunday, and the supermarket is located along the route to your office. Not paying enough attention, you might end up at your work place.

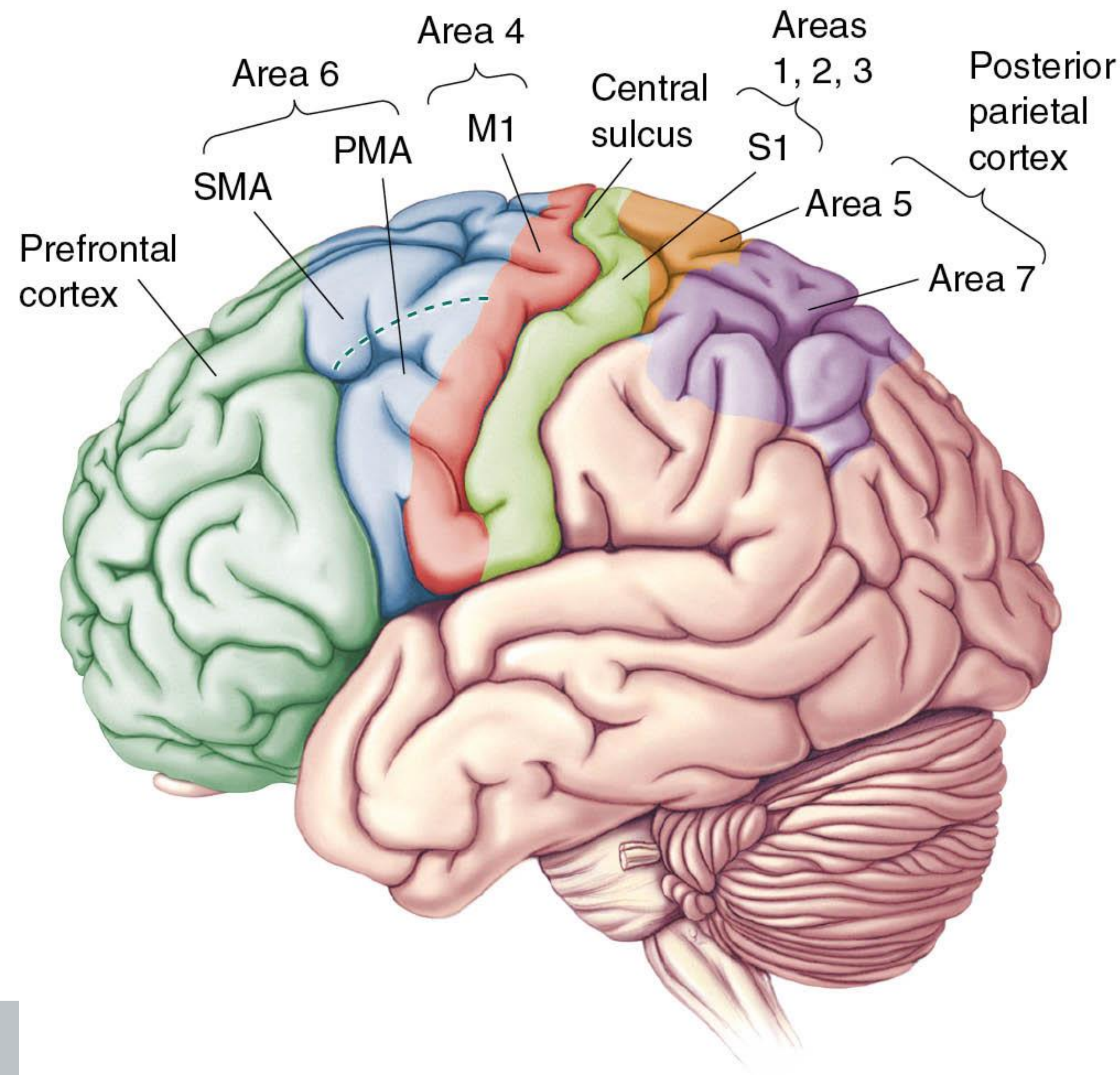
In particular, patients with frontal lobe lesions show deficits in suppressing routine (perseveration) and sometimes excessive distractibility (Baddeley, NRN, 2003).

Executive function - Prefrontal Cortex

Executive functions entail: volition, planning and decision making, purposive action, and effective performance.

Executive functions are often impaired after damage to prefrontal cortex.

Do you remember Phineas Gage, the railway worker who was hit by an iron rod (class 1 – introduction)?



Bear, Neuroscience

Delay of Gratification

Withstanding temptation and suppressing current urges to get a larger reward later are important forms of cognitive control.

Mischel et al., Science, 1989 found that the capability to delay gratification is a long-lasting trait.

4-year old children underwent the marshmallow test: they either get 1 marshmallow now, or if they wait 15 minutes they get 2.

The children who were able to resist where later found to be academically more successful as adolescents and adults. Their SAT (Scholastic Aptitude test) correlated with their ability to delay gratification.

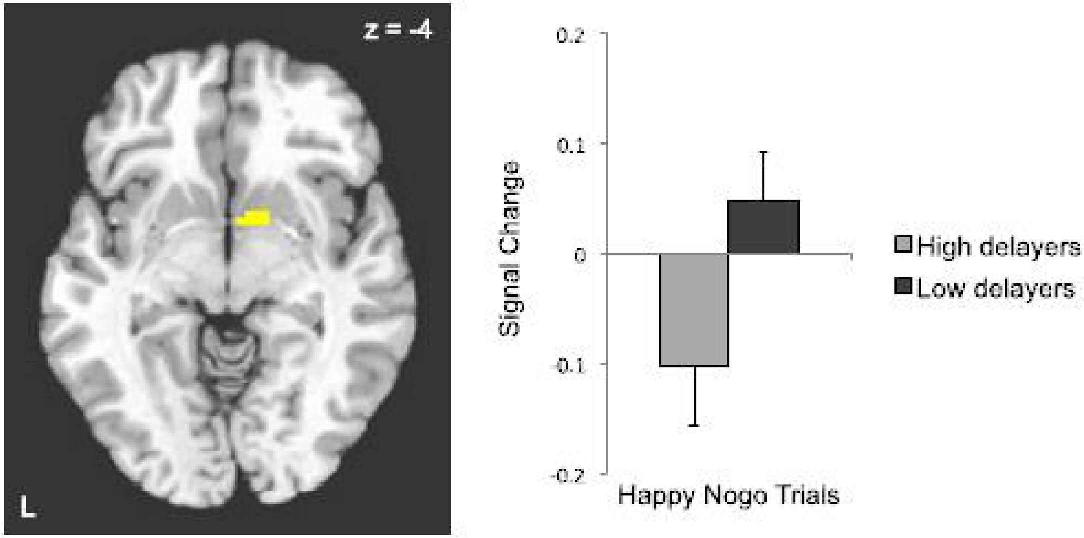
From TED talk by Joachim de Posada

Delay of Gratification

In a recent follow-up, the children (now in their 40s) who were good in delay of gratification scored better in a task to suppress responses to emotional faces (Casey et al., PNAS, 2011). The task consisted of viewing emotional faces (fearful/happy) and of responding with a button press to one category.

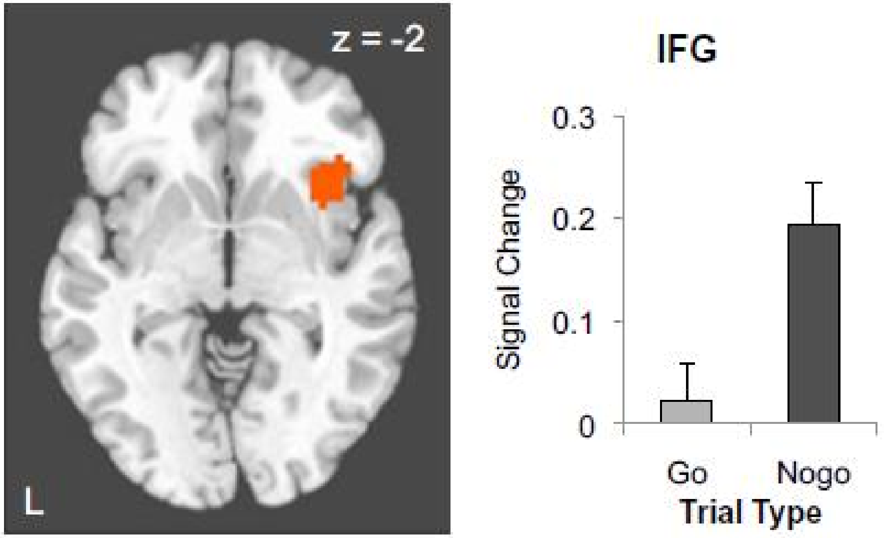
When undergoing functional magnetic resonance imaging (fMRI) during this task, the children with low delay abilities showed stronger activity in the ventral striatum when the task was not to respond to a happy face (image below).

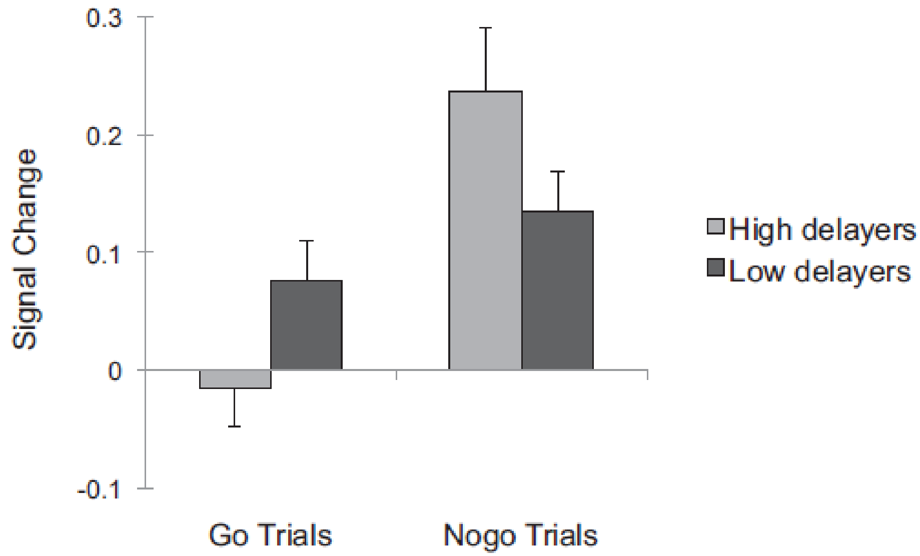
The ventral striatum is part of the dopaminergic reward system (see class 2 - motivation).



Delay of Gratification

The inferior frontal gyrus (IFG) showed more activity during the Nogo trials (Happy face->do not respond), possibly related to response suppression.





The IFG activity difference was more pronounced for the high delayers.

This suggests the importance of both frontal and striatal areas in delay of gratification and impulse control.

(Casey et al., PNAS, 2011)

Testing executive function: Stroop

Stroop test: name the color of the following words!

RED	RED	YELLOW	BLUE
BLUE	BLUE	RED	GREEN
GREEN	YELLOW	YELLOW	YELLOW
YELLOW	BLUE	GREEN	GREEN
BLUE	GREEN	BLUE	BLUE
RED	RED	GREEN	RED
GREEN	YELLOW	RED	YELLOW
BLUE	RED	GREEN	RED

Testing executive function: Stroop

RED

BLUE

GREEN

YELLOW

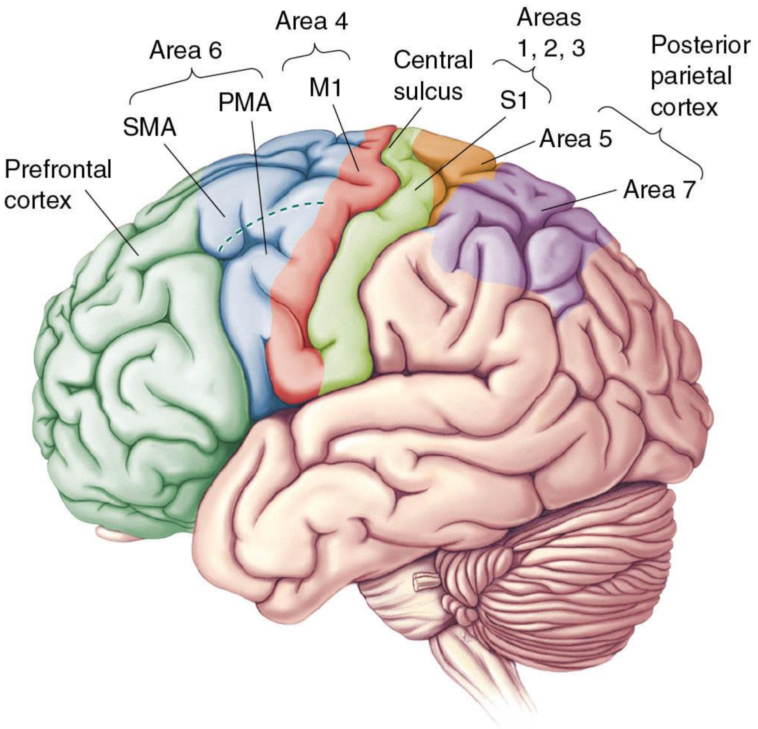
BLUE

RED

GREEN

BLUE

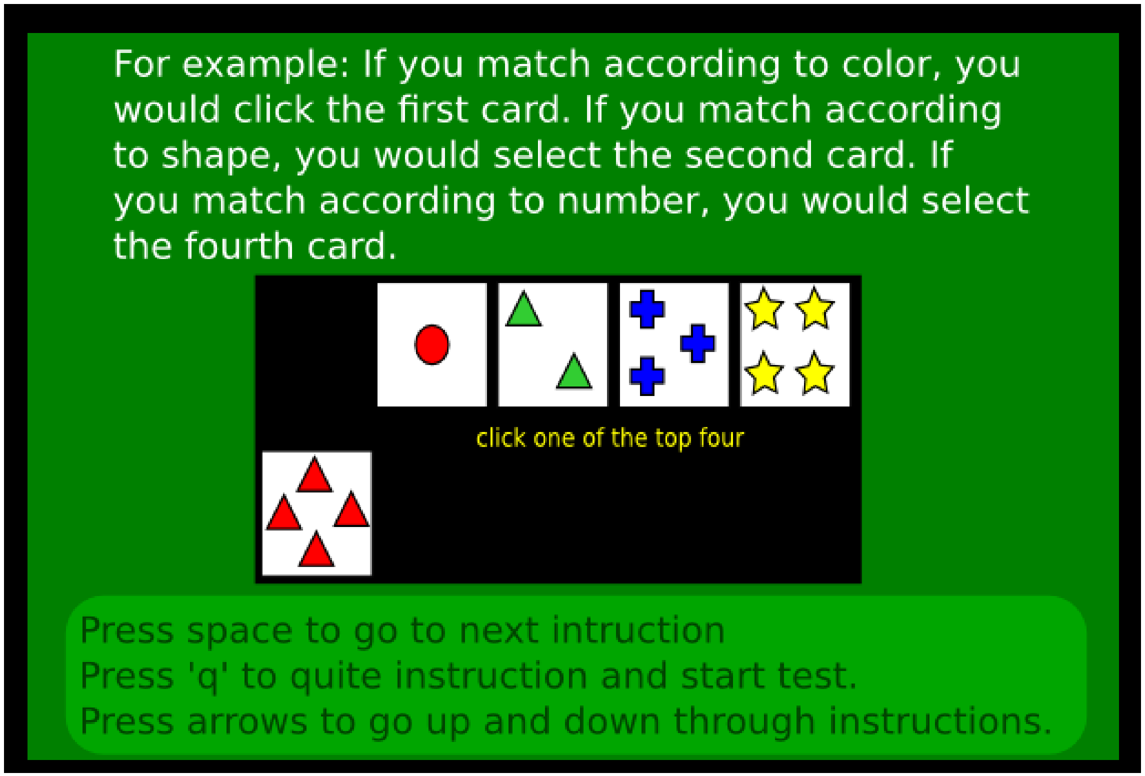
The Stroop test tests for **response inhibition**, which is impaired in patients in particular after left frontal lobe lesions (Perret, Neuropsychologia, 1974).



Bear, Neuroscience

Testing executive function: Wisconsin

http://www.psytoolkit.org/experiment-library/wcst.html



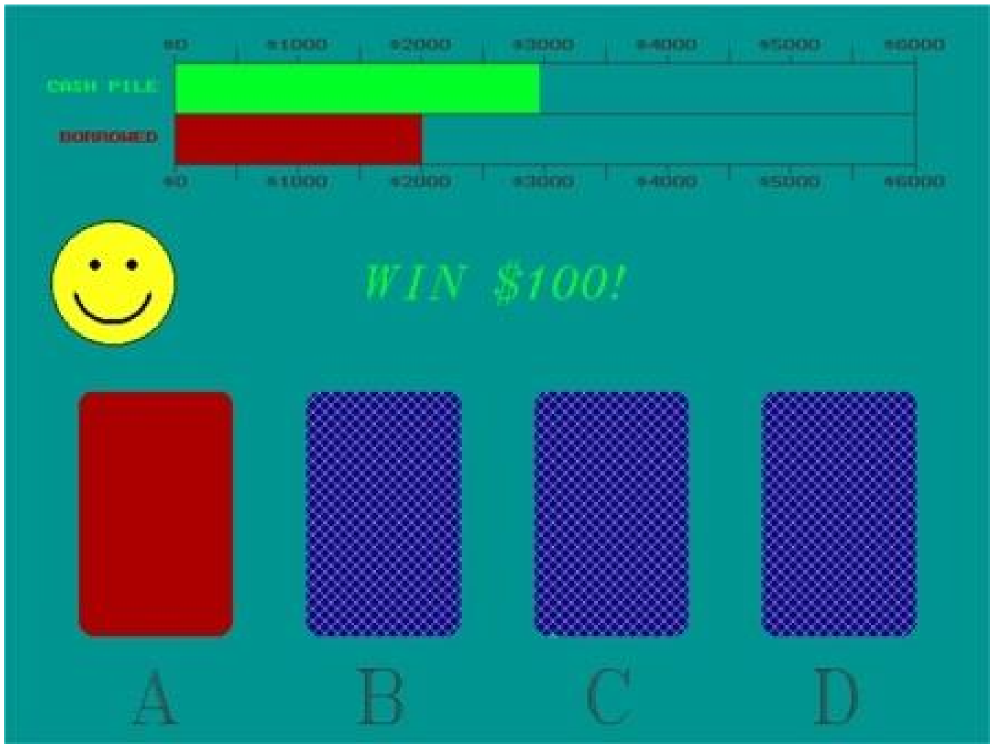
<u>Wisconsin card sorting test</u>: The patient has to sort cards (lower left) to one of four stacks (upper row) without any instruction concerning the rules. Only through feedback can they understand the rule.

The sorting rule can either be based on color, shape, or number. The rule changes from time to time.

This tests response inhibition, patients with frontal-lobe lesions will often show perseverance, i.e., they cannot adjust when the rules are changed.

Testing executive function: Iowa

Poor control of behavior→
Risk taking and rule breaking



<u>Iowa Gambling test</u>:
Players start with 2000$ and should win maximum amount.

Four decks (A, B, C, D) of 40 Cards: 20 black, 20 red
Rewards are different depending on the deck, i.e. there are good and bad decks.

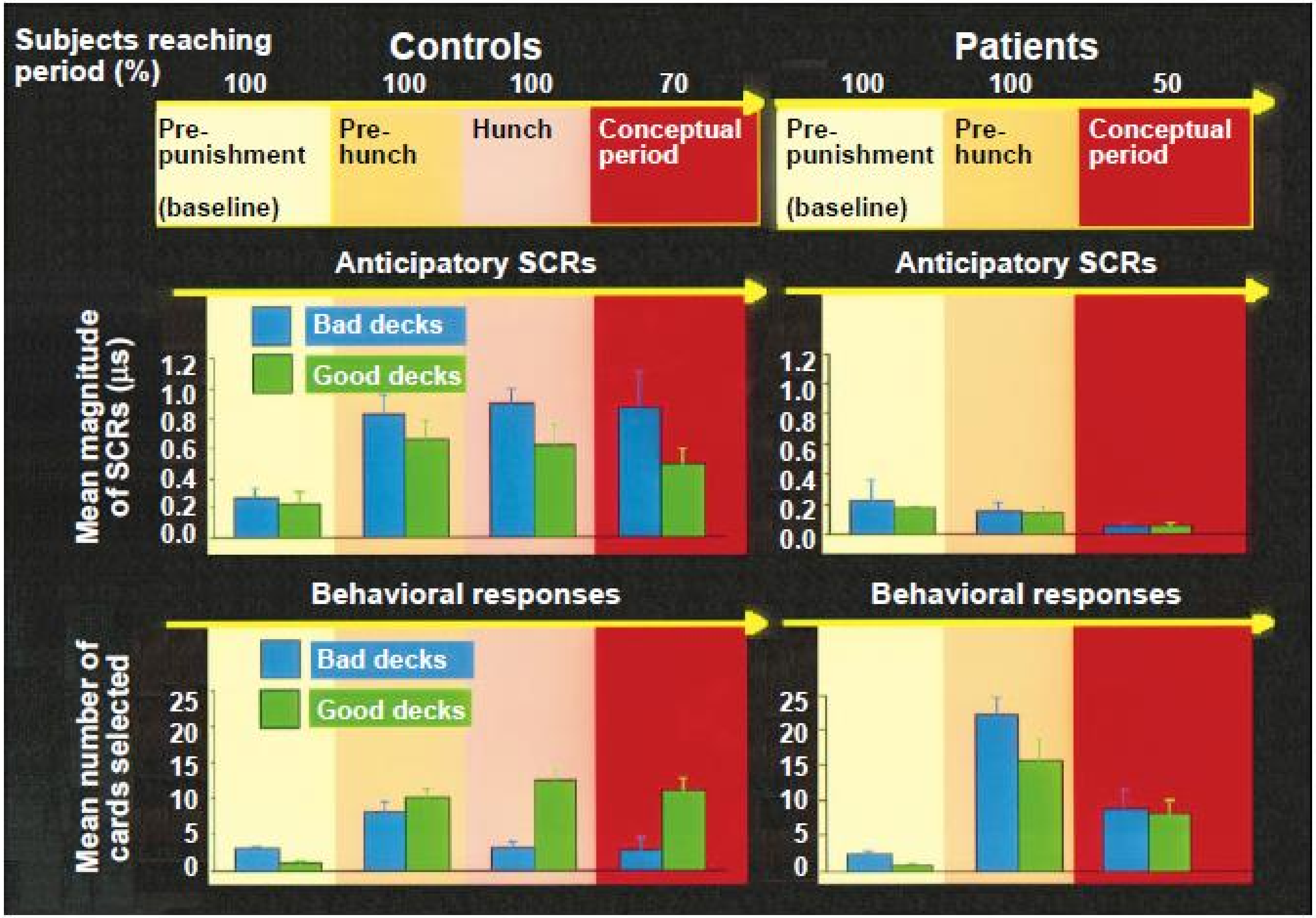
Players can freely choose the deck to draw a card from.

Patients with ventromedial frontal lesions show deficits in the Iowa Gambling test (Bechara et al., 2000). They cannot adjust to the rule that particular decks (e.g., A and B) will result in losses and go on choosing them.

Testing executive function: Iowa

Bechara et al., Science, 1997:

Normal controls tend to choose the good decks before they can explicitly say why (before they have a hunch that some decks are “bad”). Patients with ventromedial frontal cortex lesions will not develop a hunch or a preference for the good decks.

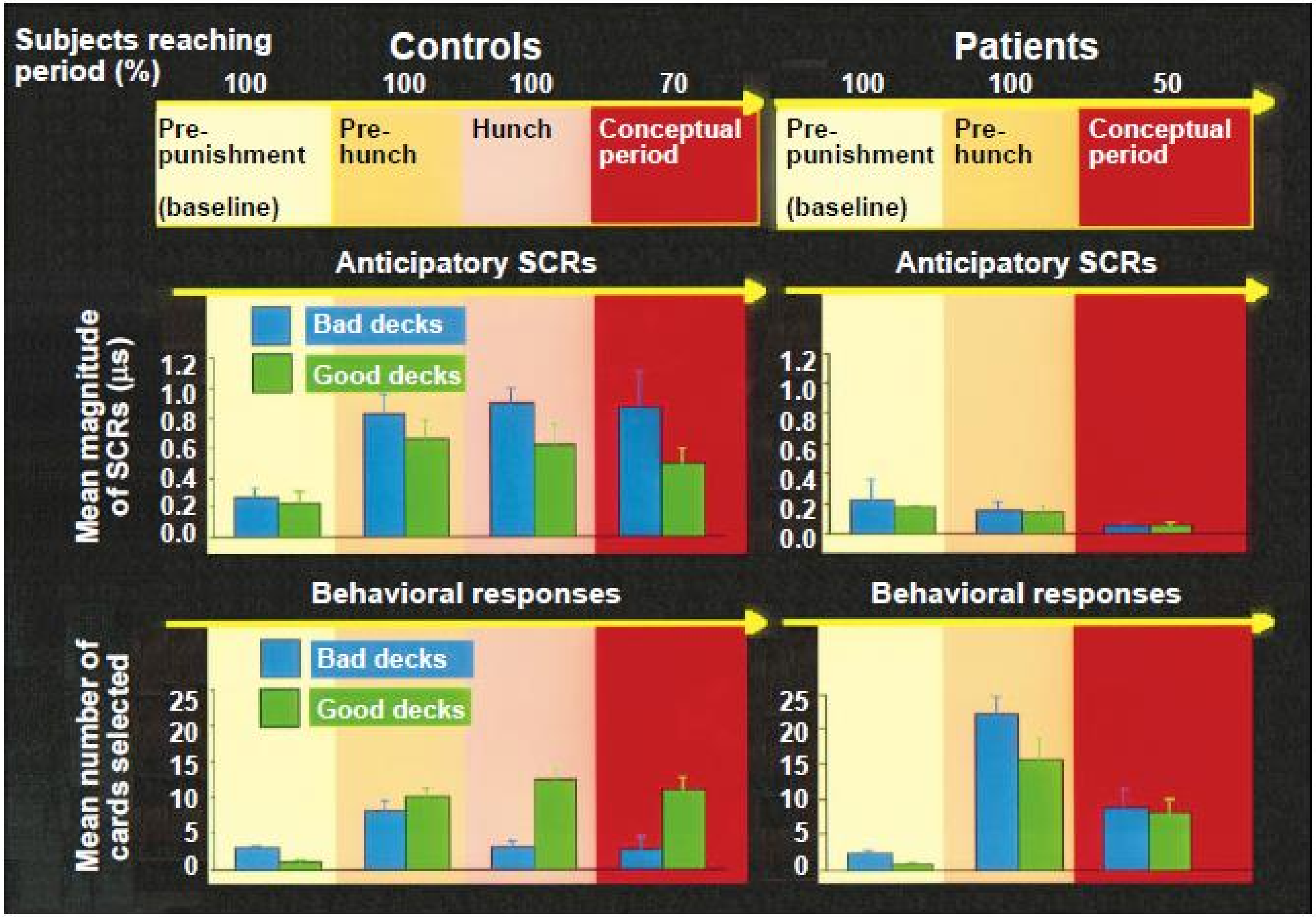


Testing executive function: Iowa

Bechara et al., Science, 1997:

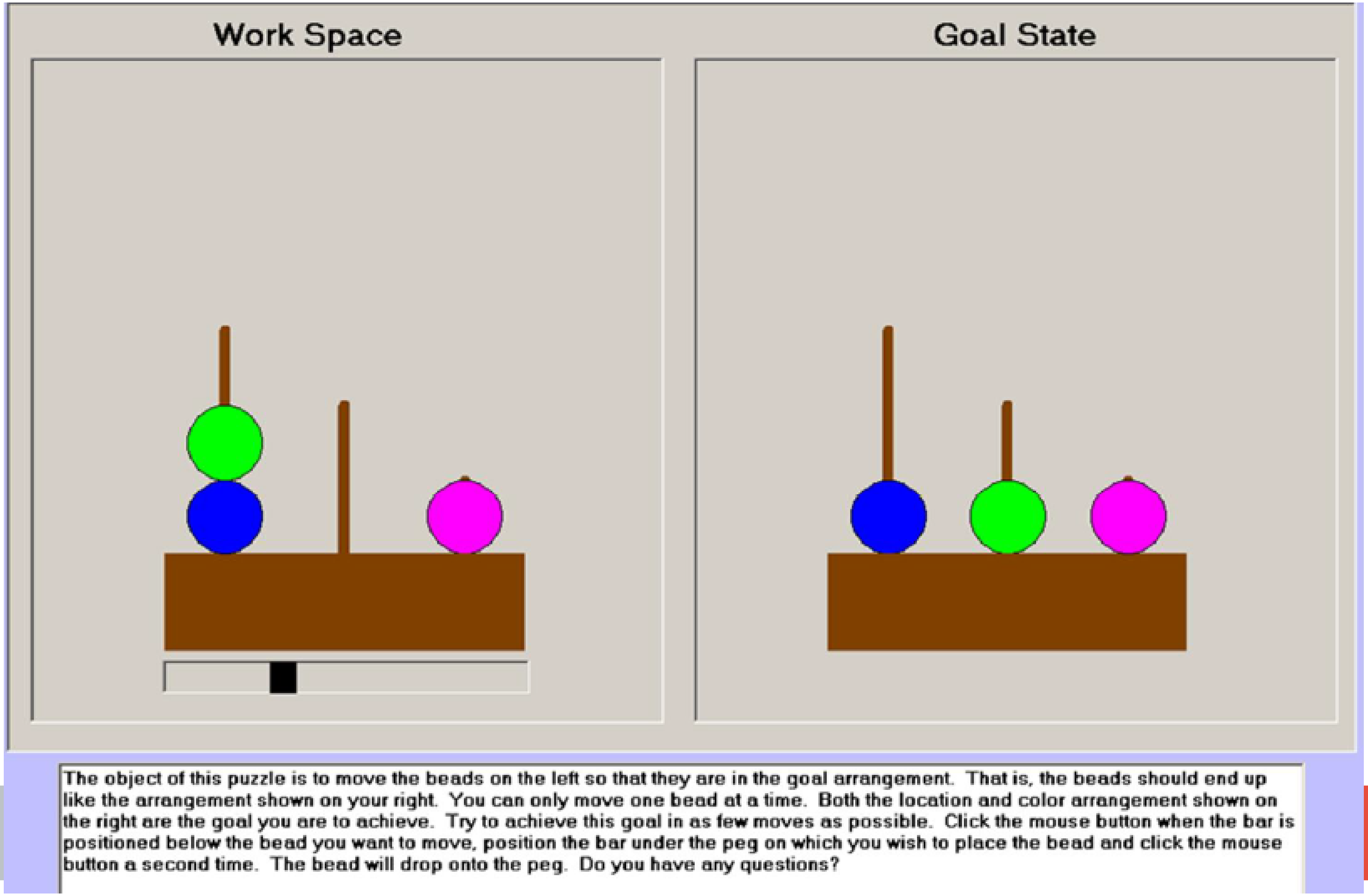
SCR: Skin conductance response, a psychophysiological measure of arousal.

Normal controls will show higher SCR before high-risk decks (even before they have a hunch). Patients with ventromedial frontal lesions do not show these SCRs.



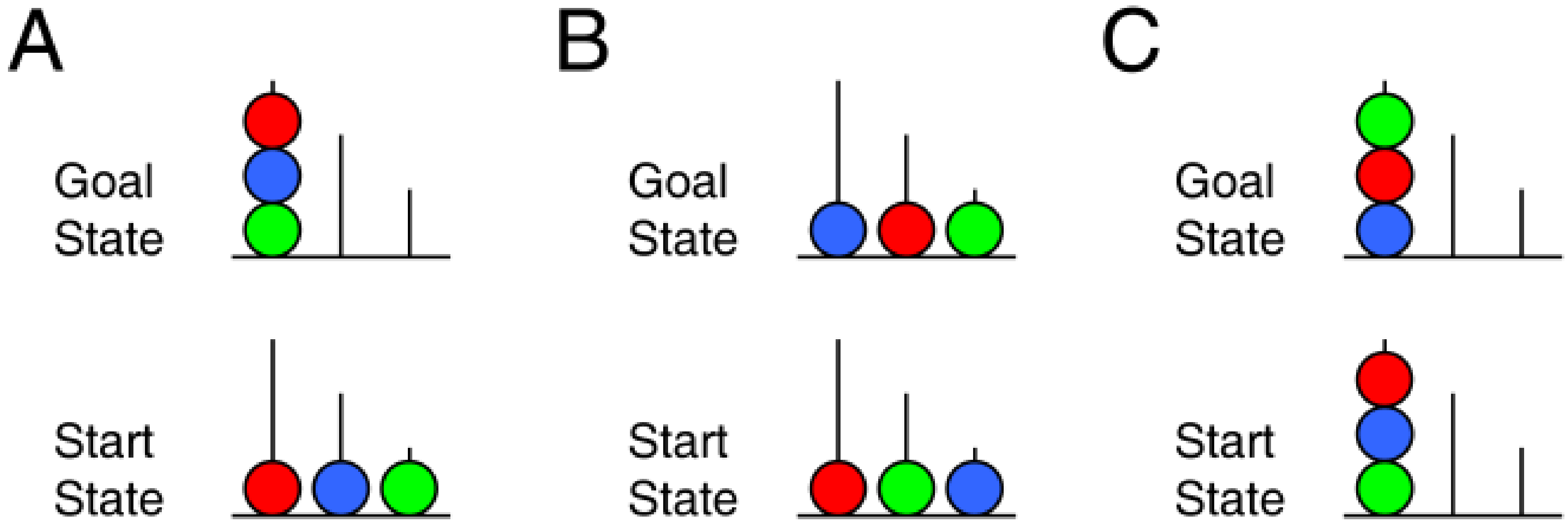
Testing executive function: Tower

Tower of London (Shallice, 1982): a test for planning, the task is to reach the goal state in as few moves as possible.
Frontal lobe patients often show a high number of excess moves.



Testing executive function: Tower

Tower of London: How many moves are necessary?



5 5 6

Testing executive function: MET

The aforementioned tests have the advantage to be standardized and results can easily be compared between patients and normal controls.

One disadvantage is the lack of ecological validity

→ The connection with the real world is lacking

For this reason, a semi-standardized test has been proposed, the **Multiple Errands Test** (MET):

At a shopping center, the patient has to

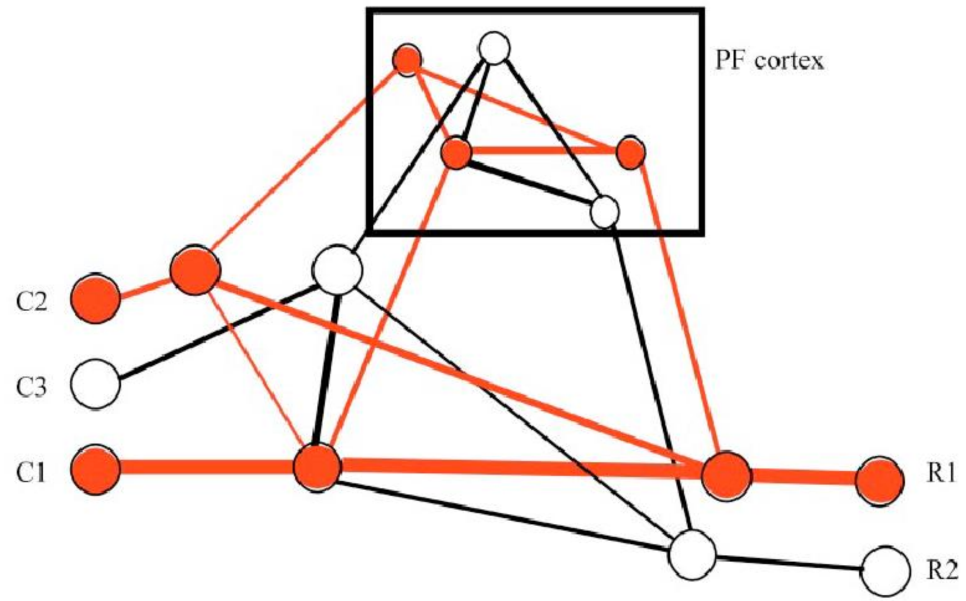
1) Buy a cookie
2) Buy a package of cough drops
3) Buy a kleenex package
4) Buy a postcard
5) Buy a book marker
6) Buy a candle
7) Meet the experimenter after 15 minutes
8) Gather information (shop with most expensive item, weather forecast, number of fast food stores, price of a dozen roses)

Models of executive function: PFC

Miller and Cohen suggested that prefrontal cortex is important in representing task rules:

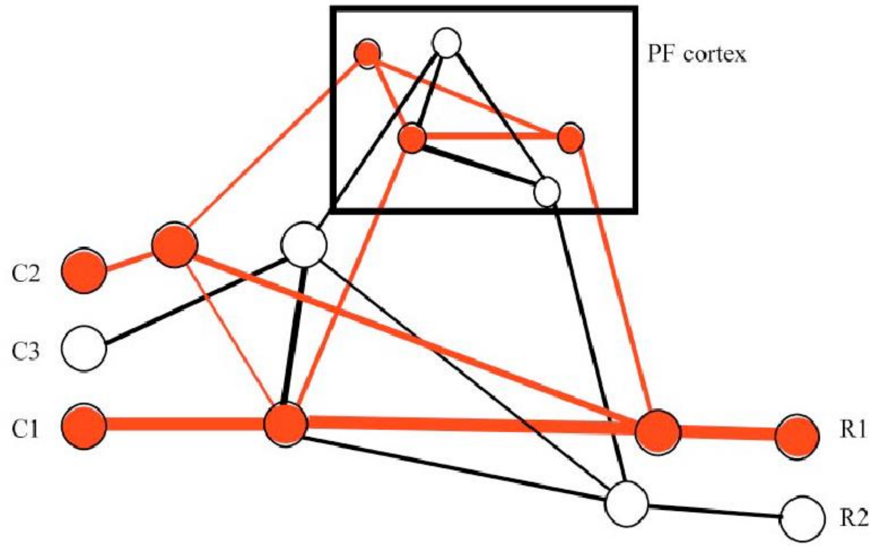
While sensory neurons (e.g., visual cortex) respond selectively for specific sensory stimuli (e.g., a specific face) and motor neurons will show selectivity for motor actions (e.g., arm movement), prefrontal cortex shows selective activity during specific tasks.

Prefrontal (PF) cortex neurons receive information about sensory input, motivational states, etc. (C1-C3, below). Depending on the context, different responses (R1, R2, below) are needed.



Miller and Cohen, Ann. Rev. Neurosci., 2001

Models of executive function: PFC

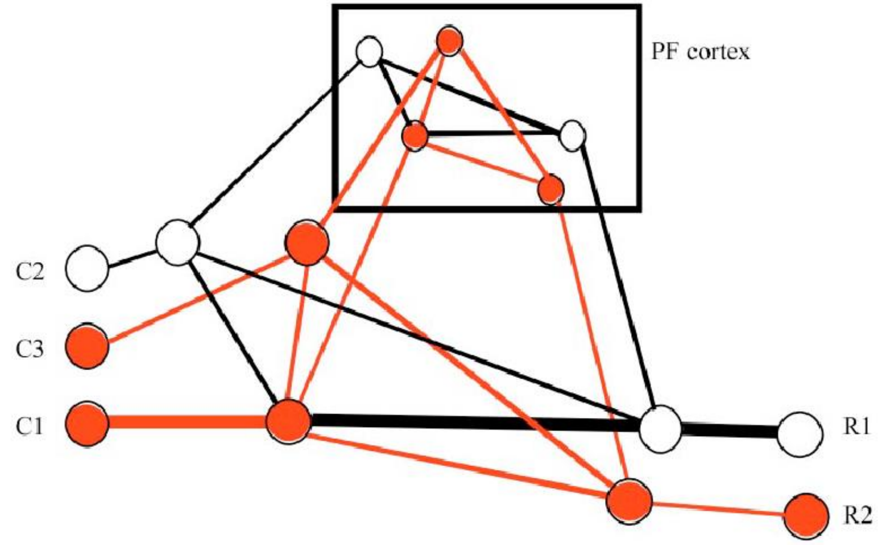


C1-C3: cue neurons: sensory input, motivational states, spatial information, etc.
R1, R2: behavioral responses

PF cortex is connected mainly to hidden units (between C and R), or association cortex

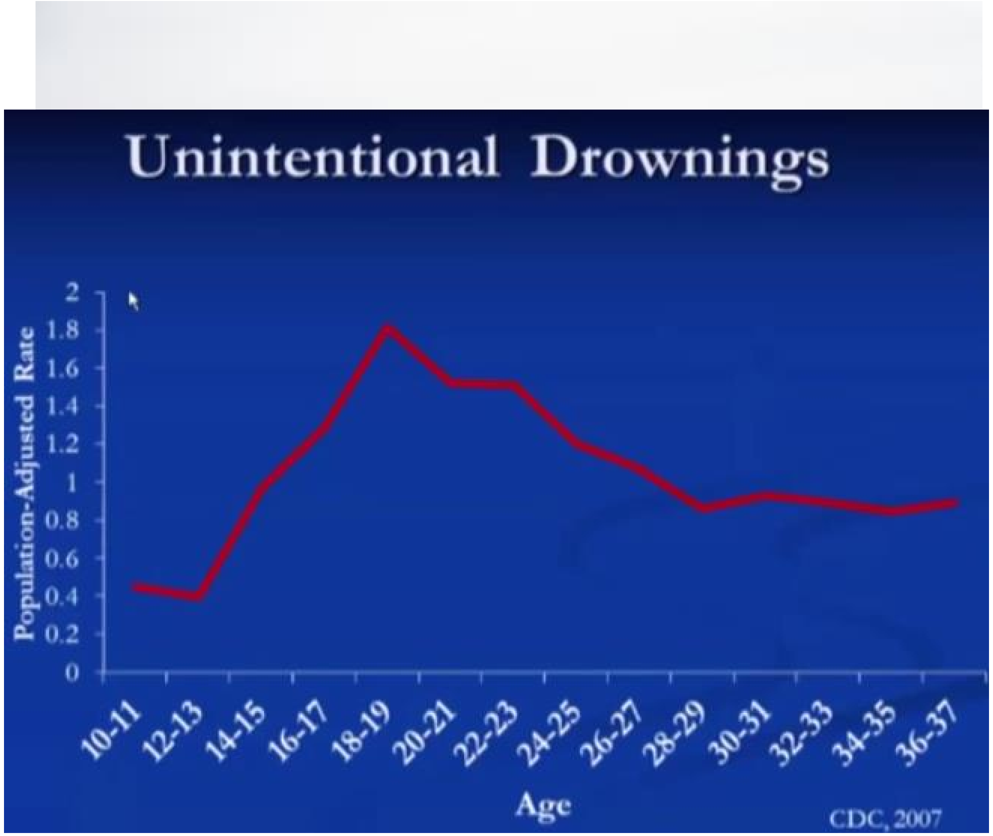
Depending on the cues, different task rules are activated, reflected in the pattern of PF neuronal activation.
These patterns guide the flow of information and mediate how input from cue neurons (e.g., sensory input) results in behavior (R).

Line width reflects strength of connections, which can be modified by learning (Hebbian).



Miller and Cohen, Ann. Rev. Neurosci., 2001

Adolescence and executive function

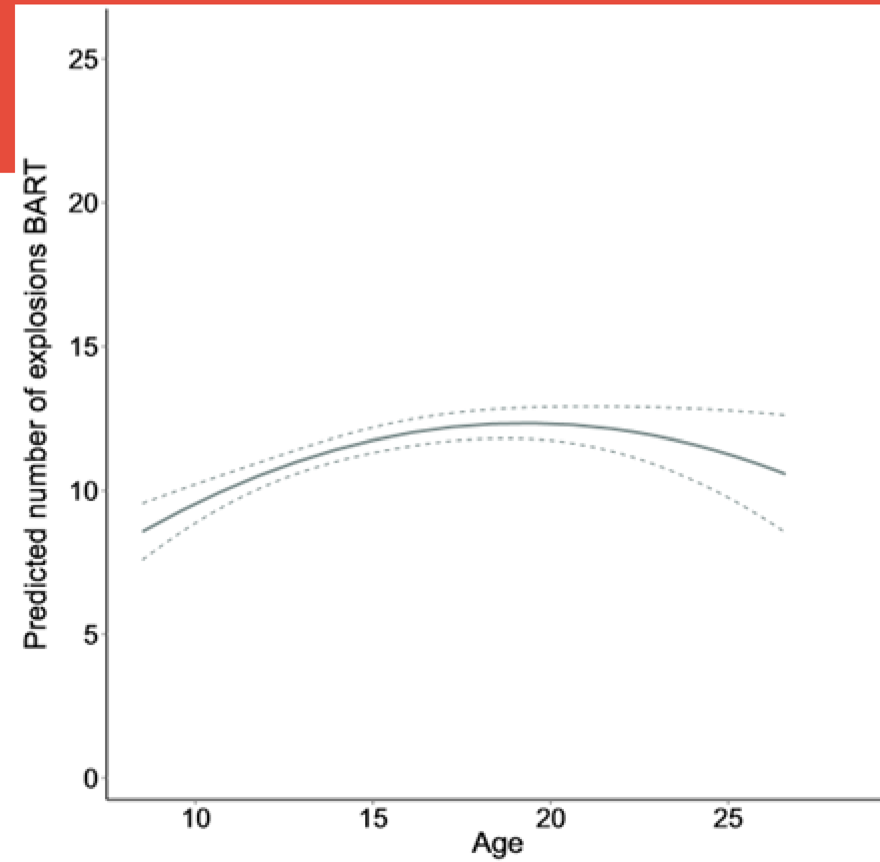


Adolescents (age range 10-22) engage in risky behavior:

- violence and crime
- accidents
- drug and alcohol abuse
- sexual risk-taking

In this age group, fatalities (death) often result from preventable and overly risky behavior.

Overall mortality increases by 200% from childhood to late adolescence.



In the balloon analogue risk task (BART), subjects can choose to continue collecting a reward by inflating a virtual balloon which will burst at some point. If the balloon bursts, there will be no reward for this trial.

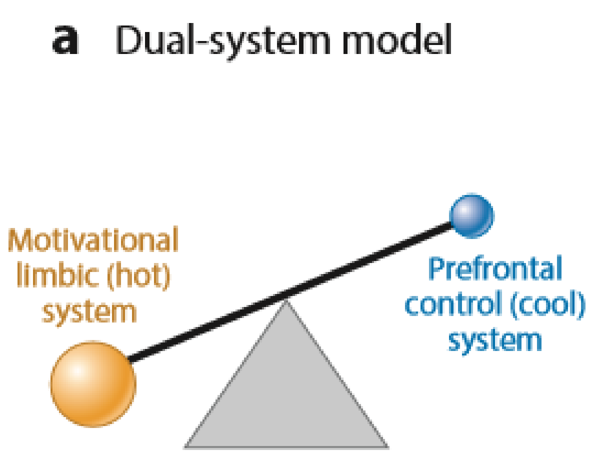
Braams et al., J. Neurosci., 2015

Participants inclined to take greater risks will cause more explosions.
The right graph shows a peak of risk-taking tendency in mid-adolescence (whole sample: ages 8-27).

Adolescence and executive function

One influential model, the dual-system model (e.g., Steinberg, Developmental Reviews, 2008), proposes that this risk-taking behavior is the result of an increased sensitivity for rewards triggered by puberty (limbic/hot system) and a still underdeveloped prefrontal control (cool) system (left graph).

Intellectual ability is already well developed at age 16, but psychosocial maturity lags behind (right graph).



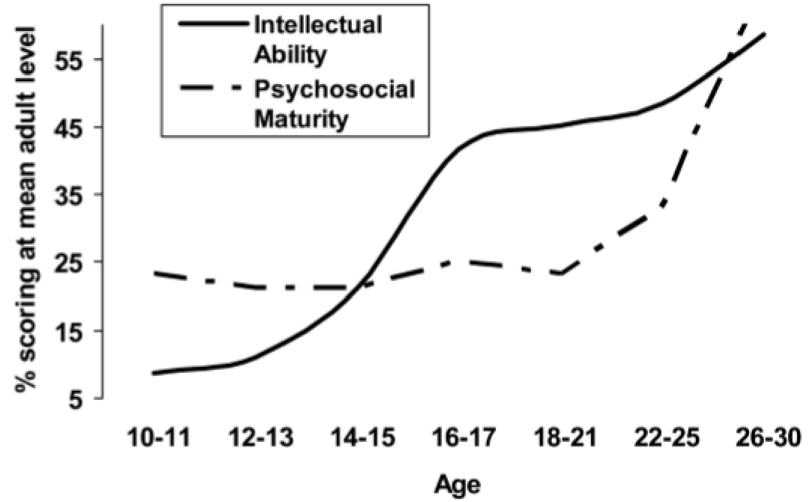


Figure 1.
Proportion of individuals in each age group scoring at or above the mean for 26- to 30- year-olds on indices of intellectual and psychosocial maturity. From Steinberg et al., 2007.

Casey, Ann.Rev.Psychol., 2016

Steinberg, Developmental Reviews, 2008

Adolescence and executive function

Reward system: with adolescence, the dopaminergic reward system undergoes several changes (e.g., pruning/decrease of dopamine receptors).
The nucleus accumbens has a peak in activity during adolescence.

Rat brain dopaminergic reward system

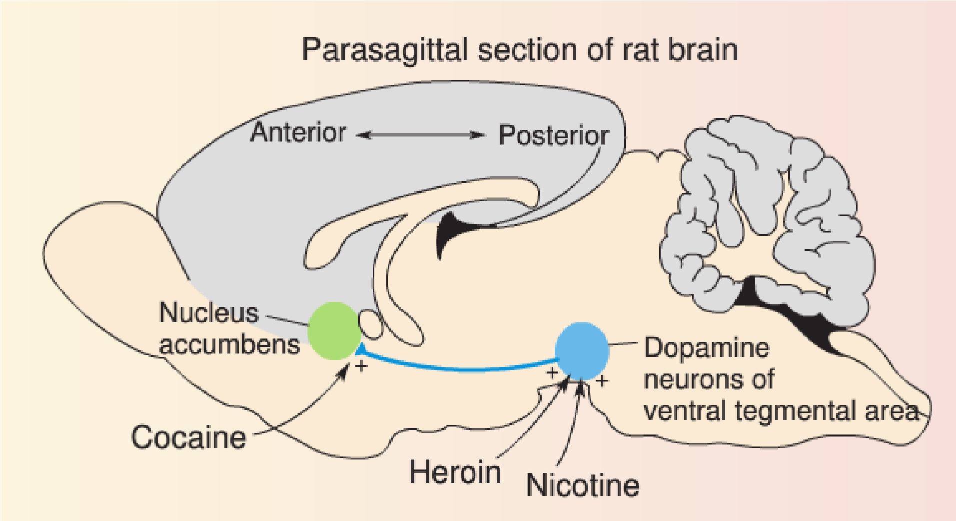
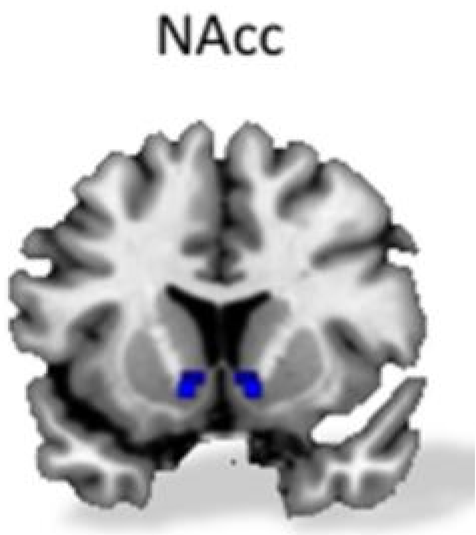


Figure A
Addictive drugs act on the dopaminergic pathway from the ventral tegmental area to the nucleus accumbens. (Source: Adapted from Wise, 1996, p. 248, Fig. 1.)

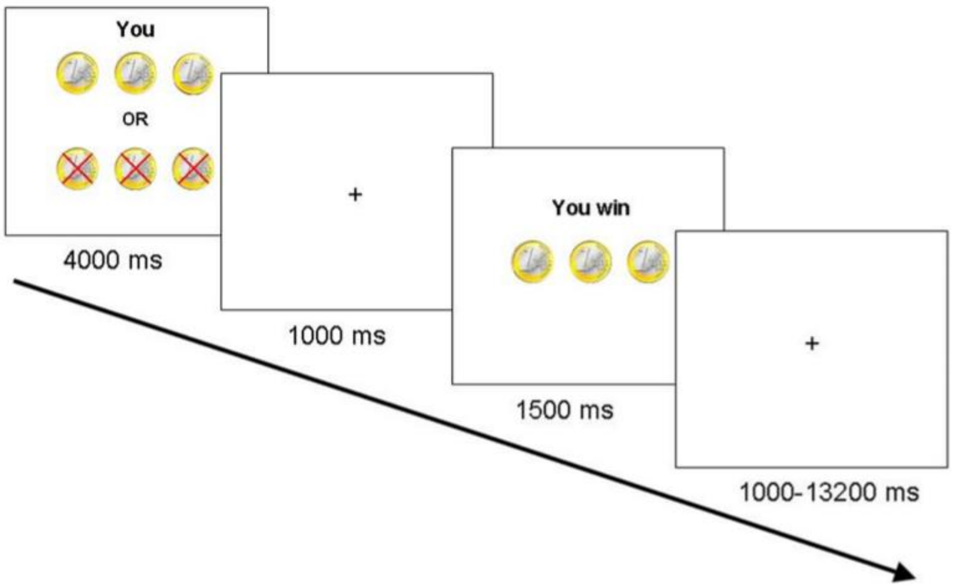
Human nucleus accumbens, part of the ventral striatum.



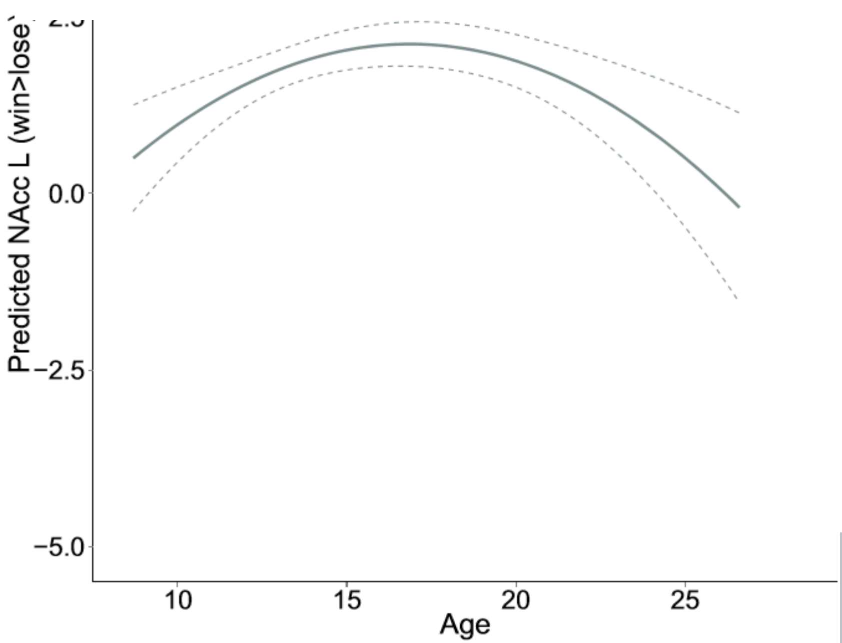
Bear, Neuroscience

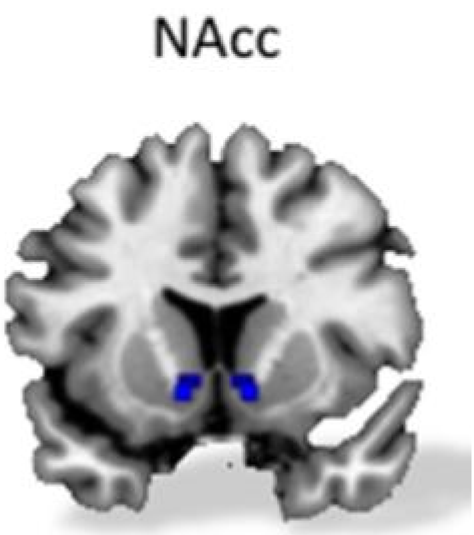
Braams et al., J. Neurosci., 2015

Adolescence and executive function



In this longitudinal study, subjects played a coin game. Brain activity (measured with functional magnetic resonance imaging) in nucleus accumbens in response to win>loss peaked during adolescence.

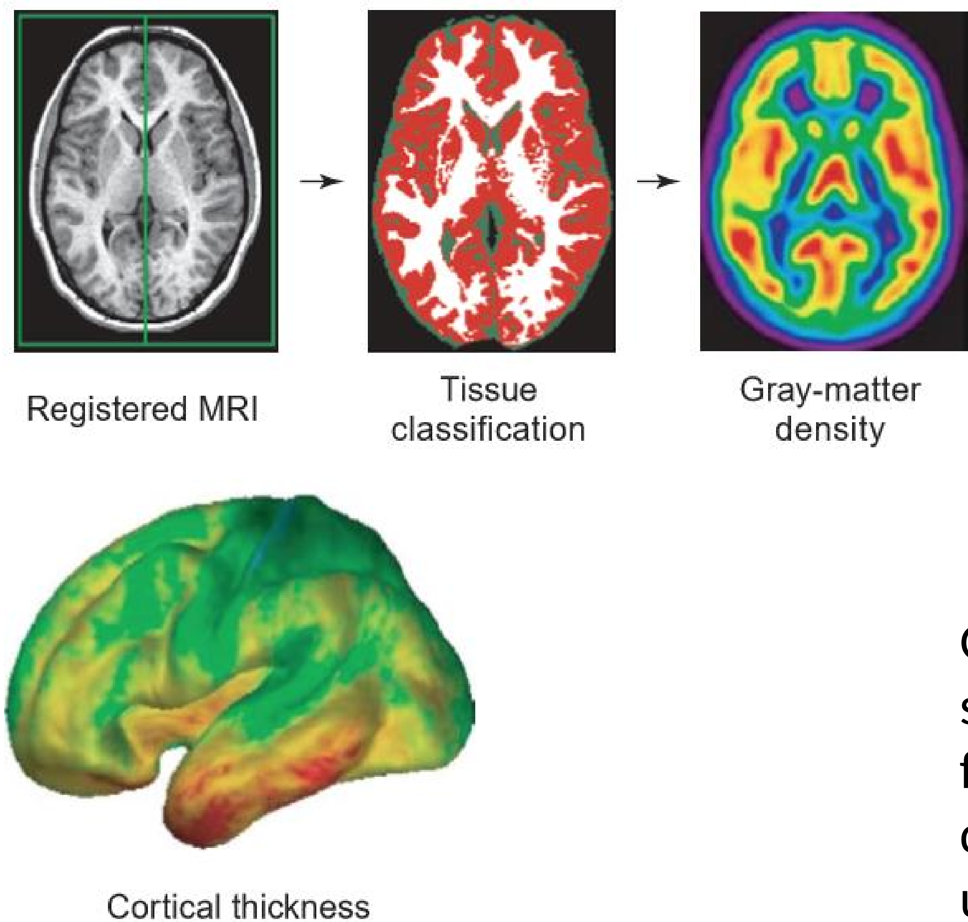


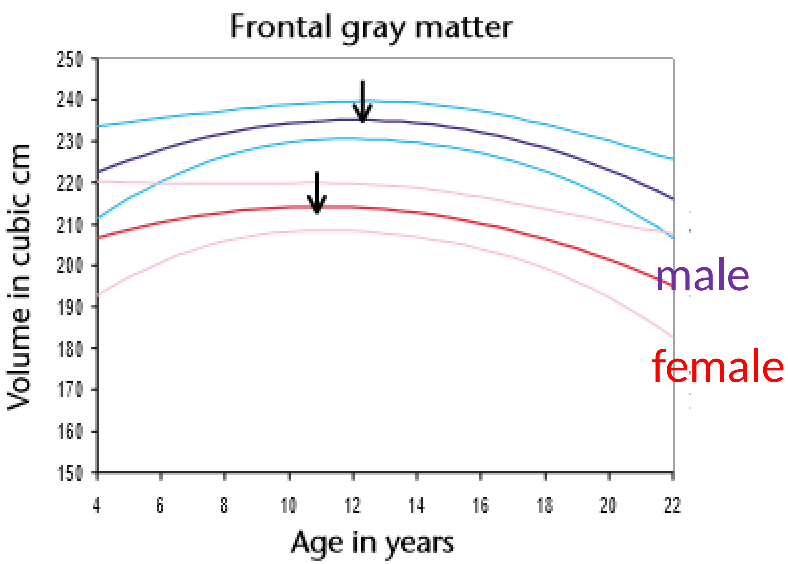


Braams et al., J. Neurosci., 2015

Adolescence and executive function

The **<u>cognitive control system</u>** still develops during late adolescence into early adulthood:



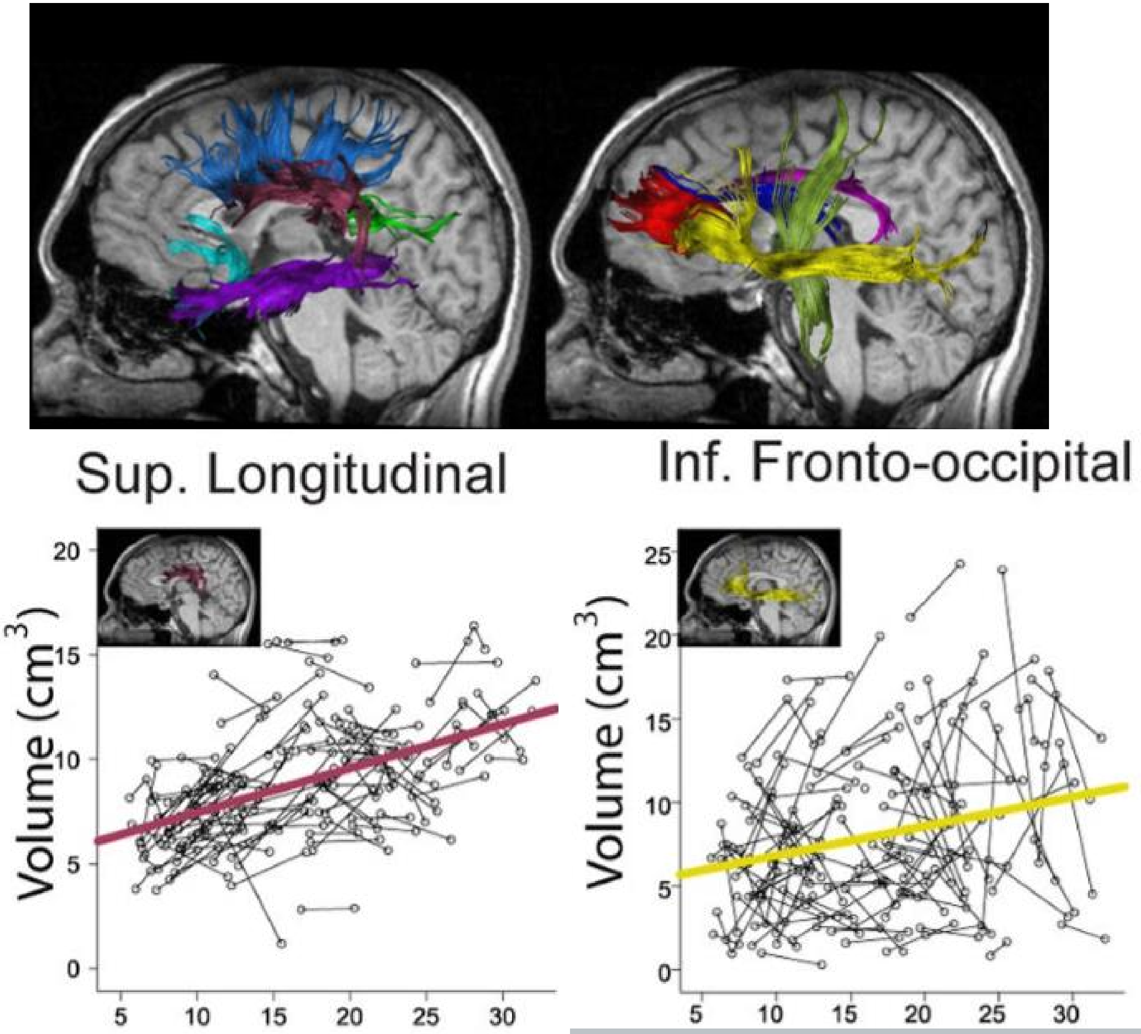


Giedd et al., Nature Neuroscience, 1999 showed a <u>reduction of gray matter</u> in the frontal cortex in adolescence: possibly due to synaptic pruning – elimination of unused synapses.

Paus, Trends in Cogn. Science, 2005

Adolescence and executive function

<u>White matter tracts (fibers) increase</u> in volume with age during adolescence, in particular those connecting to frontal association areas.



This study used diffusion tensor tractography which employs magnetic resonance imaging to measure how fluids diffuse in a tissue.

The data can be used to follow nerve fiber tracts and to estimate their volume and changes across age.

Lebel and Beaulieu, J.Neurosci., 2011

Why risk in adolescence?

Possibly, there is an evolutionary advantage of risk-taking in adolescence:

Sensation-seeking might lead to benefits in terms of exploring new territory, finding mates, and reproductive opportunities.

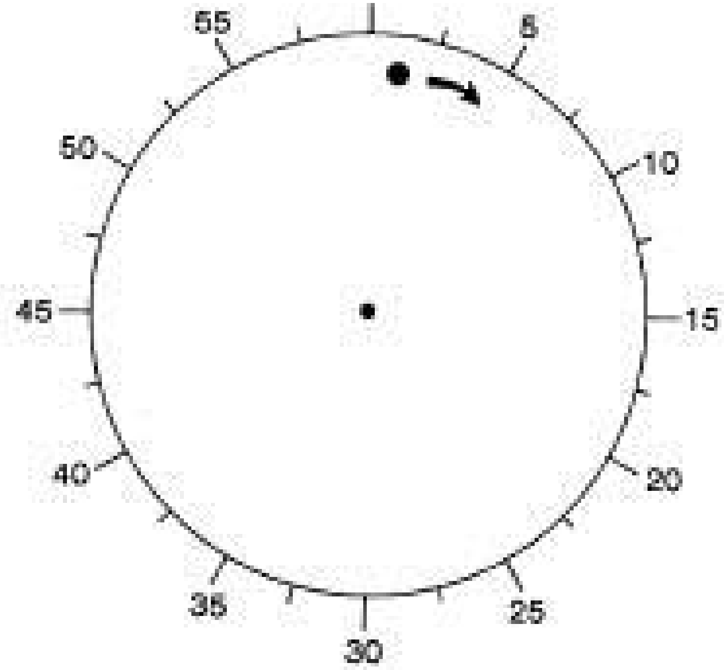
Dominance displays can be risky, but might provide later high social status with the advantages of better access to physical resources and mates.

Some of these behaviors may be typical for human males, but increased risk-taking is observed for adolescents of both sexes (Steinberg, Developmental Reviews, 2008).

from the movie Seediq Bale

Libet experiment and movement decision – “Free will”

Benjamin Libet
(1916-2007)

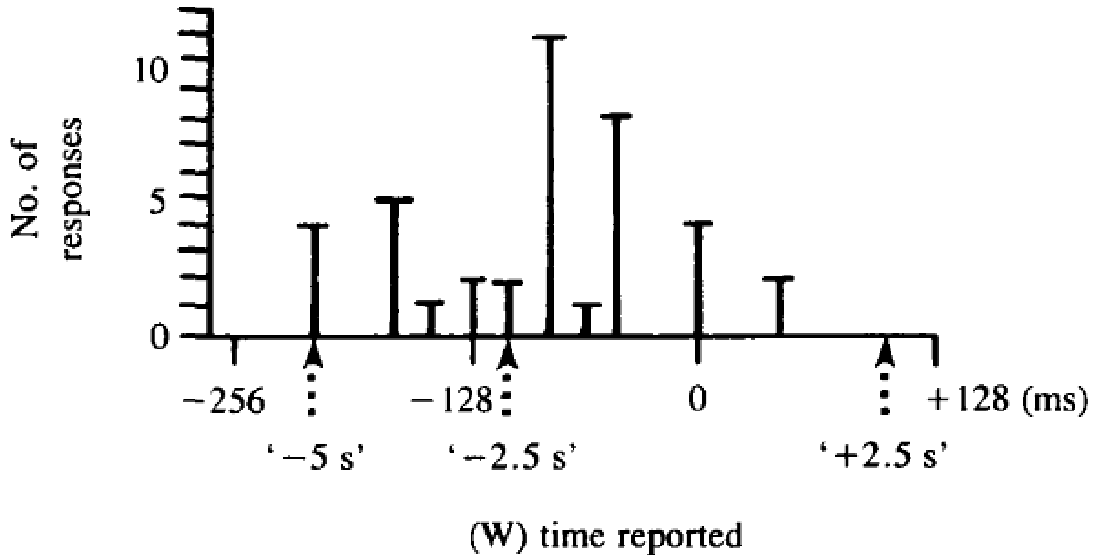


In this famous experiment (Libet et al., Brain, 1983), subjects had to spontaneously flex the fingers of their right hand. -> self-initiated movements

They had to decide when to flex entirely on their own. At the same time, a clock was running (above: 2.56 sec/rotation->100 msec/tick line) and the subjects had to report the position of the clock hand at the time of decision afterwards.

“Free will” – Libet

Example reports of time of wanting (W) for 1 sample subject:



(time before EMG trigger)

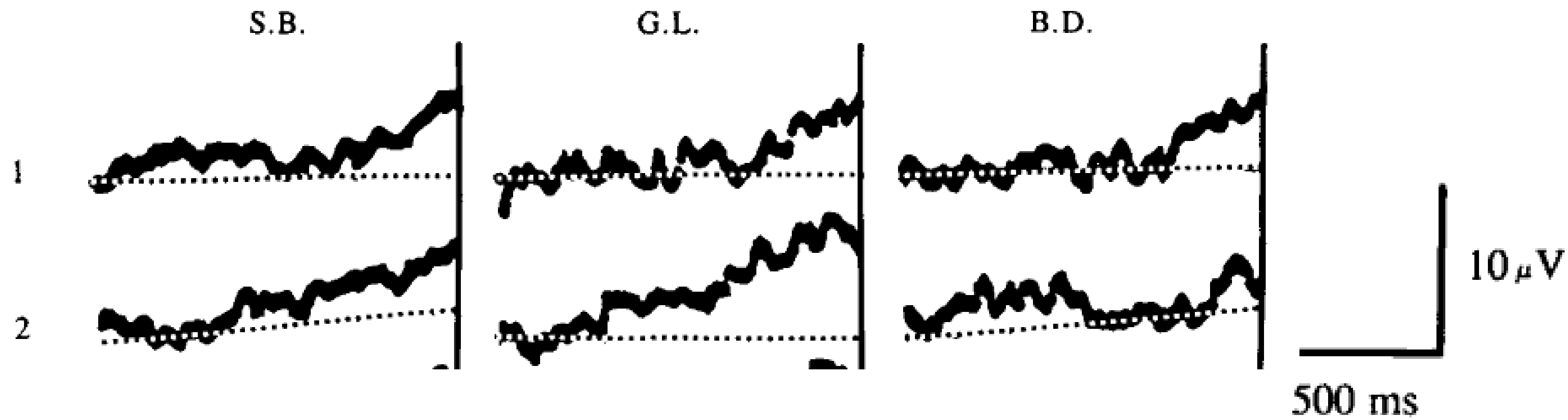
(time on the ‘clock’)

The time reported that subjects wanted to move (W time) was on average 200 ms before muscle activation was measurable (with electromyography: EMG).

Libet et al., Brain, 1983

Libet experiment

Example EEG waves (electrode Cz) of 3 subjects:

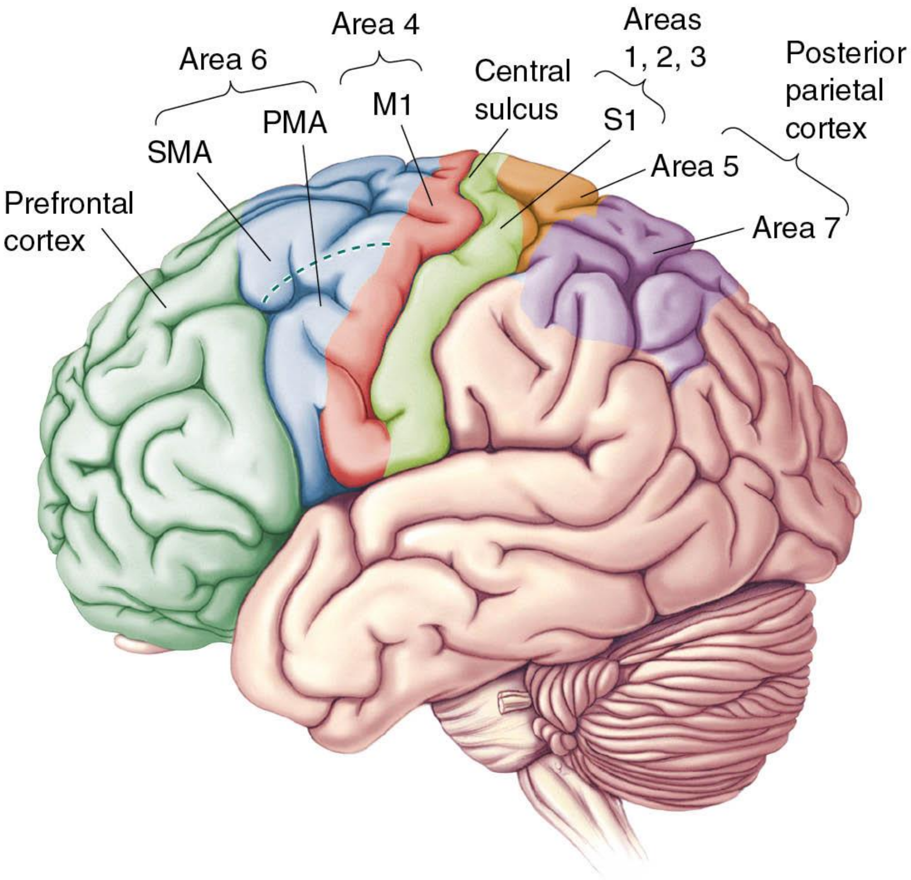


The time of onset of the Bereitschaftspotential (readiness potential) was on average at least 350 ms (type II, late BP) and up to 800 ms (type I, late BP) before the time of subjective “wanting to move” (W).

Thus, brain activity precedes the subjective decision to move which in turn precedes the actual movement.

Libet et al., Brain, 1983

Libet experiment



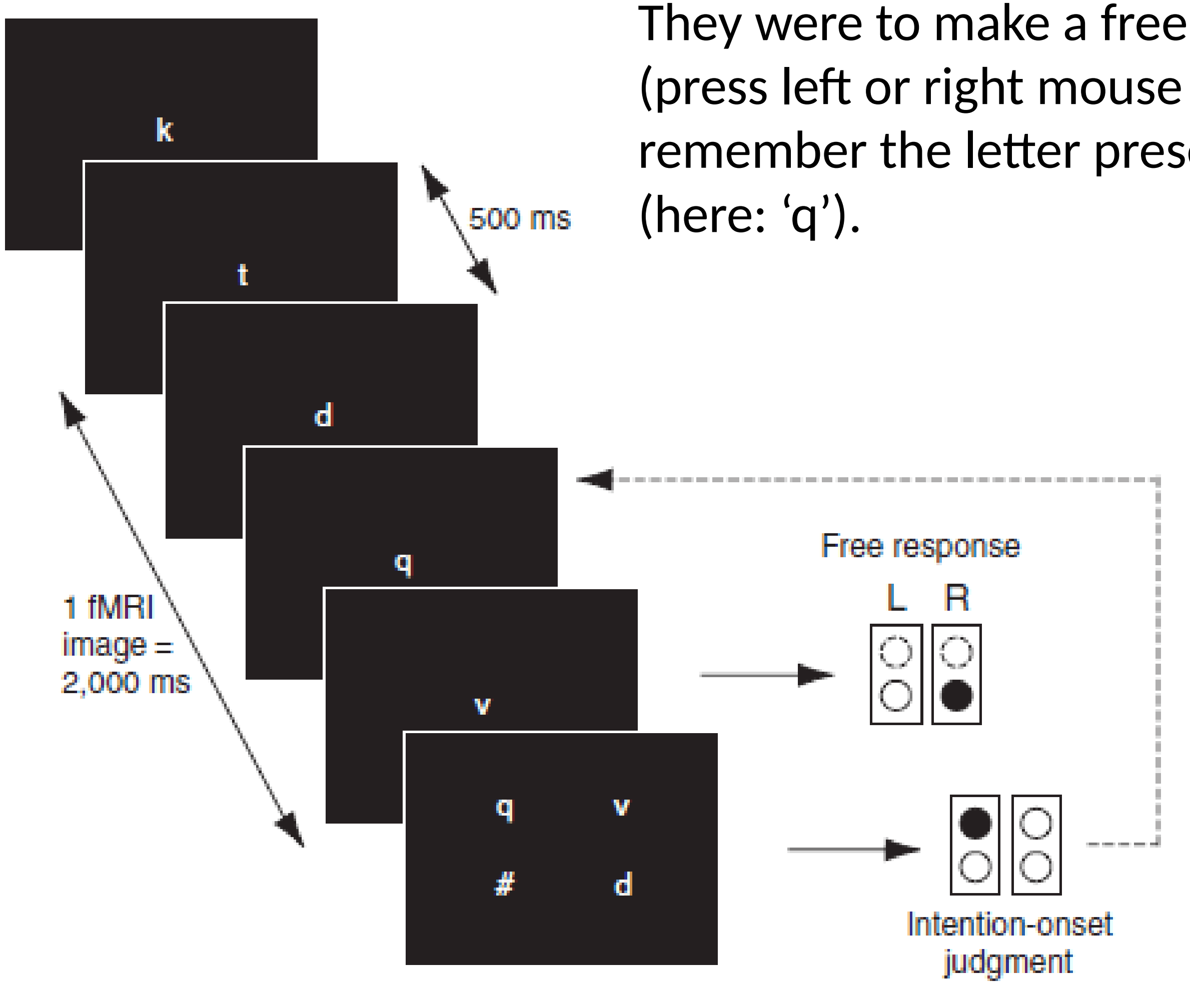
The Bereitschaftspotential (readiness potential) is assumed to be generated in the supplementary motor area (SMA), premotor area (PMA) and in motor cortex (M1).

Bear, Neuroscience

Libet experiment → FMRI

In a later fMRI (functional magnetic resonance imaging) study, subjects watched a letter stream (new letter every 500 ms).

They were to make a free response from time to time (press left or right mouse button). They should also remember the letter presented at the time of decision (here: ‘q’).

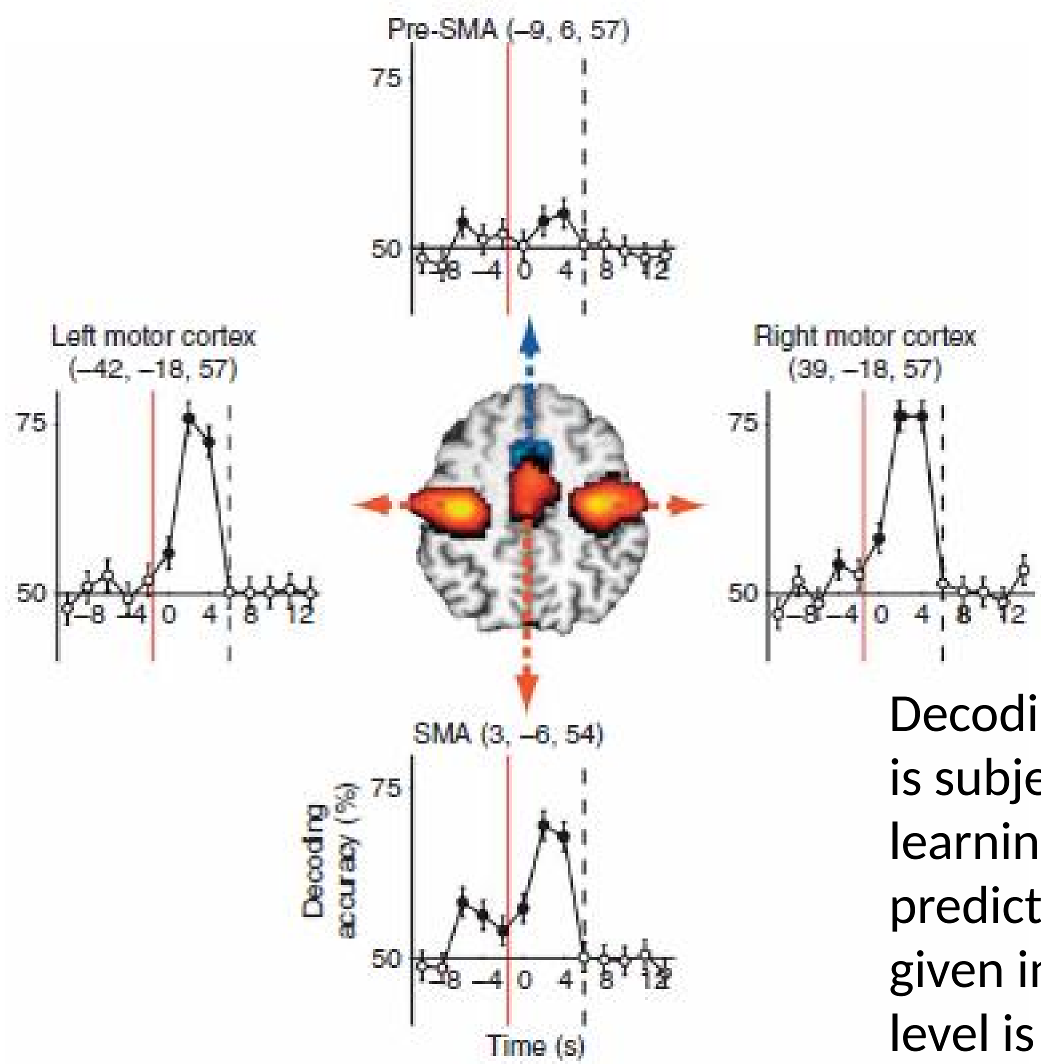


At the end of the trial, they had to report the letter by selecting the corresponding button (intention-onset judgment).

Time of subjective decision was in the 1000 ms before movement.

Soon et al., Nature Neuroscience, 2008

“Free will”

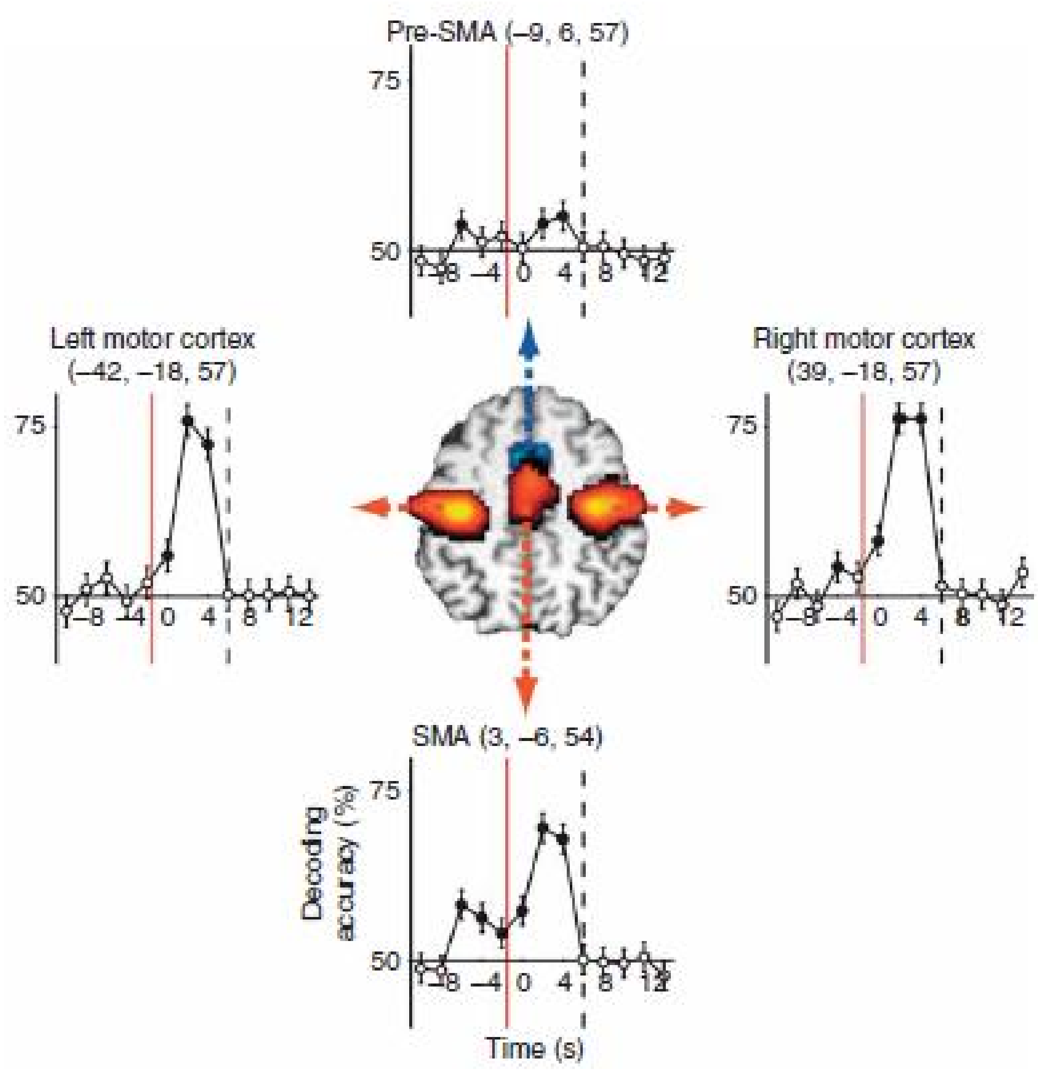


The resulting fMRI data was used to predict (decode) whether the subsequent button was left or right.

Decoding means that the data in a local area is subjected as a pattern to train a machine learning algorithm. This algorithm then predicts the outcome of response (left/right) given independent fMRI data (test). Chance level is 50%.

Soon et al., Nature Neuroscience, 2008

Predicting decision with FMRI

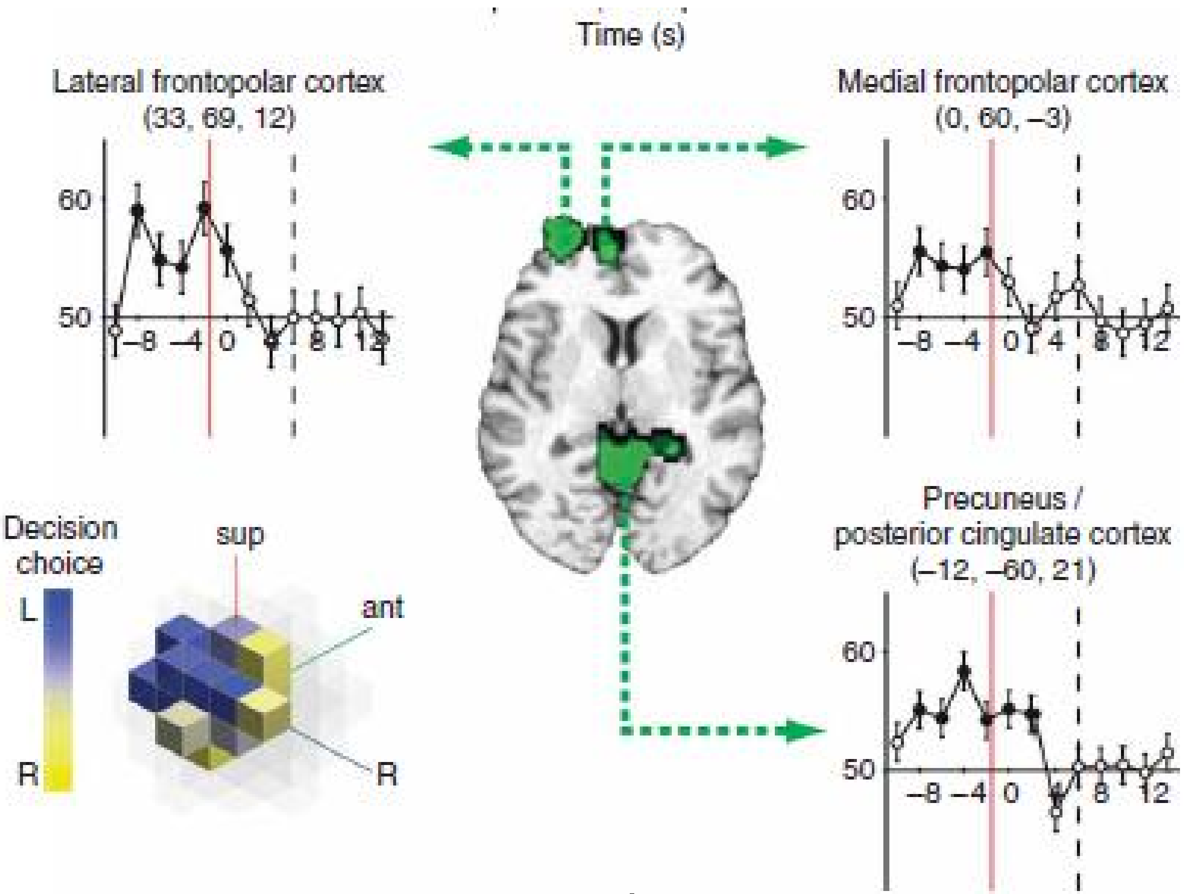


The vertical red line shows the time of decision. Areas in SMA and motor cortex predicted well the response after the time of decision (accuracy 70-75%).

Soon et al., Nature Neuroscience, 2008

Predicting decision with FMRI

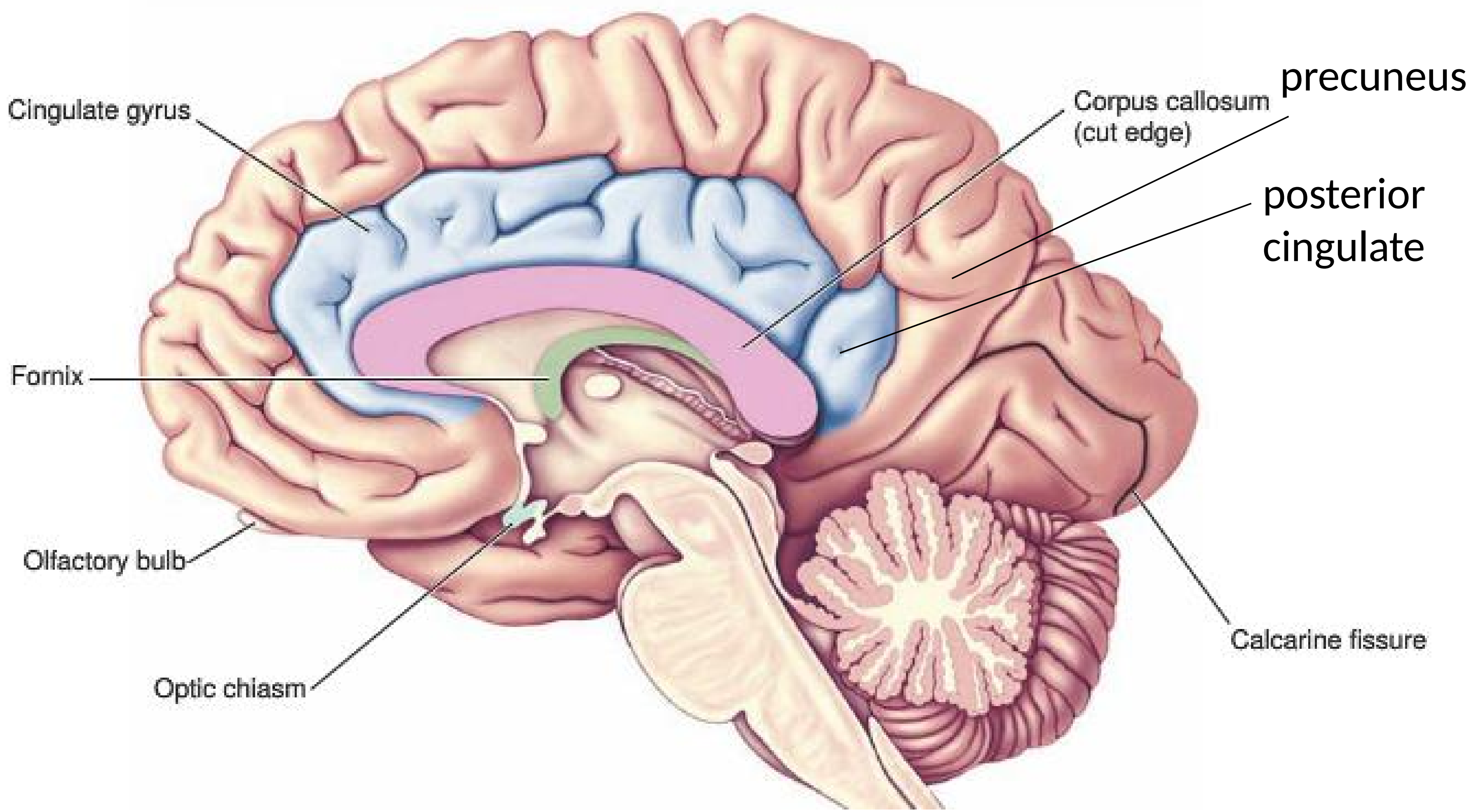
Some areas could predict the response before subjective decision: frontopolar cortex and medial parietal cortex (precuneus / posterior cingulate cortex).



This was about 7 s before the subjective decision. Accuracy was up to 60%. Considering the lag of the fMRI signal, brain activity predictive of a motor decision could occur 10 s before subjective decision.

Soon et al., Nature Neuroscience, 2008

Free will in the brain



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Summary: Executive Function

Executive Functions and Planning

1) Executive functions help us to coordinate our daily lives: volition, planning and decision making, purposive action, and effective performance. They are often impaired after prefrontal cortex damage.
2) Delay of gratification has been shown to be a stable personality trait and to correlate with later success and response inhibition.
3) Tests of executive function: Stroop test, Wisconsin card sorting test, Iowa gambling task, Multiple errands test
4) Model of frontal lobe functions (Miller/Cohen): prefrontal neurons may have an important role to guide our behavior depending on sensory input, context, and current goals.
5) Risk-taking behavior in adolescence may be caused by enhances reward sensitivity and a delayed development of frontal cortex dependent cognitive control.
6) Experiments by Libet on movement decisions show brain activity signaling decision before conscious awareness.