Neuroeconomics :

Neuroscience of decision making

Lecture N6

Dual process theory of decision making

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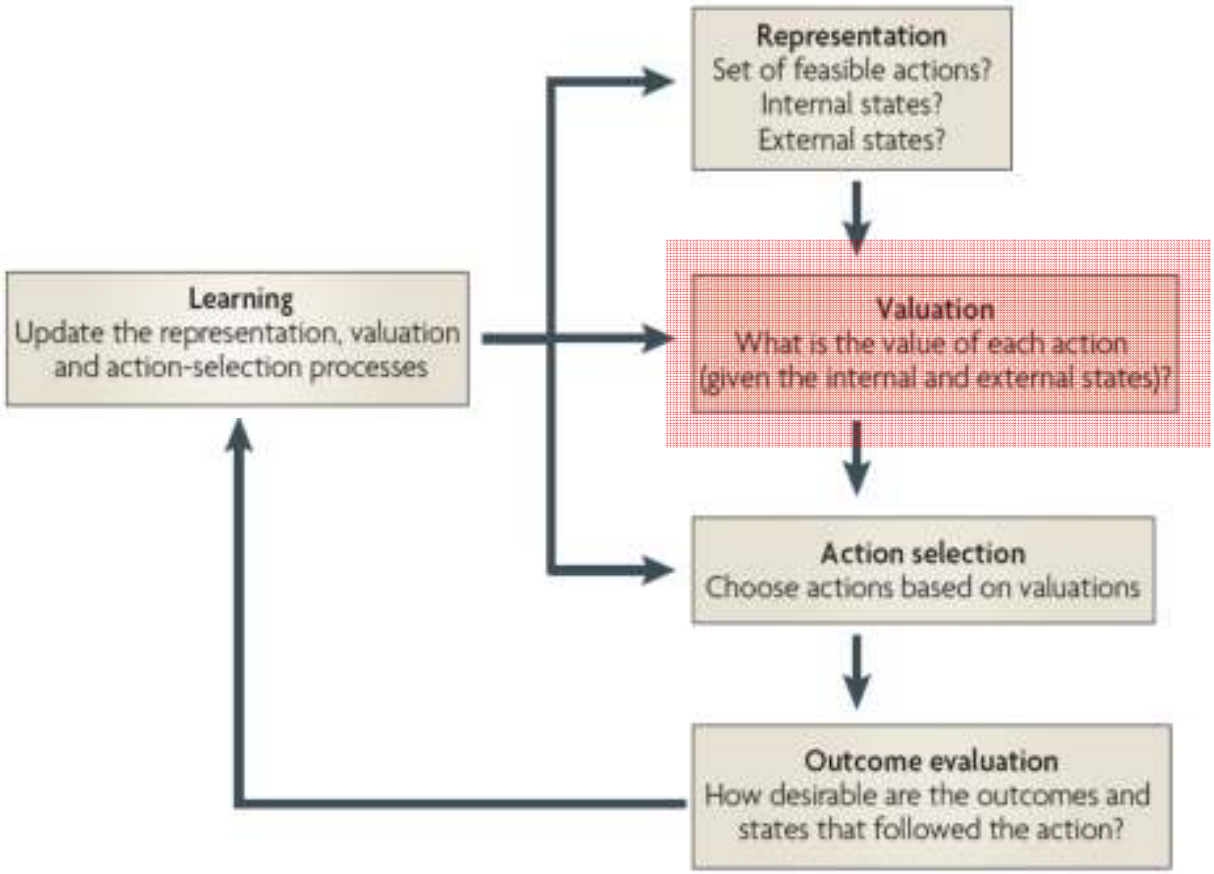
Decision making in Neuroeconomics



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Assigning a value…

- **Value** is an objective measure, e.g.122 $
- **Real values** are subjective!

✓ **Utility** is a measure of the desirability of consequences of an action.

✓ **Expected utility** is the weighted average of all possible outcomes, with the weights being assigned by the probability of outcomes.

✓ **Prospect theory** $U = \Sigma w(p)v(x)$

U – expected utility; *v* – function that assigns a value to an outcome. *w* –probability weighting.

✓ **Neuroeconomics utility** –the averaged firing rate (real number: 0,2,…1000 etc) of a population of neurons that encodes the subjective value of the object. It predicts choices.

Subjective value = *r* (firing rate) = $\sum r_n/n$

✓**Neuroeconomics utility** –the averaged firing rate (real number: 0,2,…1000 etc) of a population of neurons that encodes the subjective value of the object. It predicts choices.

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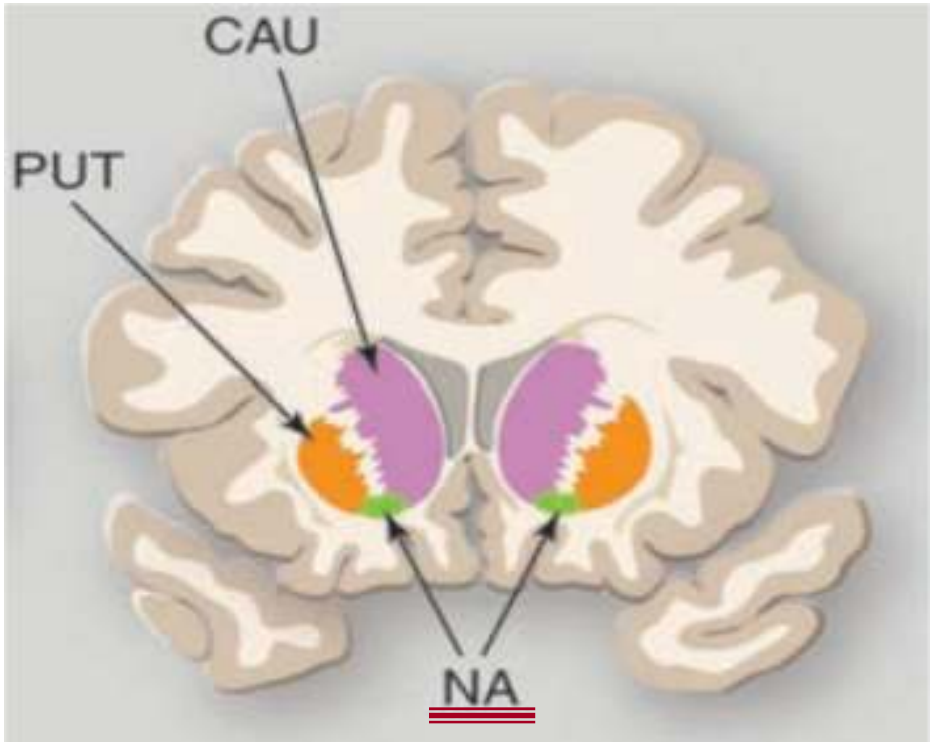
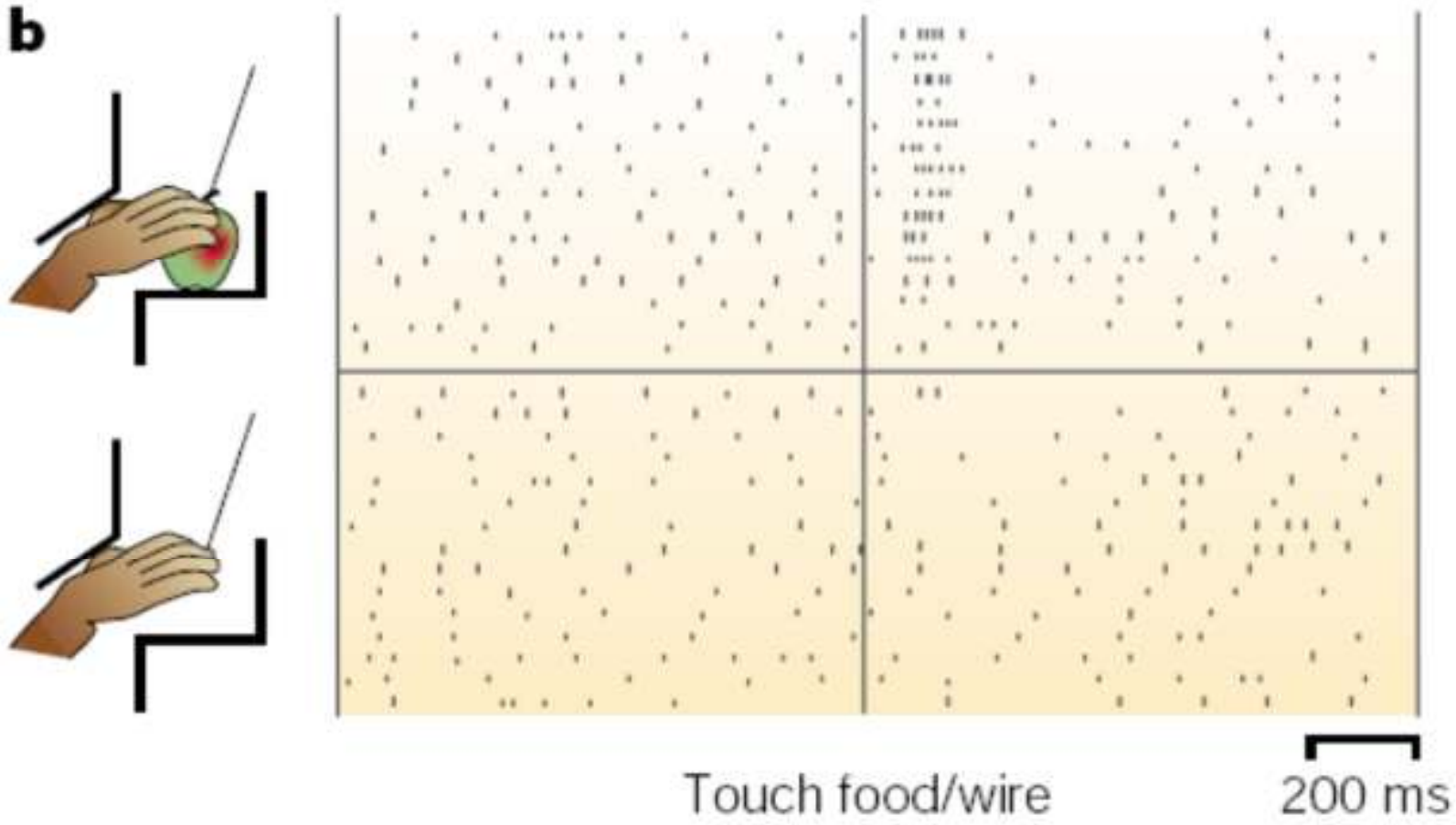


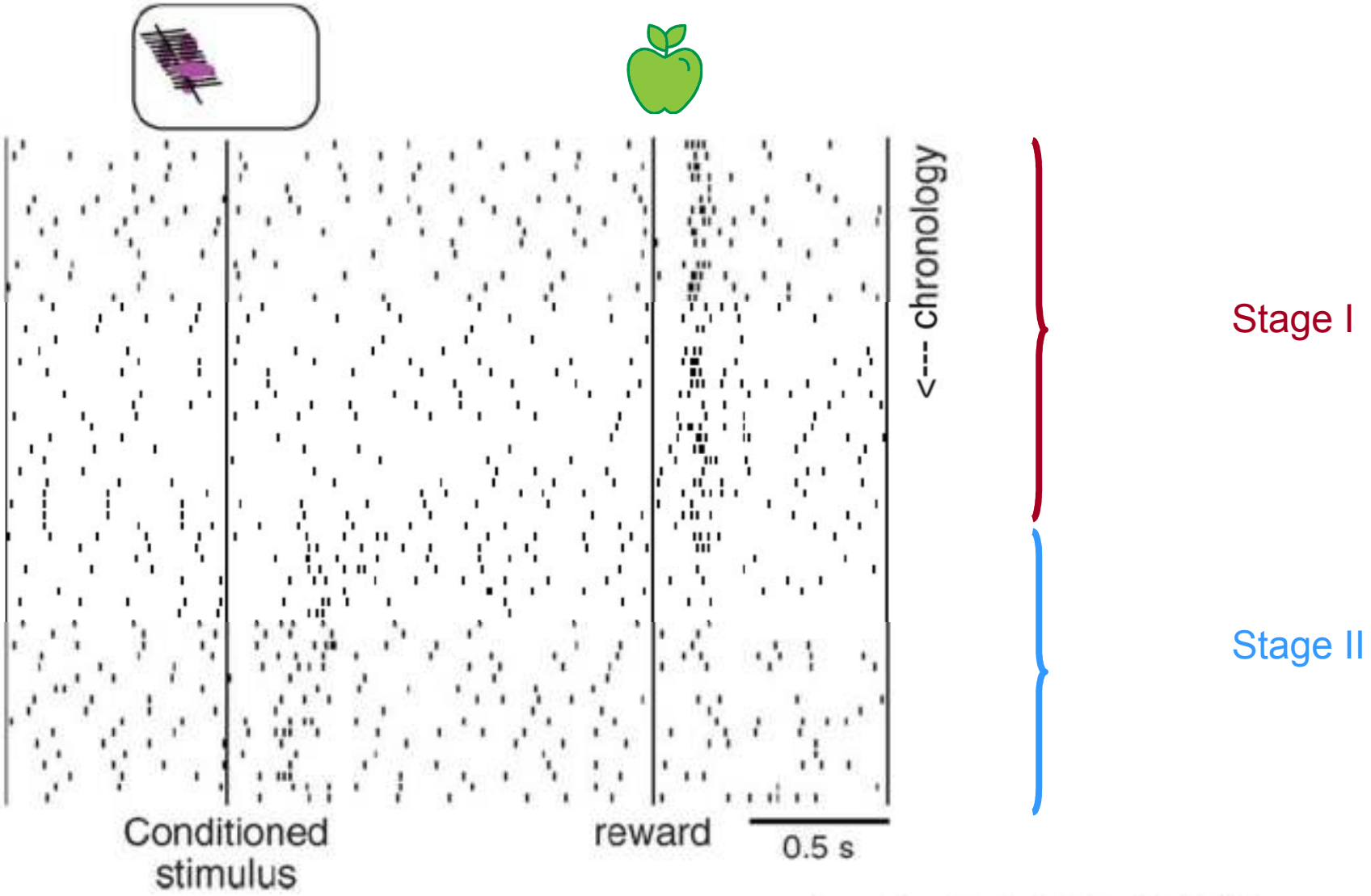
Nucleus accumbens (NAc = ventral striatum) – anticipated gain magnitude. Risk-seeking.

NAc reacts to reward!

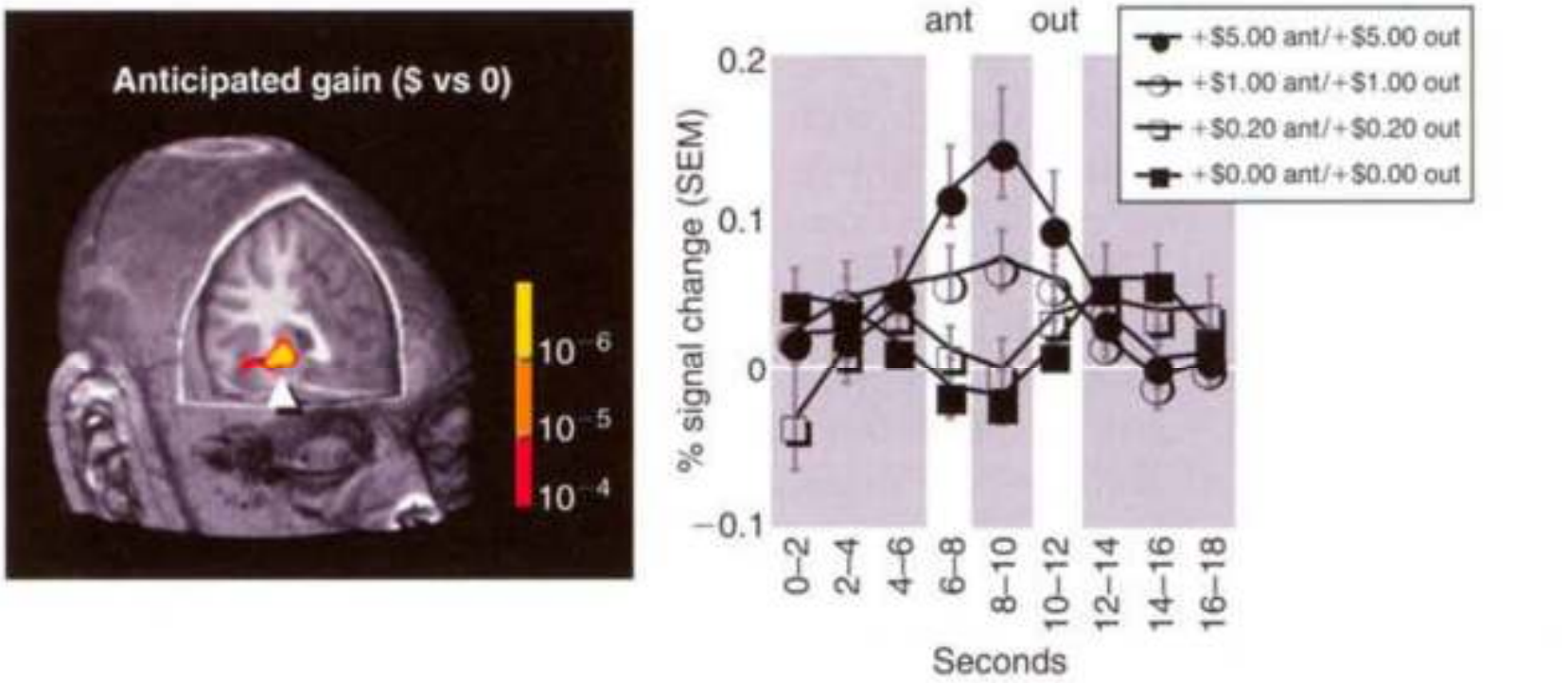


Wolfram Schultz

Actual reward and prediction of reward in NAc during Pavlovian conditioning



Annu. Rev. Psychol. 2006. 57:87–115

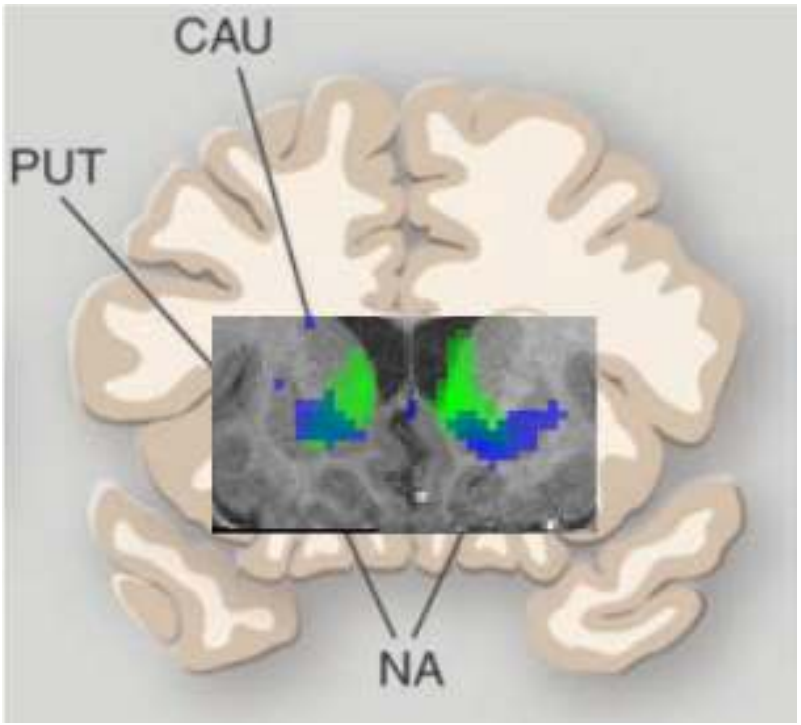


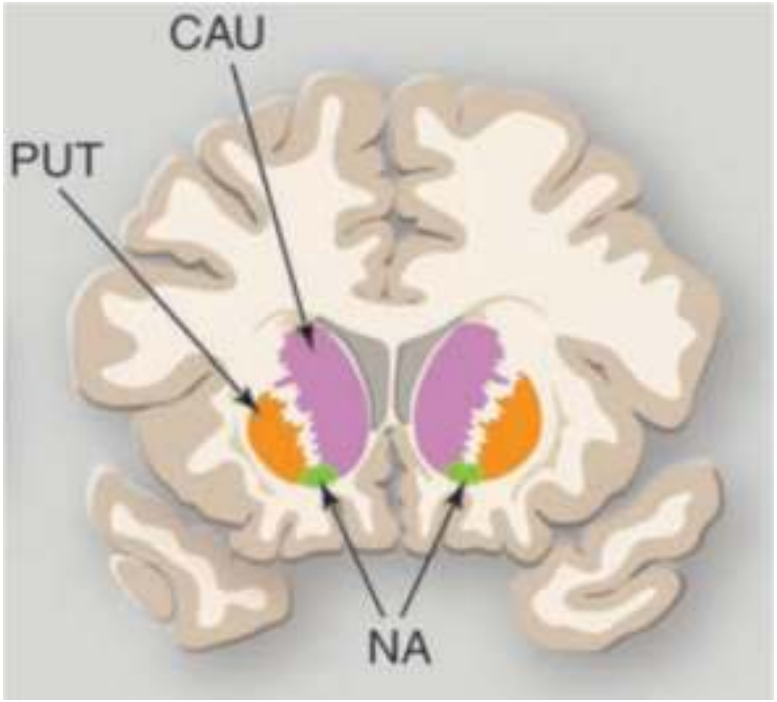
Anticipation of monetary gains of increasing magnitude elicits proportionally increasing NAcc activation.

nucleus accumbens = ventral striatum

Knutson et al., 2009

$EV = \sum p\ V$





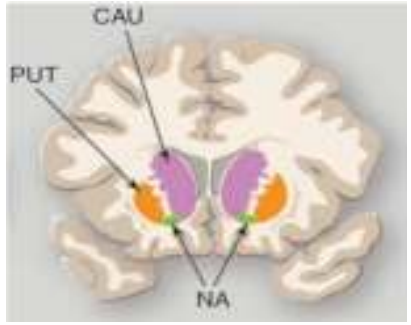
Probability

Reward magnitude

Yacubian et al., 2007

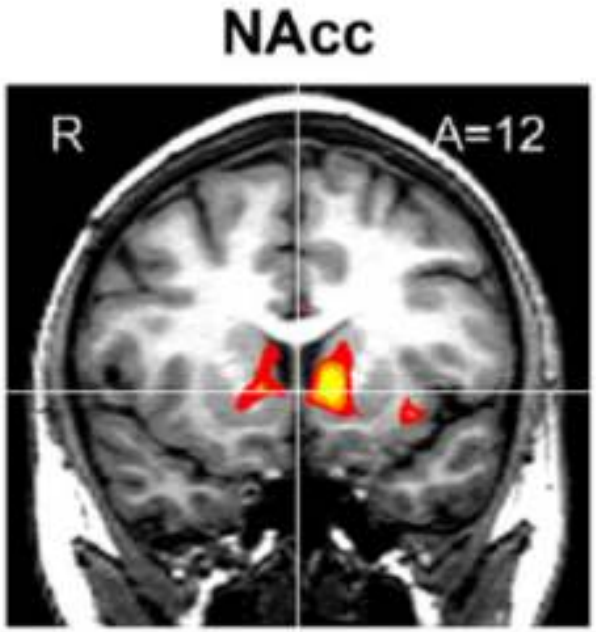
- Subcortical *nucleus accumbens* (NAc) activity is proportional to anticipated gain magnitude.

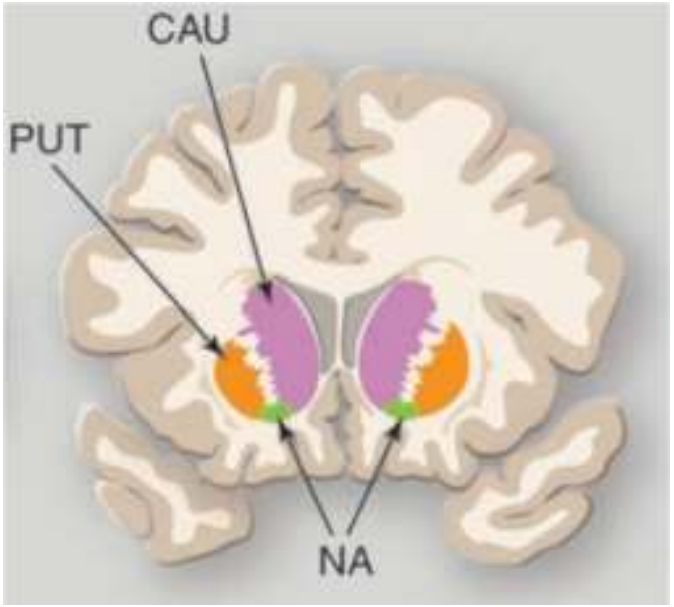
- Certain populations of NAc neurons are more sensitive to expected reward probability and other populations are more sensitive to reward magnitude (NAc, perhaps, codes *expected utility*).

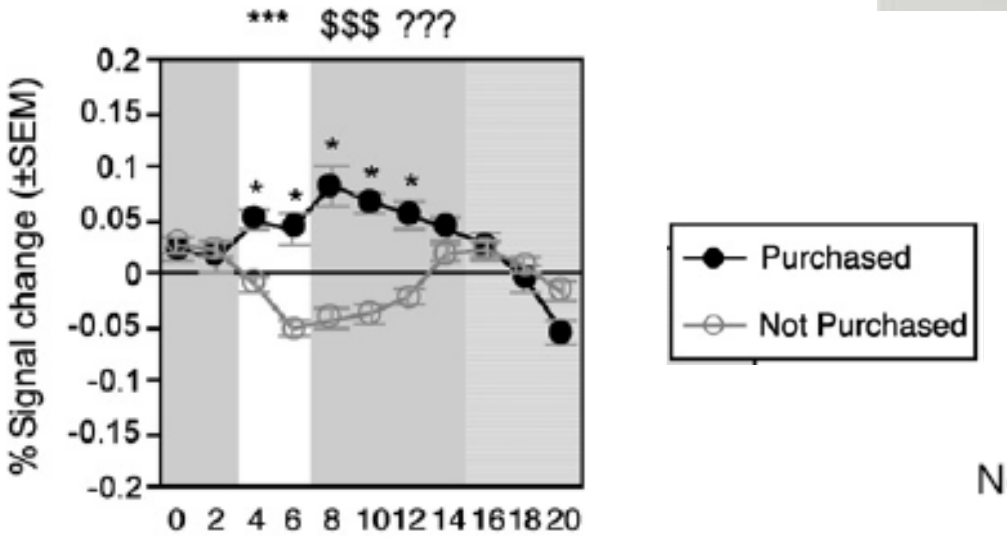


?

Purchasing







Neuron 53, 147–156, January 4, 2007

***, product period; $$$, price period; ???, choice period;

NAc is in a unique position to participate and perhaps mediate goal-directed behaviors.

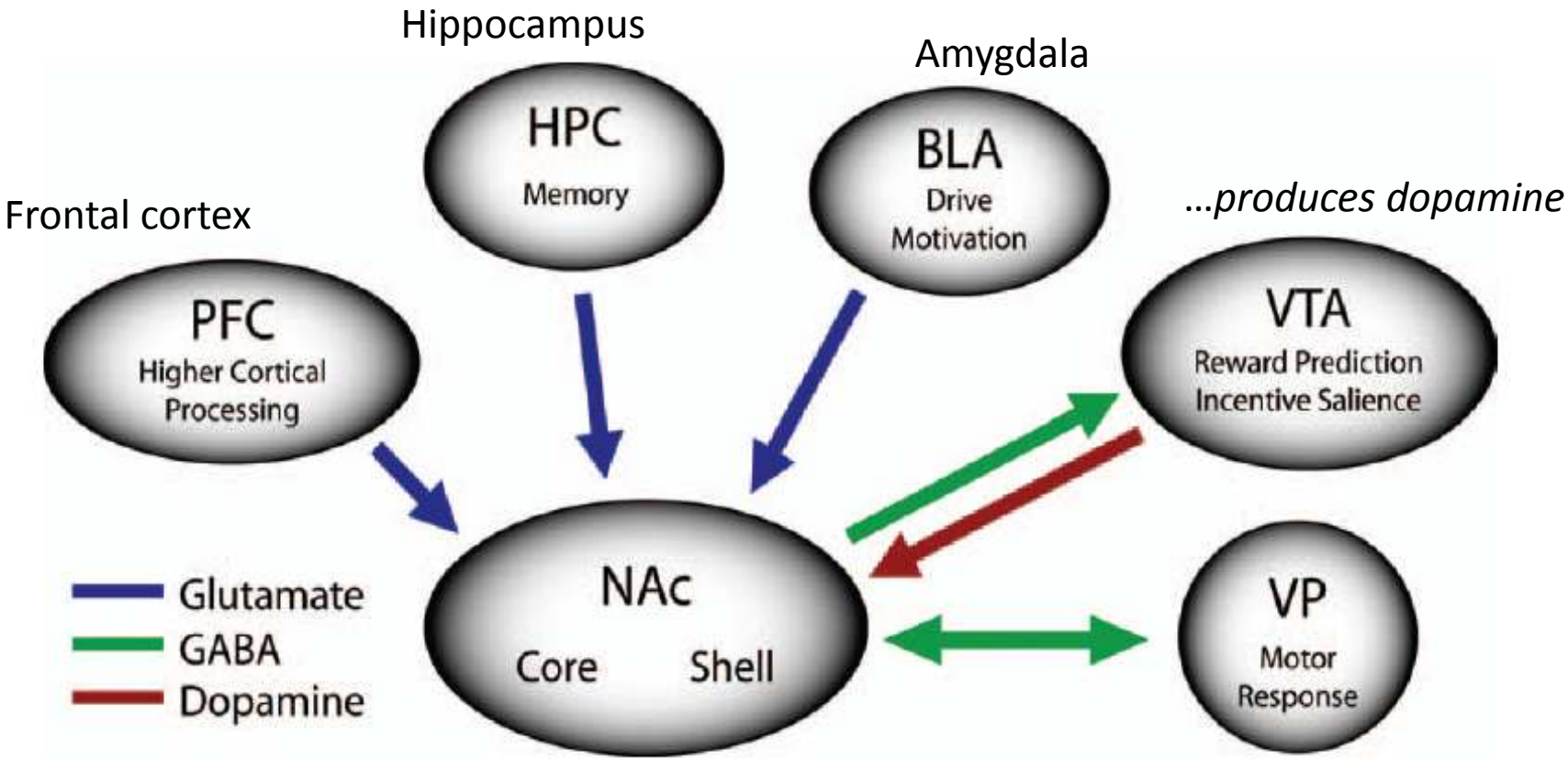


Fig. 1. General overview of key nucleus accumbens (NAc) afferent and efferent projections. See text for more information on the anatomic organization of the NAc. Note that placement of arrows does not necessarily indicate degree or precise location of projection. PFC, prefrontal cortex; HPC, hippocampus; BLA, basolateral amygdala; VTA, ventral tegmental area; VP, ventral pallidum; NAc, nucleus accumbens.

Carelli 2002

?

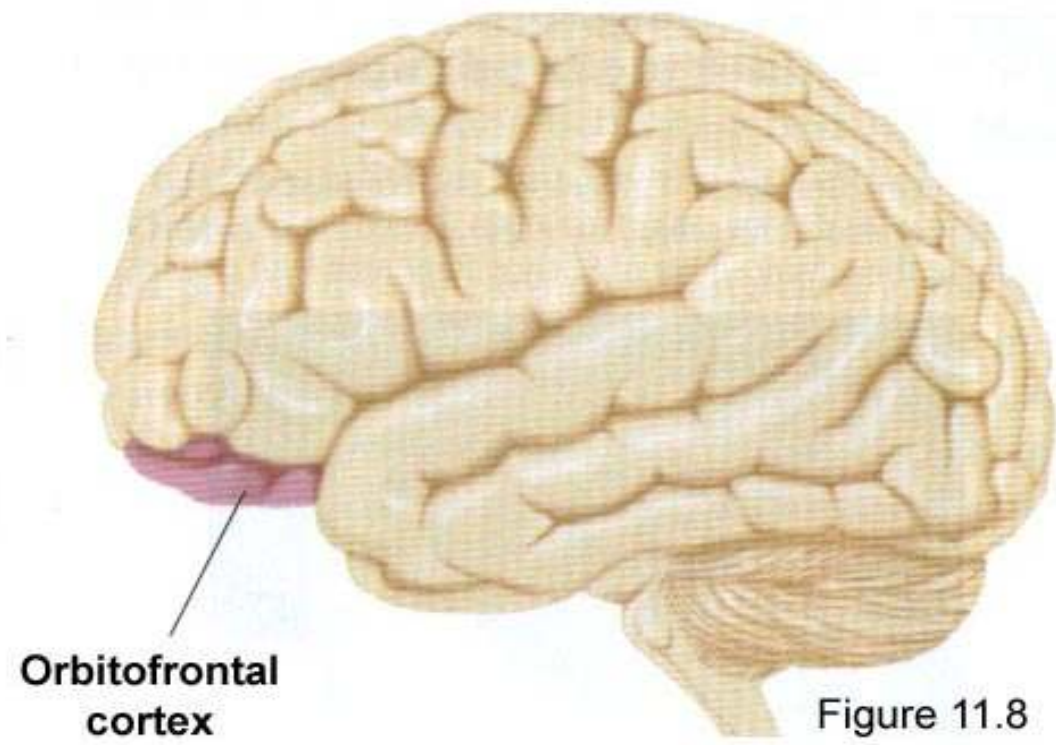
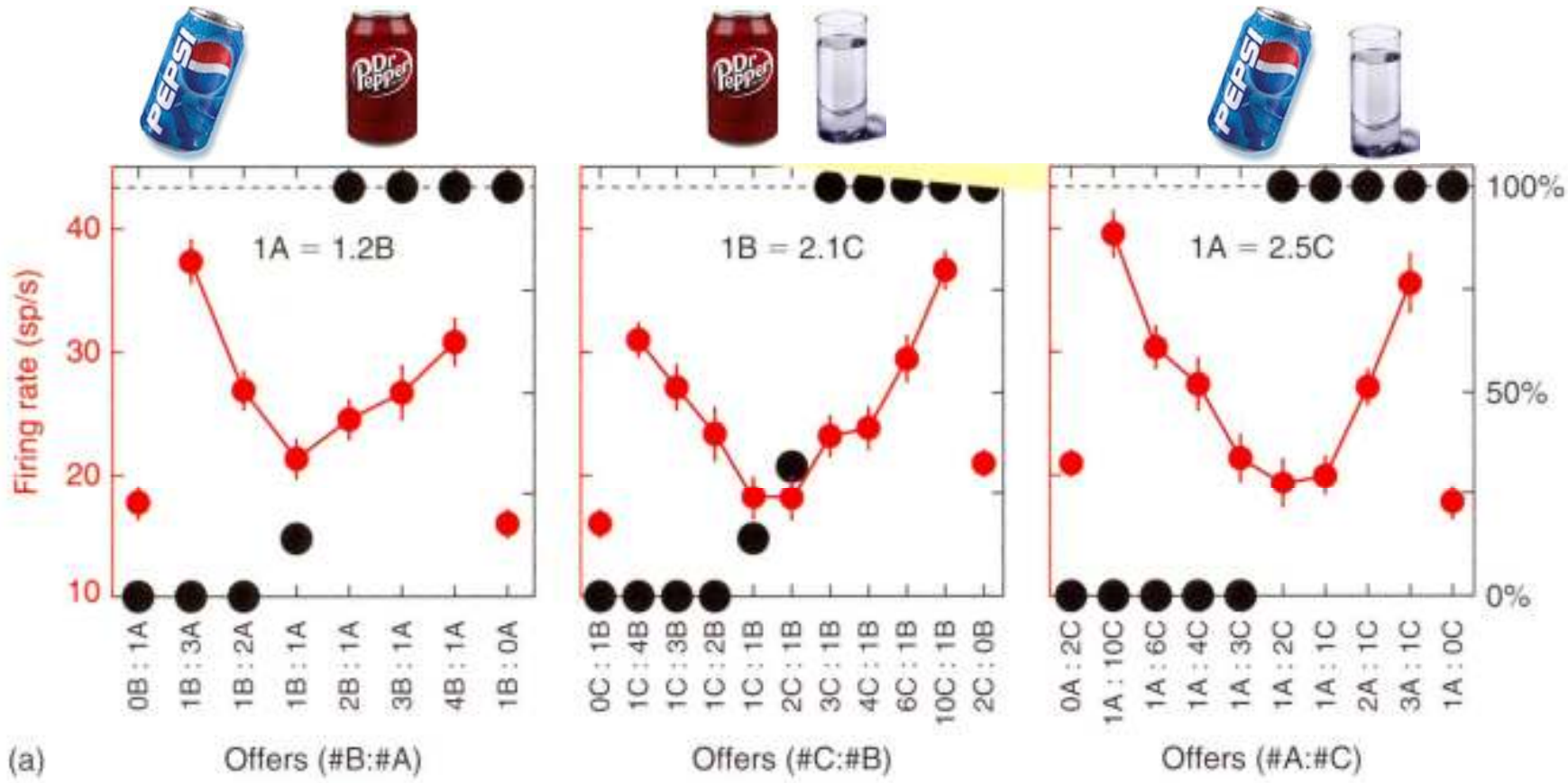


Figure 11.8

Orbitofrontal cortex (OFC) – compares / integrates multiple information regarding the reward outcome

Fast emotional (reverse) learning

Code relative values: OFC is not sensitive to the Menu



(Platt, 2009, Padoa-Schioppa, 2008)

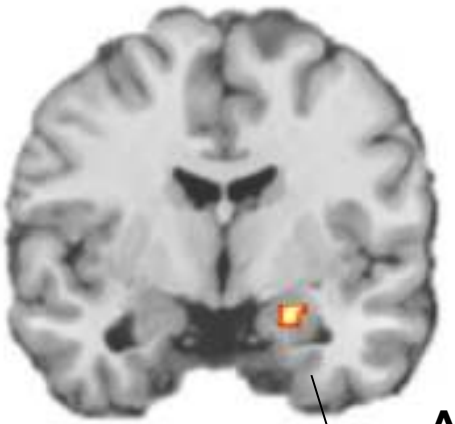
Orbitofrontal cortex – OFC

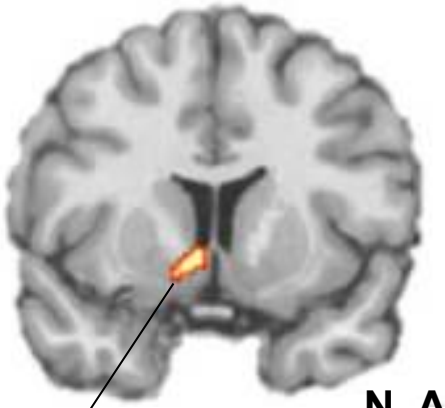
- **OFC** plays a key role in processing reward: It integrates multiple sources of information regarding the reward outcome to derive a value signal.
- **OFC** supervises Nac.

?

Fugu contains lethal amounts of the poison tetrodotoxin in its organs. 30-60 victims per year, an average fatality rate of 6.8%.

Costs & Benefits

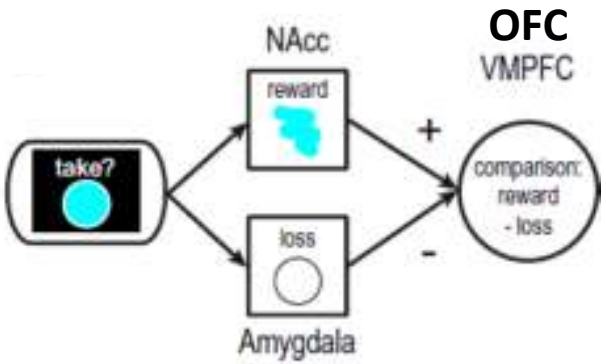


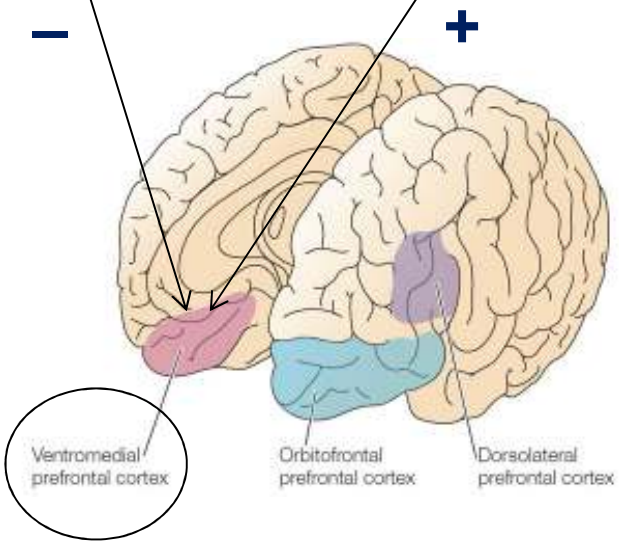


Amg.

N. Acc.

cost–benefit comparison



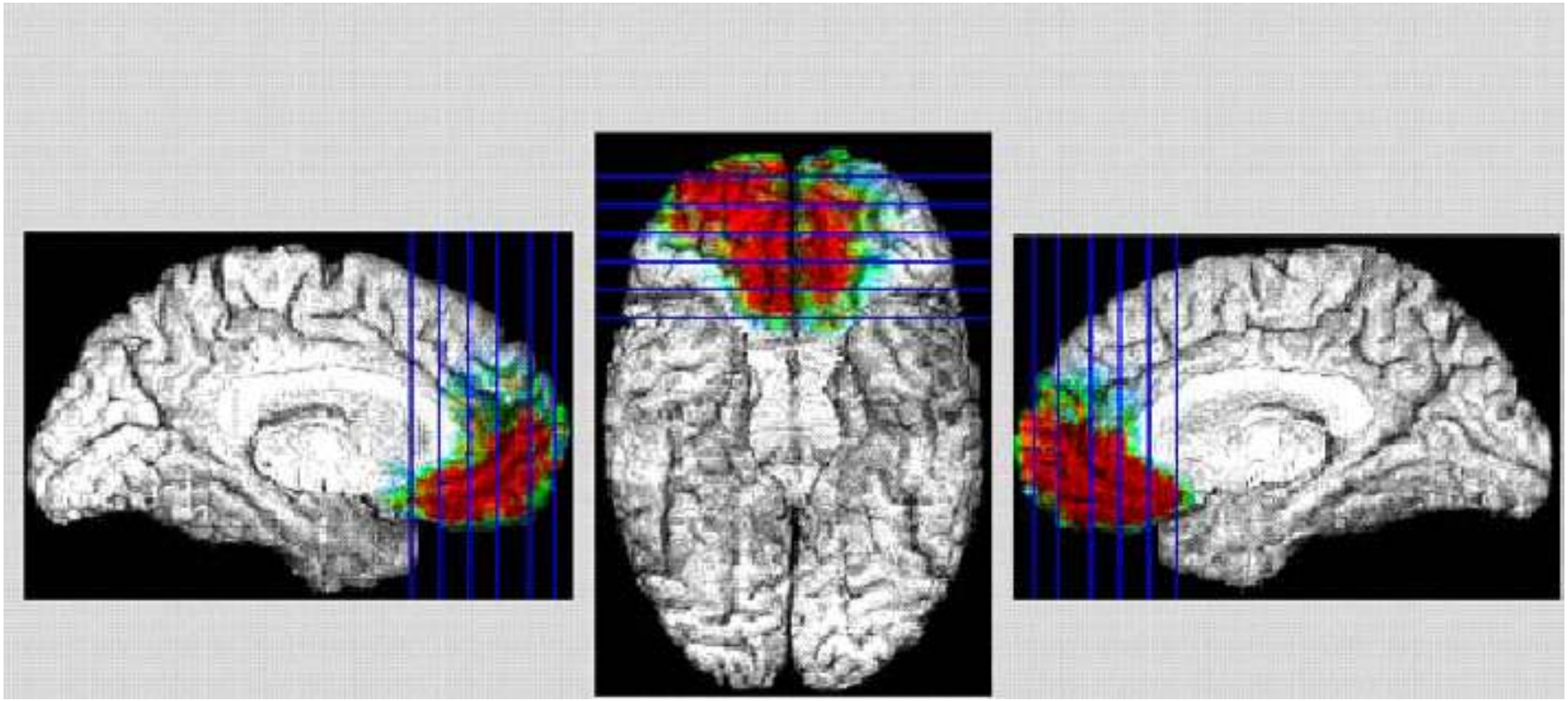


OFC

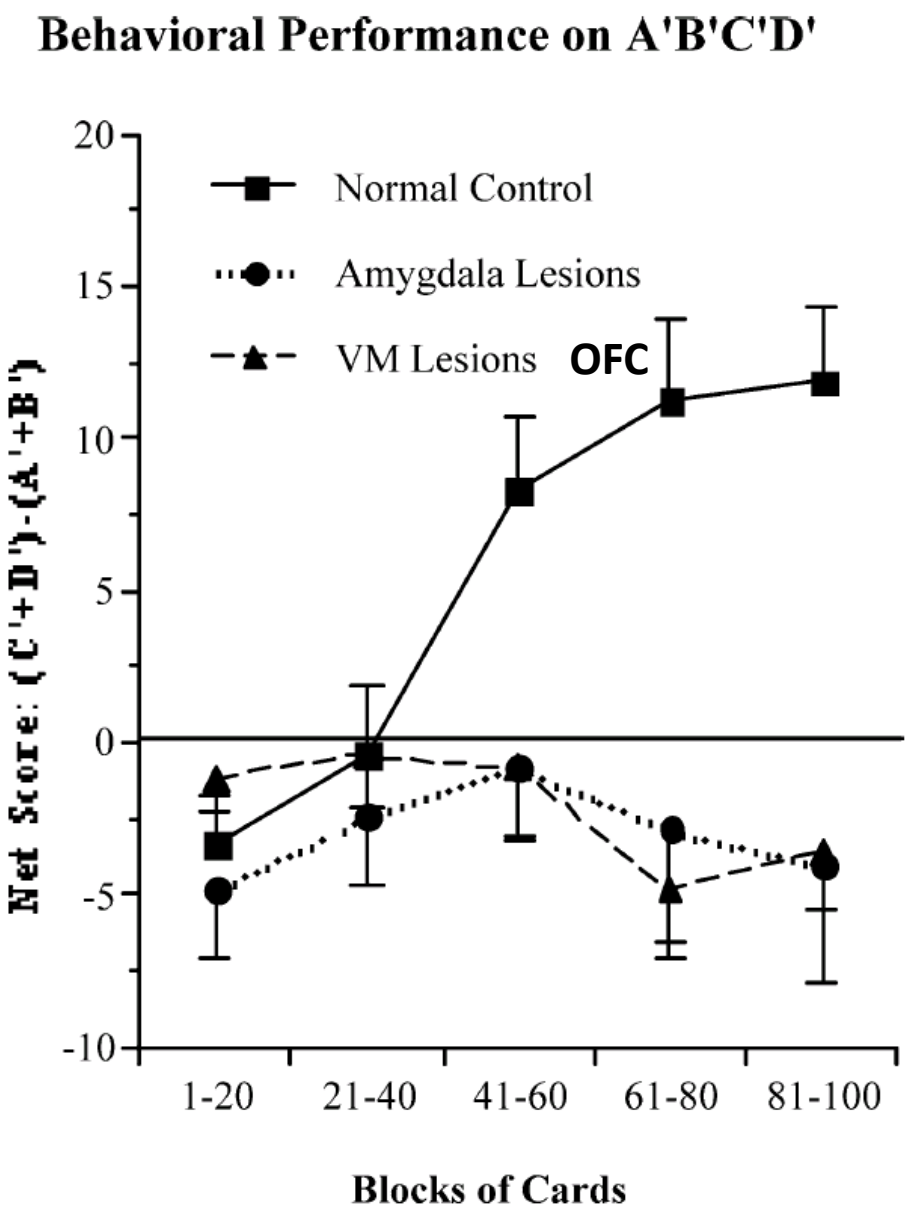
Basten et al 2010 PNAS

?

Antonio Damasio's patients:



Orbitofrontal / ventromedial prefrontal cortex



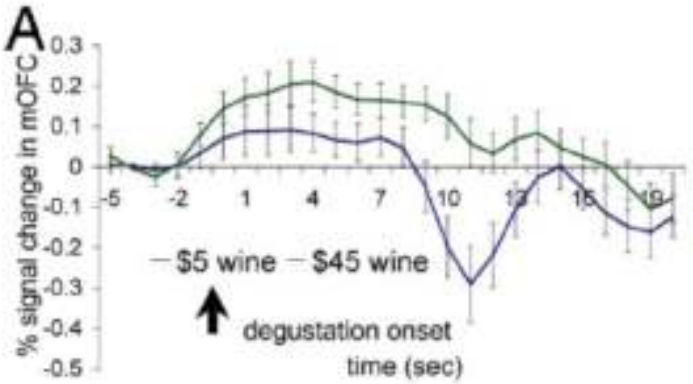
decks of cards (***A*** and ***B***) yield high immediate gain but larger future loss, i.e. long term loss (disadvantageous decks)

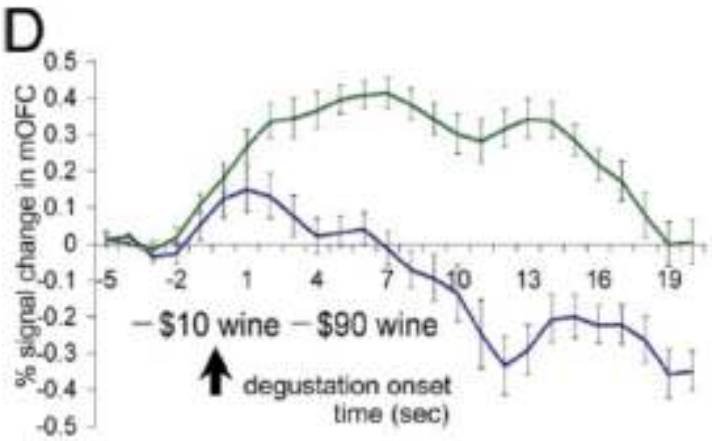
decks (***C*** and ***D***) yield lower immediate gain but a smaller future loss, i.e. a long term gain (advantageous decks).

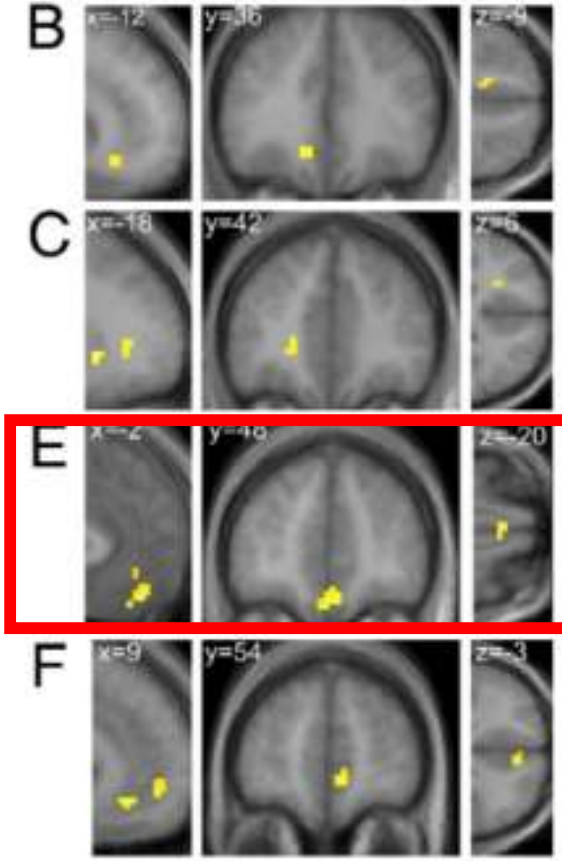
Bechara et al. 1997

12.0 €

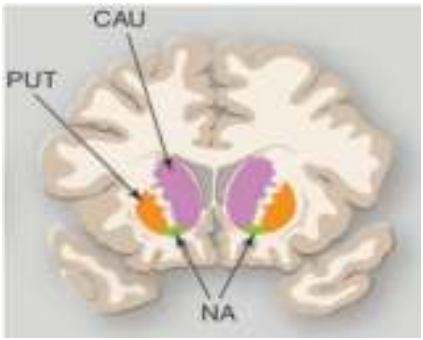
?


A
% signal change in mOFC
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
-5
-2
1
4
7
10
13
16
19
$5 wine
$45 wine
degustation onset
time (sec)

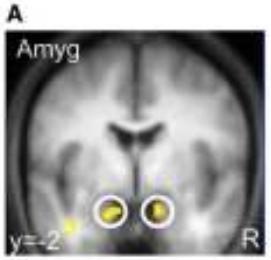

D
% signal change in mOFC
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
-5
-2
1
4
7
10
13
16
19
$10 wine
$90 wine
degustation onset
time (sec)


B
C
E
F
x=12
y=36
x=-18
y=42
x=9
y=54
z=3
z=20

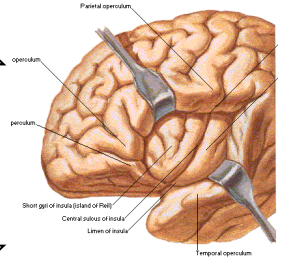
Wine 2



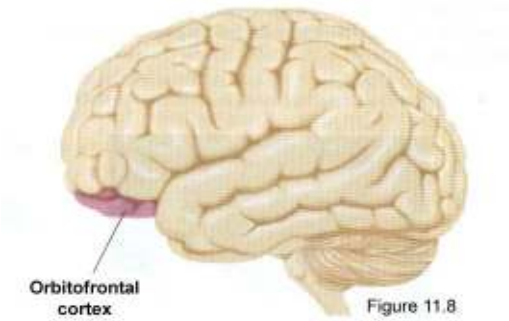
Nucleus accumbens (NAc) – subjective value / anticipated gain magnitude. Risk-seeking.



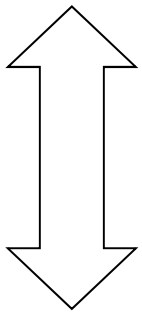
Amygdala – costs estimation, rigid learning & framing.

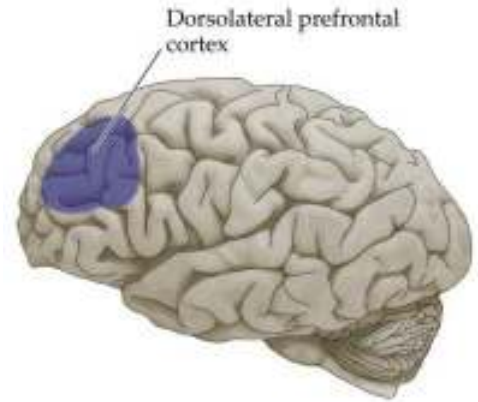


Insula – emotional body response & risk evaluation.



Orbitofrontal cortex (OFC) – compares / integrates multiple information regarding the reward outcome, fast learning.





Dorsolateral prefrontal cortex (DLPFC) – cognitive control & planning.

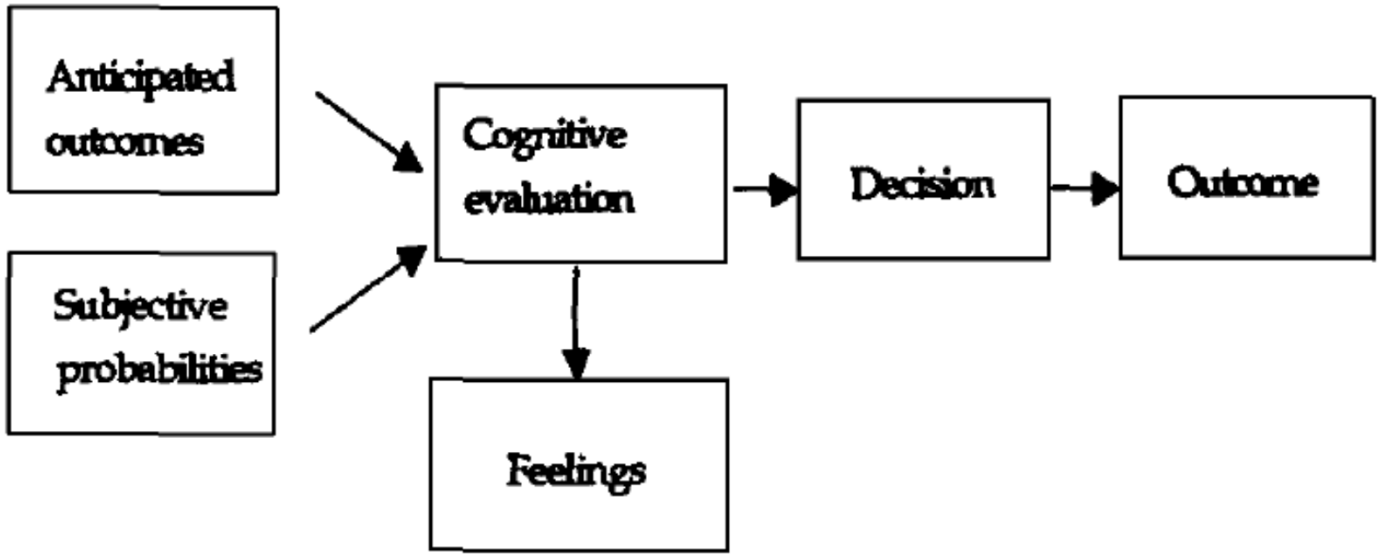
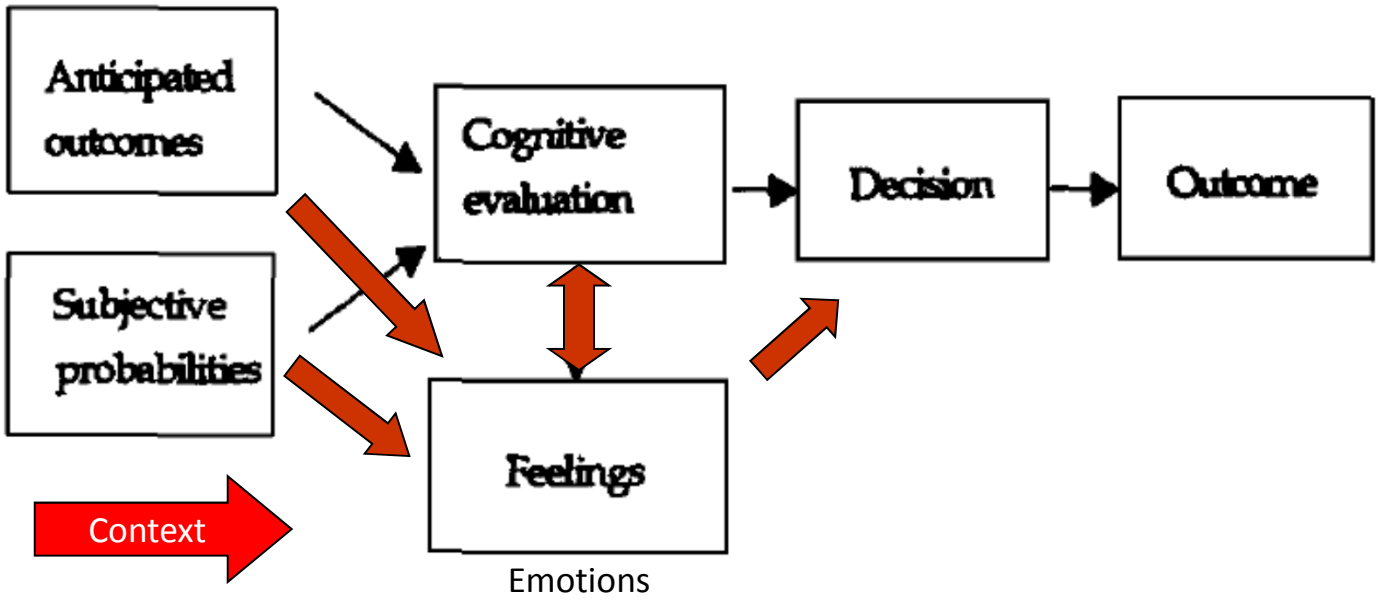


Figure 1. Consequentialist perspective.

G. Loewenstein et al., 2001

~ Emotions are states elicited by stimuli with subjective values (utility≠ 0)

Utility is a component of emotion. Valuation process is normally emotional.

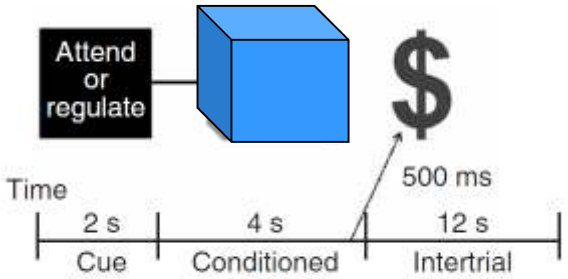


(a) feelings can arise without cognitive mediation (probabilities, outcomes, and other factors can directly give rise to feelings)

(b) the impact of cognitive evaluations on decisions (behavior) is mediated, at least in part, by affective responses (cognitive evaluation gives rise to feelings that in turn affect behavior).

G. Loewenstein et al., 2001

Self-regulation



- Attend to the stimulus (that is, ‘‘think of the meaning of the blue square, such as a potential reward’’)

or

- Regulate emotional response to the stimulus (that is, ‘‘think of something blue in nature that calms you down, such as the ocean’’).

Delgado et al., 2008

CS-

CS+

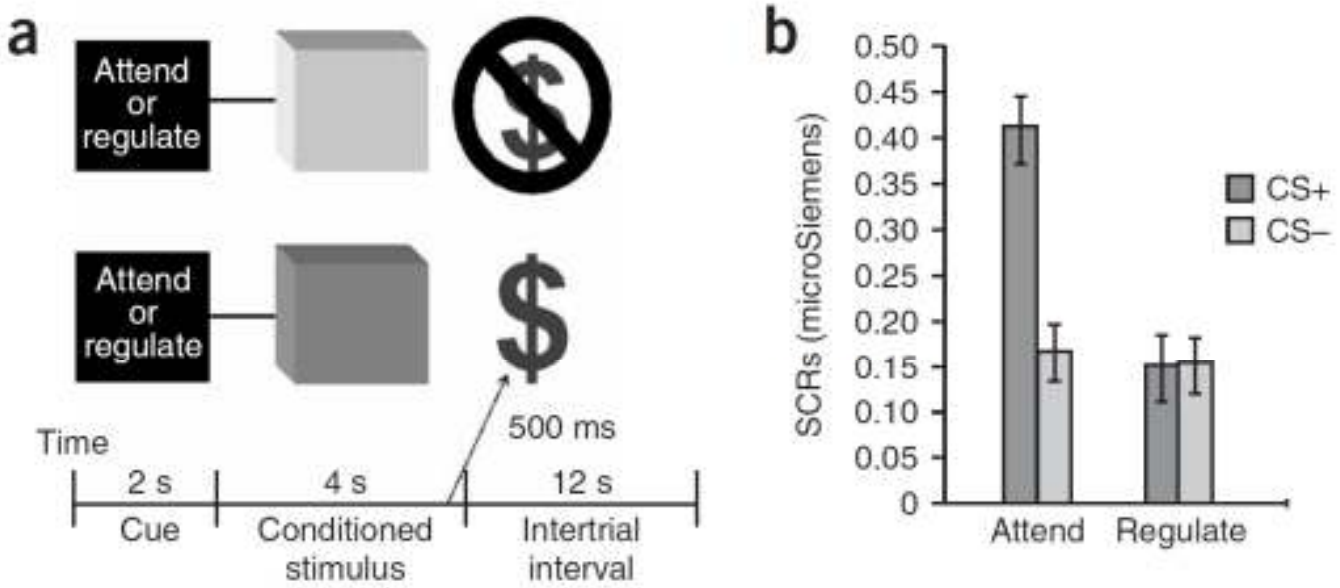
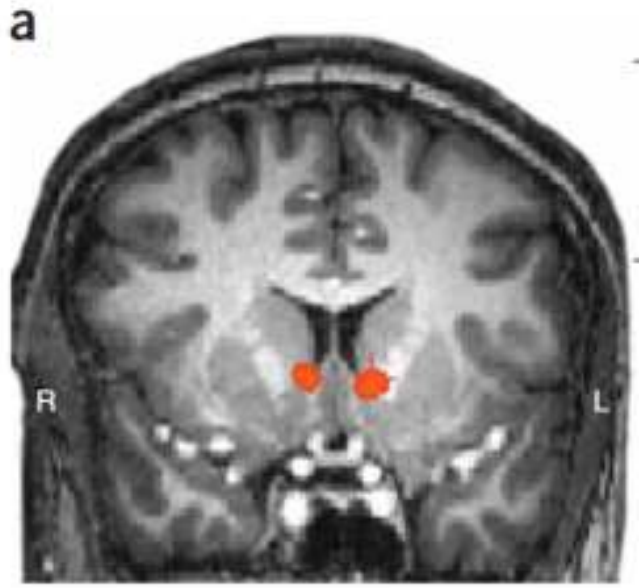
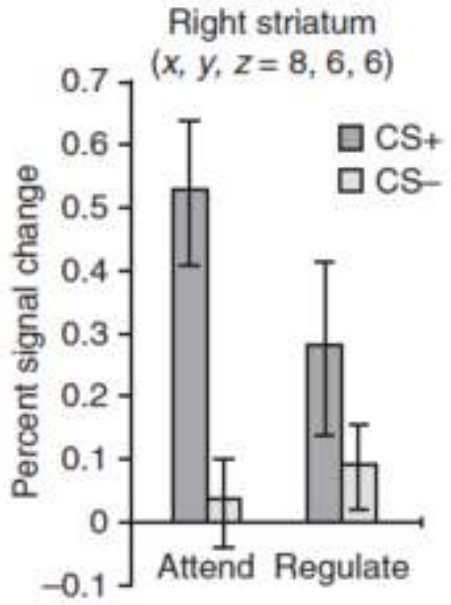
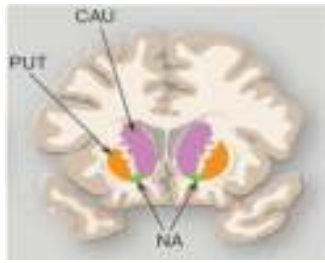


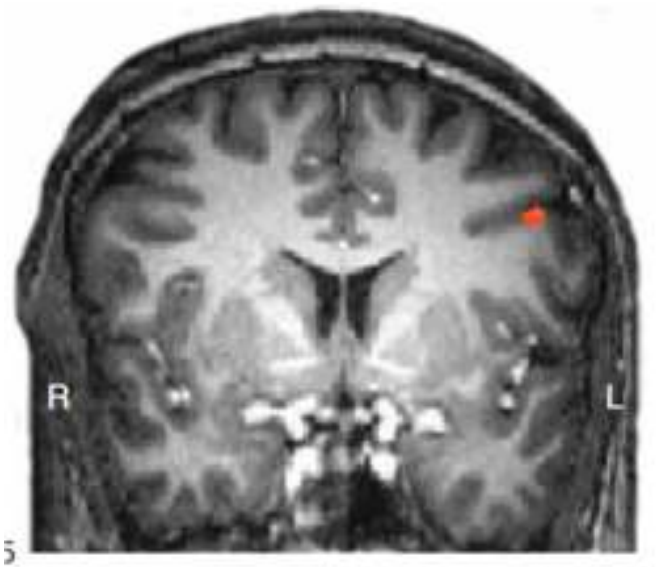
Figure 1 Depiction of task-related events and behavioral results. (**a**) Participants were presented with two conditioned stimuli (CS, colored squares depicted in figure as dark and light gray squares). The CS+ trial (dark gray) predicted a potential monetary reward ($4.00), whereas the CS– trial (light gray) predicted no monetary reward ($0). Prior to conditioned stimuli onset, the cues 'Attend' or 'Regulate' served as instructions for that trial. (**b**) SCRs from 15 participants showing an interaction between type of conditioned stimulus (CS+, CS–) and type of instruction (attend, regulate; ± s.e.m.).

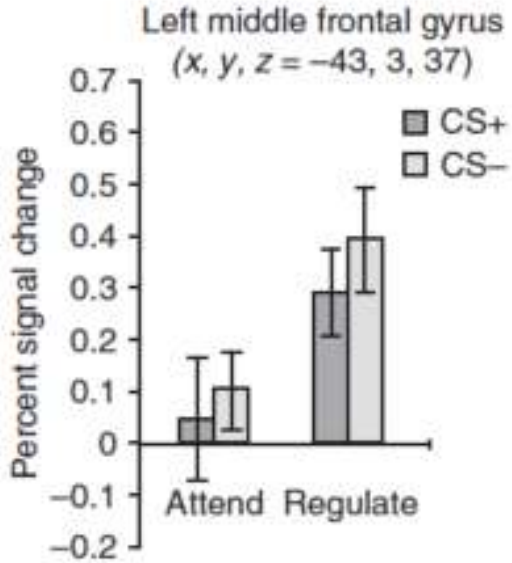
Delgado et al., 2008

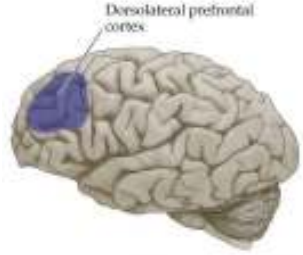












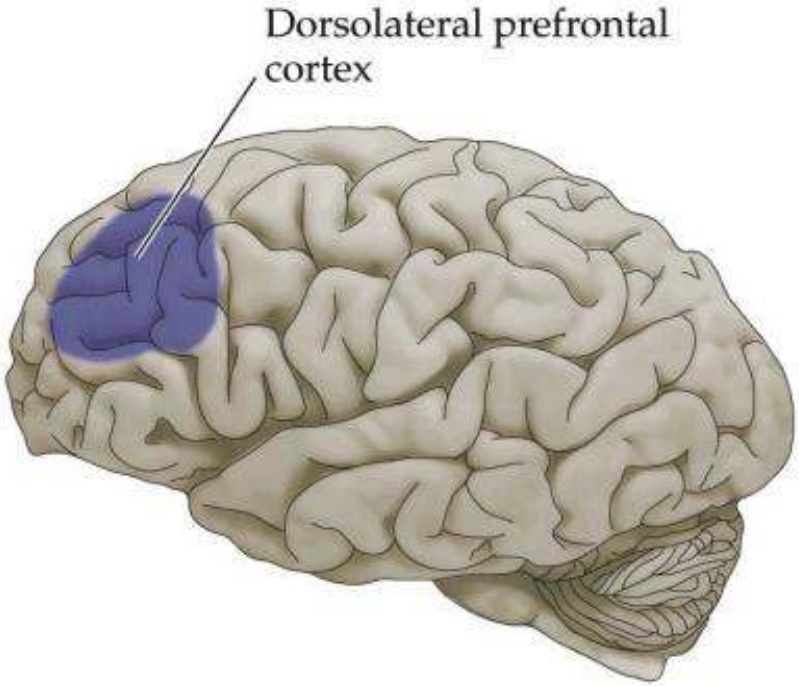
Delgado et al., 2008

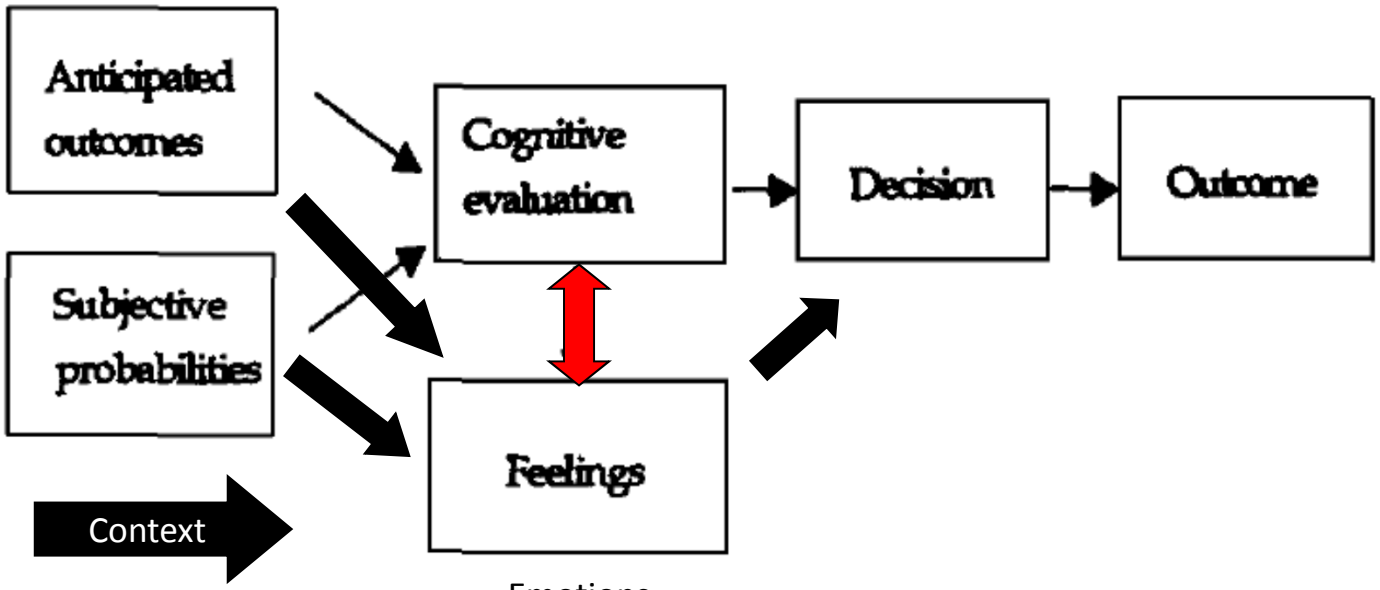
Summary

- An attenuation in both the physiological (skin conductance) and neural correlates (striatum) of reward expectation was observed as participants engaged in emotion regulation.

- The self-regulation (regulate versus attend trials) activated the dorsolateral prefrontal cortex (DLPFC).

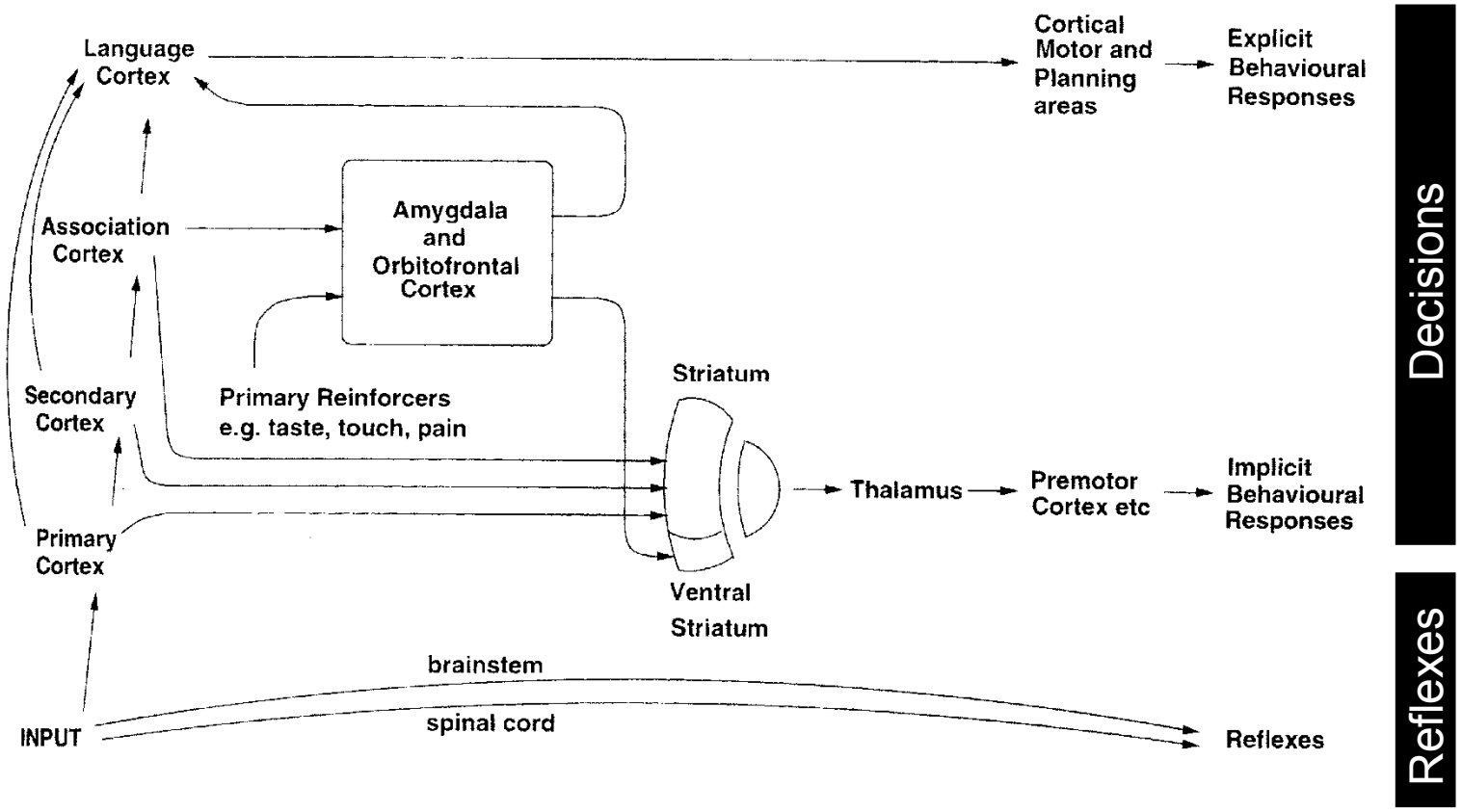
Delgado et al., 2008


Dorsolateral prefrontal
cortex



G. Loewenstein et al., 2001

Dual routes to action (decisions)



E. Rolls

Kahneman and Frederick (2002)

✓A bat and a ball cost $1.10 in total.

✓The bat costs $1 more than the ball.

✓How much does the ball cost?”

$X^{ball} + (X + \$1)^{bat} = \$1.10$

$2X = \$0.10$

$X = \$0.05$

Almost everyone reports an initial tendency to answer “10 cents” because the sum $1.10 separates naturally into $1 and 10 cents and because 10 cents is about the right magnitude:

Fifty percent (47/93) of Princeton students and 56% (164/293) of students at the University of Michigan gave the wrong answer.

Process and Content in Two Cognitive Systems

	PERCEPTION	INTUITION SYSTEM 1	REASONING SYSTEM 2
PROCESS	Fast Parallel Automatic Effortless Associative Slow-learning Emotional		Slow Serial Controlled Effortful Rule-governed Flexible Neutral
CONTENT	Percepts Current stimulation Stimulus-bound	Conceptual representations Past, Present and Future Can be evoked by language	

Daniel Kahneman September 2003 • American Psychologist

Table 1 Labels attached to dual-processes in the literature, aligned on the assumption of a generic dual-system theory

References	System 1	System 2
Fodor (1983, 2001)	Input modules	Higher cognition
Schneider & Schiffrin (1977)	Automatic	Controlled
Epstein (1994), Epstein & Pacini (1999)	Experiential	Rational
Chaiken (1980), Chen & Chaiken (1999)	Heuristic	Systematic
Reber (1993), Evans & Over (1996)	Implicit/tacit	Explicit
Evans (1989, 2006)	Heuristic	Analytic
Sloman (1996), Smith & DeCoster (2000)	Associative	Rule based
Hammond (1996)	Intuitive	Analytic
Stanovich (1999, 2004)	System 1 (TASS)	System 2 (Analytic)
Nisbett et al. (2001)	Holistic	Analytic
Wilson (2002)	Adaptive unconscious	Conscious
Lieberman (2003)	Reflexive	Reflective
Toates (2006)	Stimulus bound	Higher order
Strack & Deustch (2004)	Impulsive	Reflective

Jonathan St. B. T. Evans

Annu. Rev. Psychol. 2008. 59:255–78

System 1/System 2

- The operations of System 1 are typically fast, automatic, effortless, associative, implicit and often emotionally charged; and are difficult to control or modify.
- The operations of System 2 are slower, serial, effortful, more likely to be consciously monitored and deliberately controlled; relatively flexible and potentially superior.
- As in several dual-process models, one of the functions of System 2 is to monitor the quality of behavior.

On Making the Right Choice: The Deliberation-Without-Attention Effect

Ap Dijksterhuis,* Maarten W. Bos, Loran F. Nordgren, Rick B. van Baaren

Contrary to conventional wisdom, it is not always advantageous to engage in thorough conscious deliberation before choosing. On the basis of recent insights into the characteristics of conscious and unconscious thought, we tested the hypothesis that simple choices (such as between different towels or different sets of oven mitts) indeed produce better results after conscious thought, but that choices in complex matters (such as between different houses or different cars) should be left to unconscious thought. Named the "deliberation-without-attention" hypothesis, it was confirmed in four studies on consumer choice, both in the laboratory as well as among actual shoppers, that purchases of complex products were viewed more favorably when decisions had been made in the absence of attentive deliberation.

SCIENCE VOL 311 17 FEBRUARY 2006

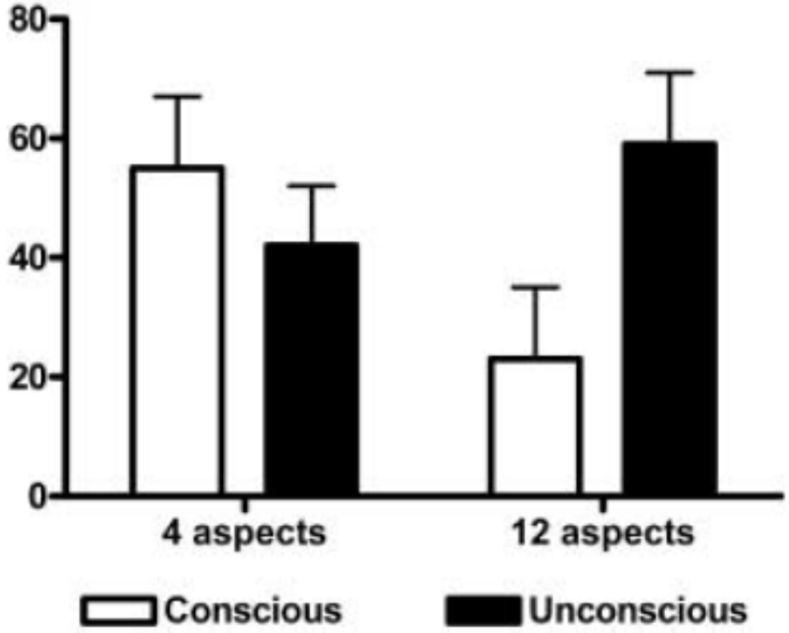
All participants read information about four hypothetical cars.

- 4 attributes (simple)
- or 12 attributes (complex).

The attributes were either positive or negative.

Conscious thought condition – participants have to think about the cars for 4 min before they chose their favourite car.

Unconscious thought condition – participants were distracted for 4 min (they solved anagrams) and were told that after the period of distraction they would be asked to choose the best car.



The percentages of participants who chose the best car

Dijksterhuis et al 2006

At the IKEA (complex products) or Bijenkorf (simple products) exit, shoppers were asked the following questions:

- What did you buy?
- How expensive was it?
- Did you know the product before you went on the shopping trip?
- How much did you think about the product between seeing it for the first time and buying it?

A few weeks later:

- (over the phone) How satisfied they were with their purchases?

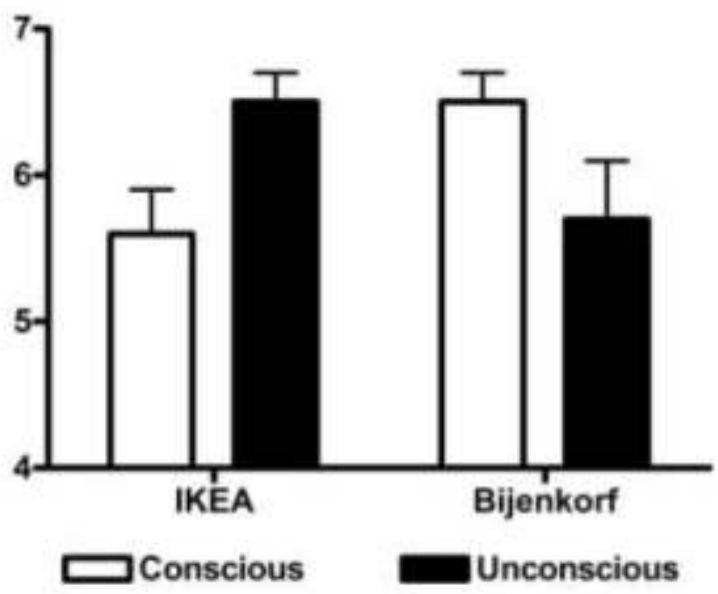
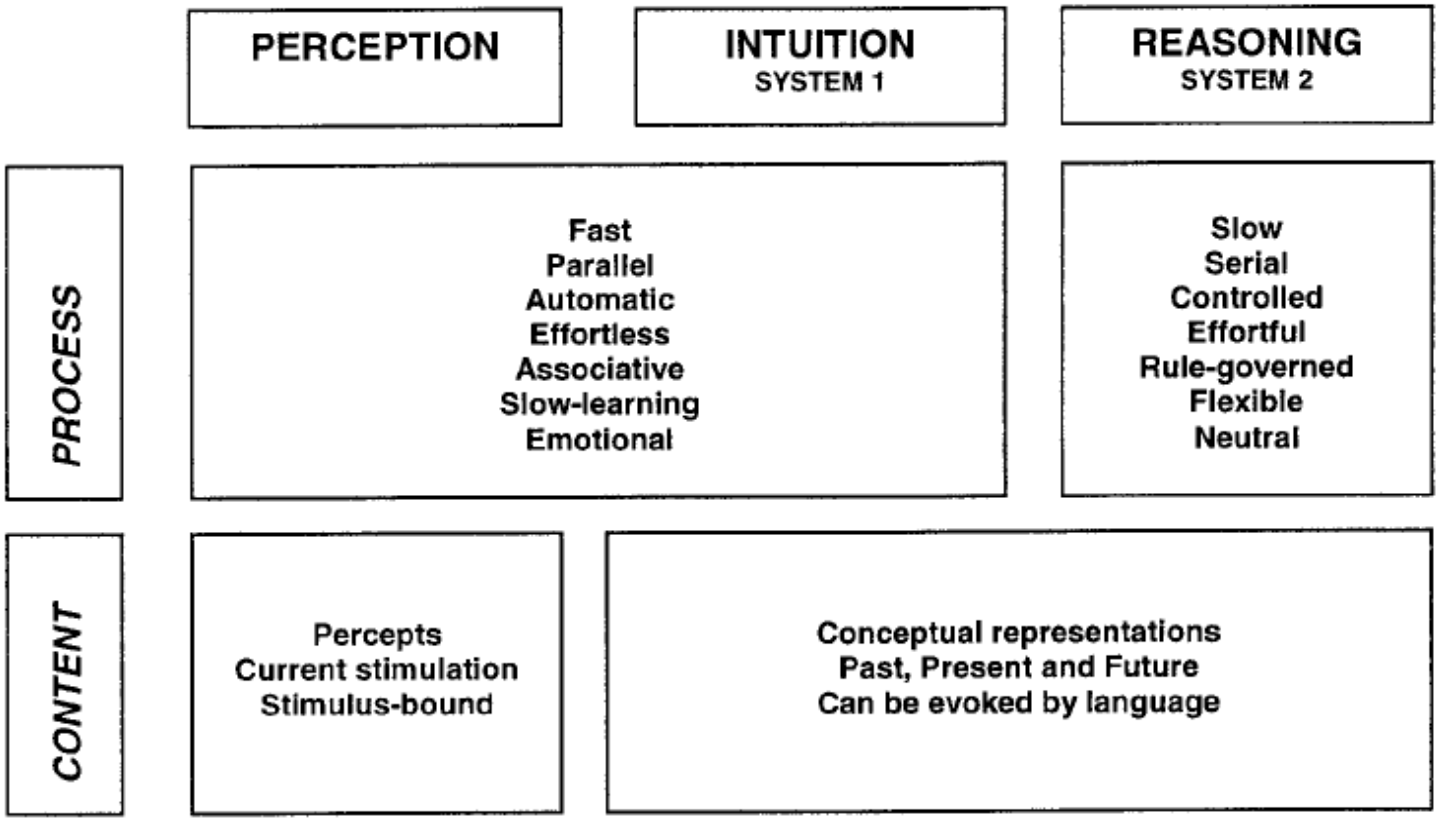


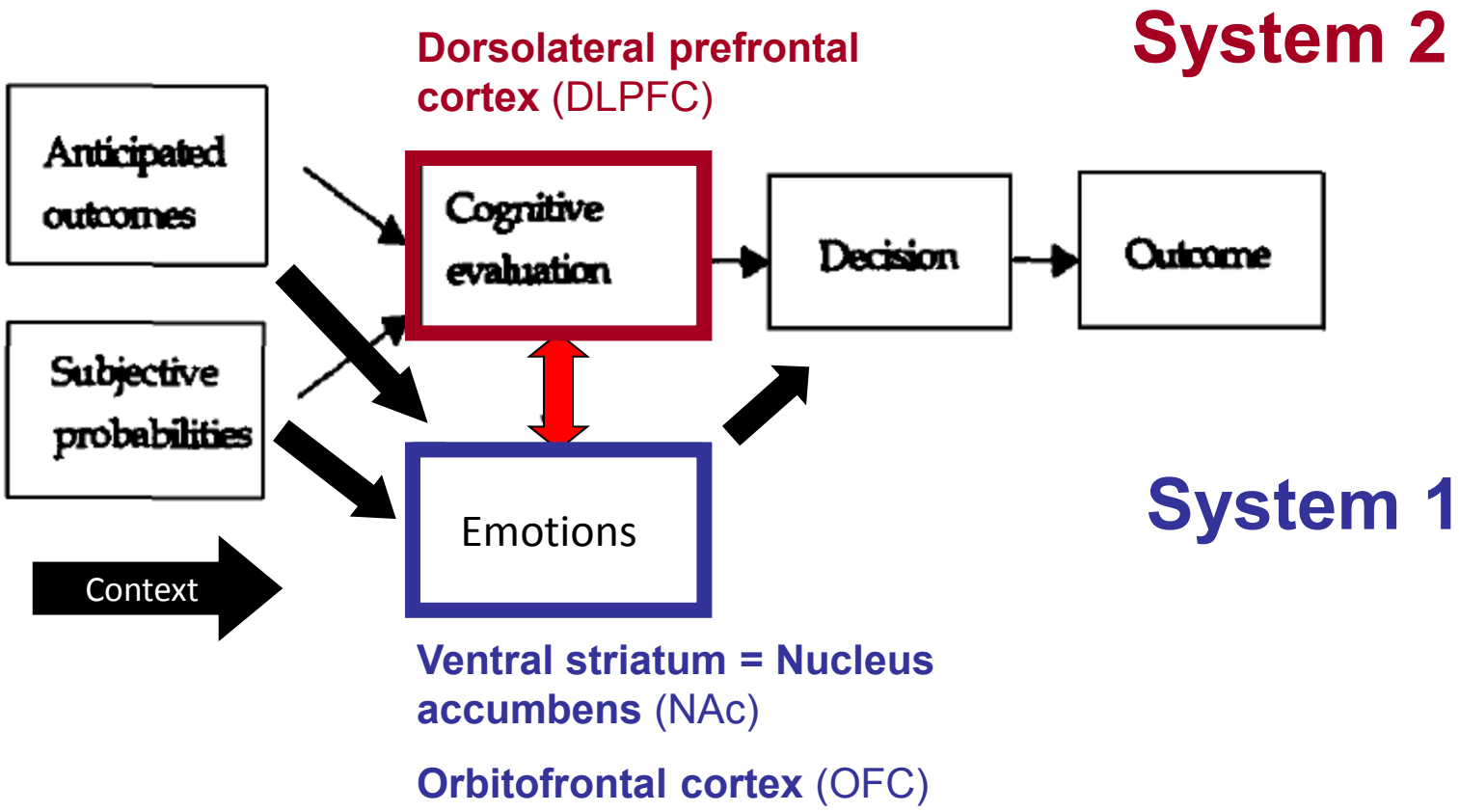
Fig. 4. Postchoice satisfaction of IKEA ($n = 27$) and Bijenkorf ($n = 27$) shoppers as a function of mode of thought. Error bars represent the standard error.

Dijksterhuis et al 2006

Process and Content in Two Cognitive Systems



Daniel Kahneman September 2003 • American Psychologist



G. Loewenstein et al., 2001

Example N1: Instruction

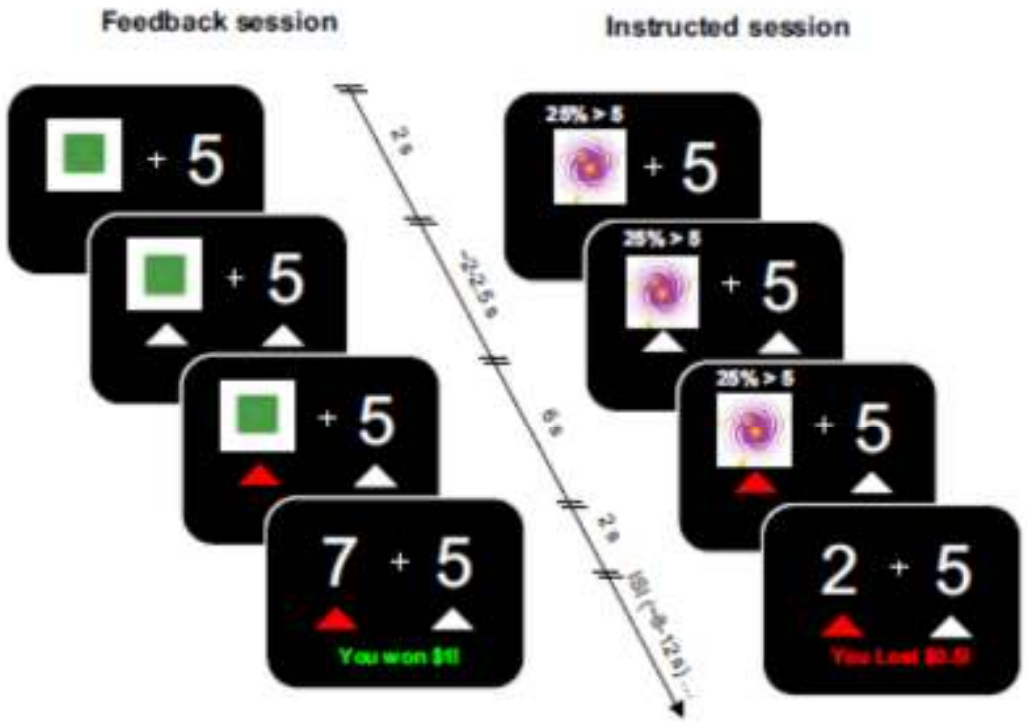


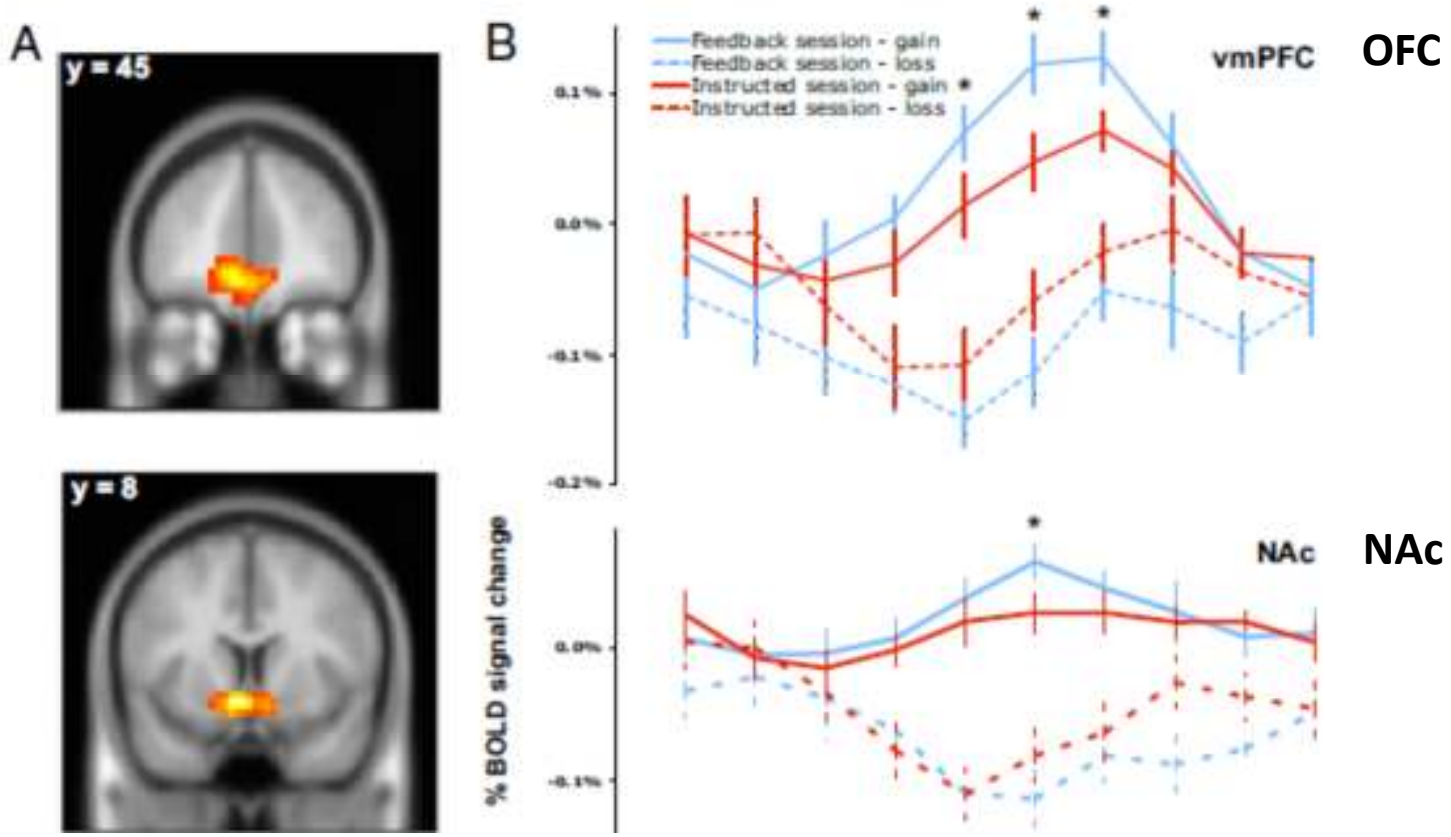
Fig. 1. Experimental design. In feedback session, the number 5 and a specific visual cue were displayed on the screen. In the instructed session, additional probability information was displayed on top of the visual cue.

Will number be greater or less than 5 (value $\in$ {1, 2, 3, 4, 6, 7, 8, 9})?

Four different visual cues represented different probabilities (P $\in$ {25, 50, 75, 100%}) of the number underneath the cue being greater than 5 were presented to participants.

Li et al 2010 PNAS

Outcomes



Li et al 2010 PNAS

Negative connectivity

Functional connectivity is defined as the correlation between different brain regions.

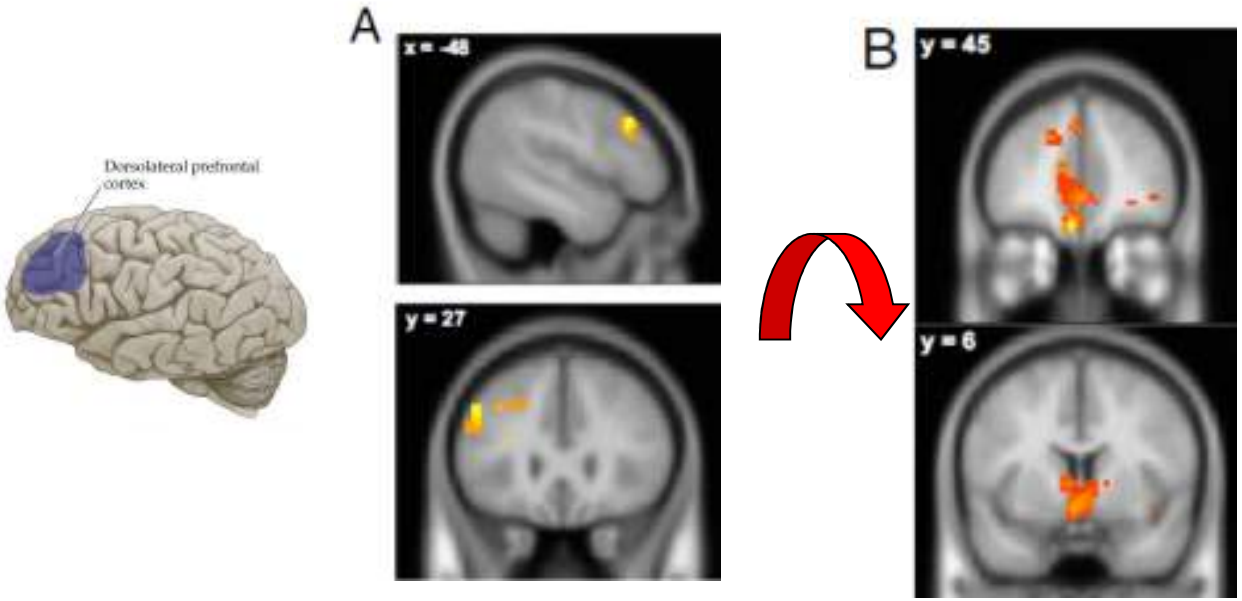


Fig. 5. Left DLPFC activity showed negative functional connectivity to brain structures related to reward valuation. (*A*) Left DLPFC showed relatively greater activation to monetary gains in the instructed than the feedback session ($P < 0.05$, corrected). (*B*) PPI analysis showing regions negatively correlated with the left DLPFC on win trials in the instructed session ($P < 0.05$, corrected) but not in the feedback session ($P < 0.01$, uncorrected) (*SI Appendix*, Fig. S2).

Summary

- Instructed knowledge diminishes valuation responses in the nucleus accumbens (ventral striatum) and ventromedial OFC.
- This decrease was functionally correlated with activation of the dorsolateral prefrontal cortex (DLPFC).
- These results suggest that the DLPFC dynamically adjusts valuation responses in “valuation” regions.

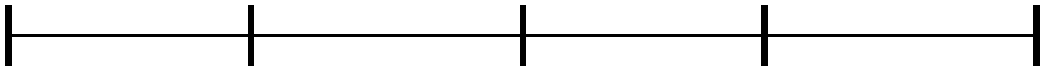
Example N3: Diet…

Subjects:
37 self reported dieters

Reference

Vs.

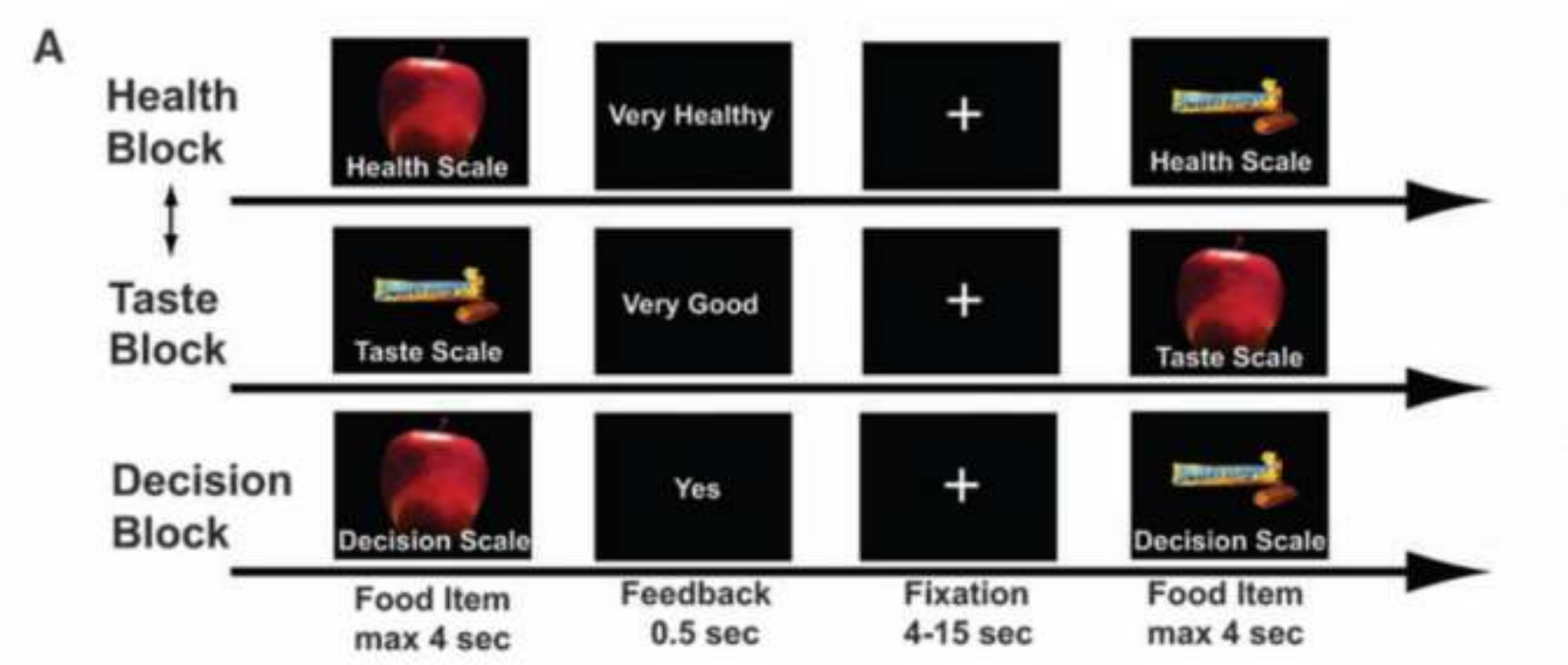
Would you eat this food at the end of the test?



Strong No Neutral Strong Yes

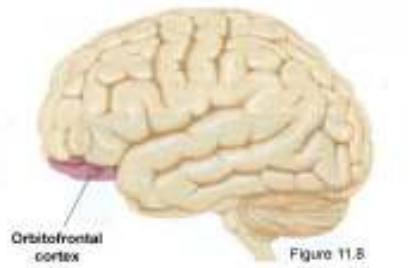
Hare et al 2009

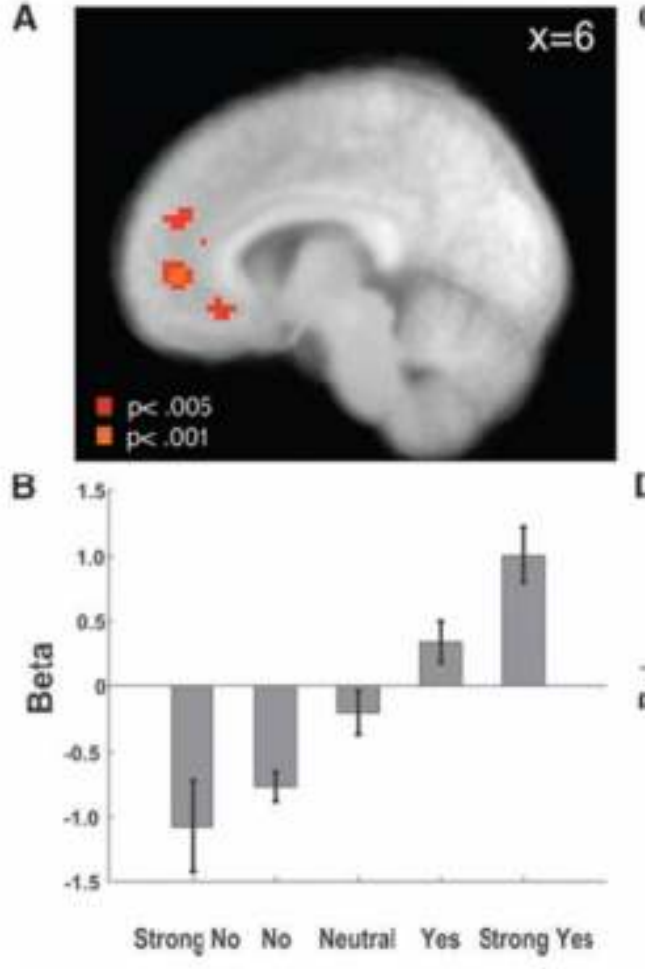
50 food items



Hare et al 2009

vmPFC (OFC) activity correlates with subjective values

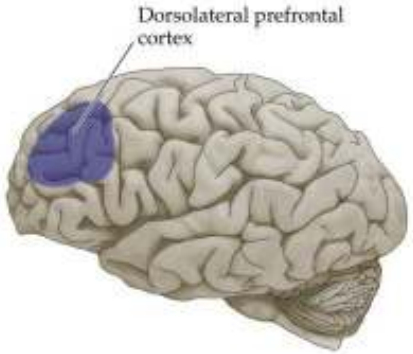


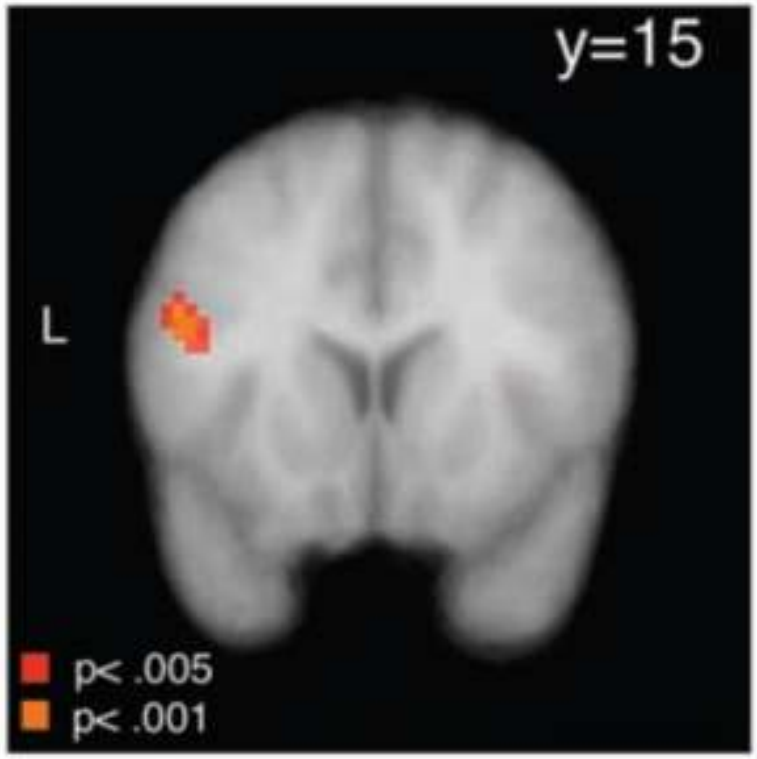


Regions of vmPFC (OFC) in which activity correlated with goal values across all participants and regardless of their degree of self-control

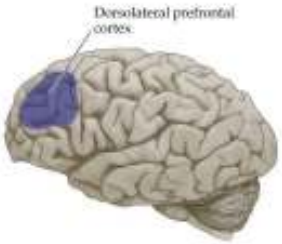
Hare et al 2009

SC - Successful self-controllers
NSC - Nonsuccessful self-controllers



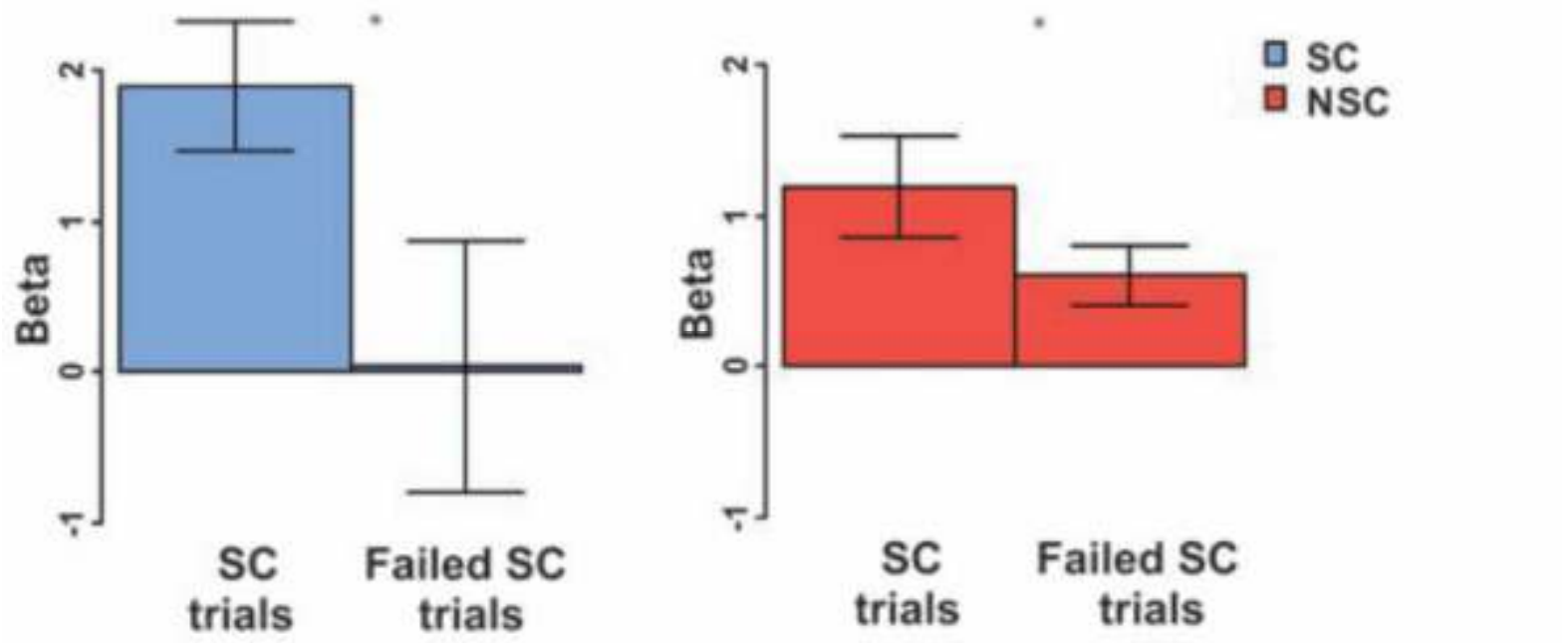


left DLPFC showed greater activity in successful self-control trials in the SC than the NSC group.



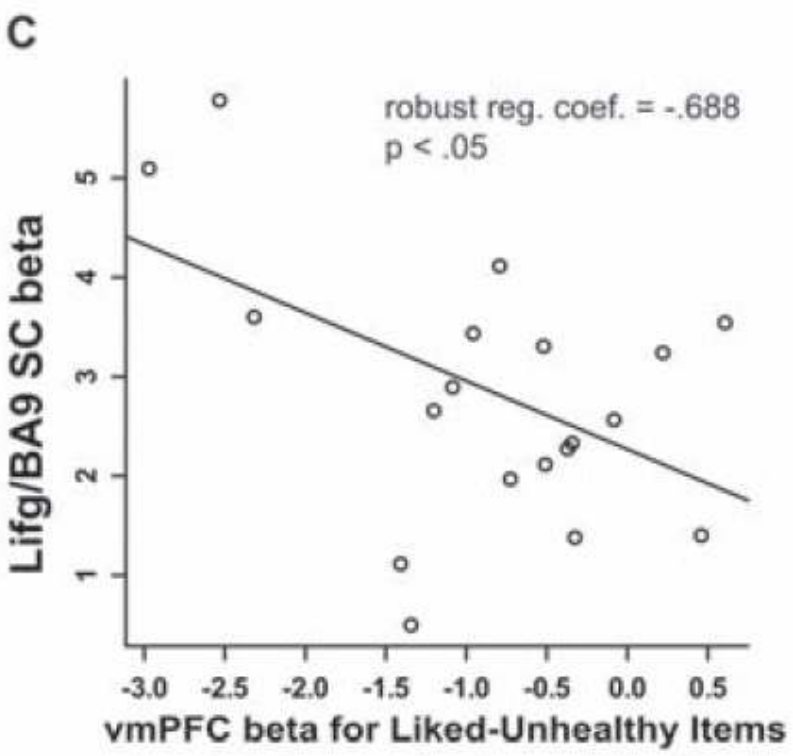
SC - Successful self-controllers

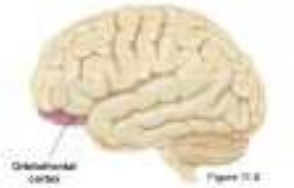
NSC - Nonsuccessful self-controllers



Both groups showed greater activity in DLPFC for successful versus failed self-control trials.

SC - Successful self-controllers





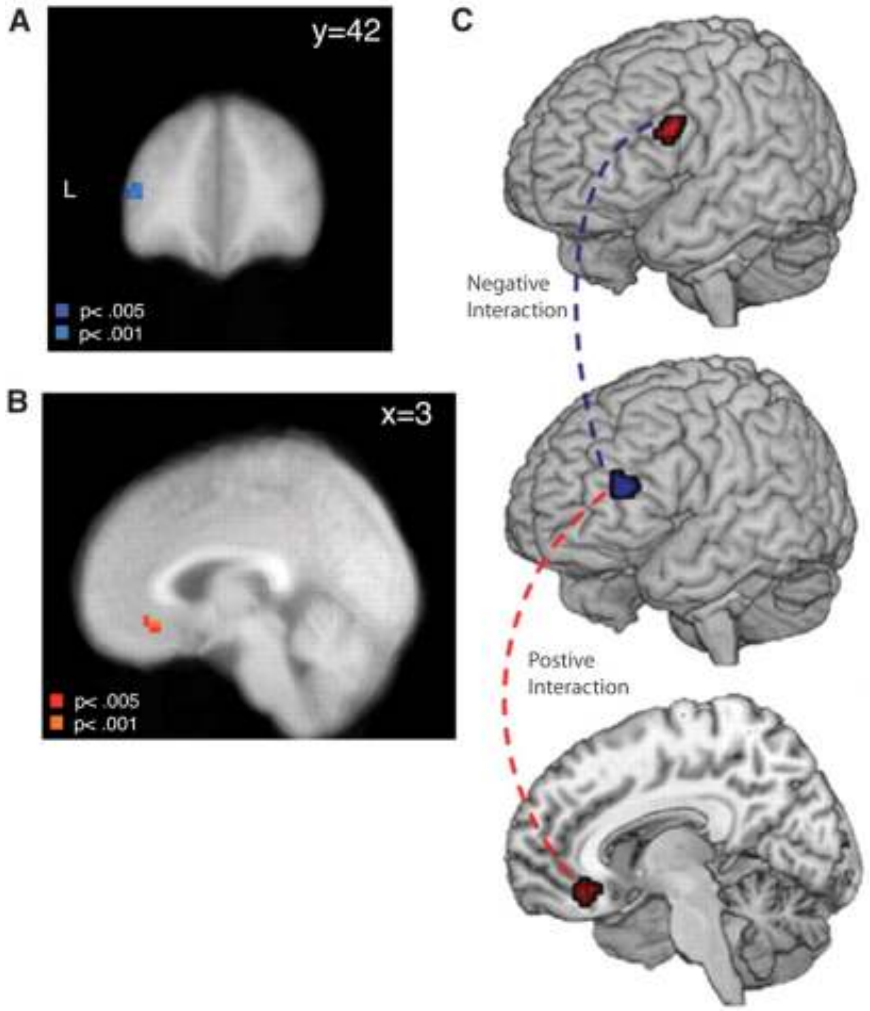
Activity in left DLPFC was negatively correlated with vmPFC activity in the SC group during trials in in which liked-but-unhealthy foods were avoided.

DLPFC (System 2) is functionally connected to vmPFC (OFC - System 1)

Diagram illustrates the path through which the left DLPFC might modulate activity in the vmPFC (OFC).

Blue lines - negative interactions.

Red lines - positive interactions.



Summary

- A common value signal is encoded in ventromedial prefrontal cortex (OFC).
- Exercising self-control involves the modulation of this value signal by dorsolateral prefrontal cortex (DLPFC).
- Activity in DLPFC increased when subjects exercised self-control and correlated with activity in vmPFC.

Example N3: Fairness

Ultimatum Game

Sum =100$

Split = 95:5$

Decision?

Two anonymous players

1st player divides a sum of money

2nd player can accept or reject this proposal.

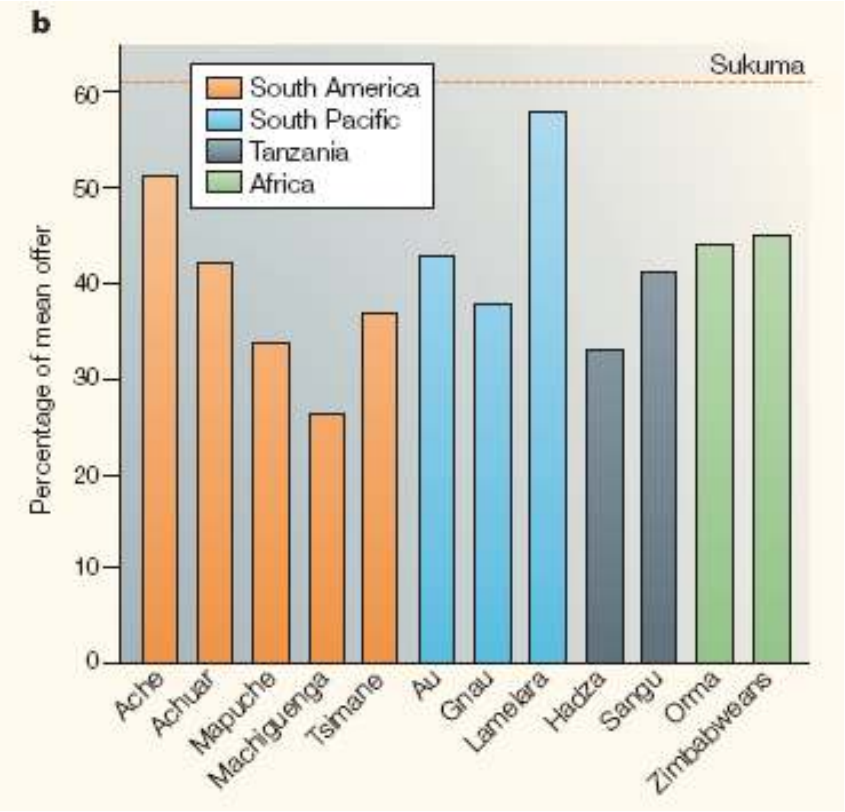
- If he/she rejects, neither player receives anything
- If he/she accepts, the money is split according to the proposal

Game is played only once, and anonymously - reciprocation is not an issue.

Player 2

-
- Many people reject low offers (less than 20%) in the game, even if stake levels are as high as a 3 months' income.

Player 1



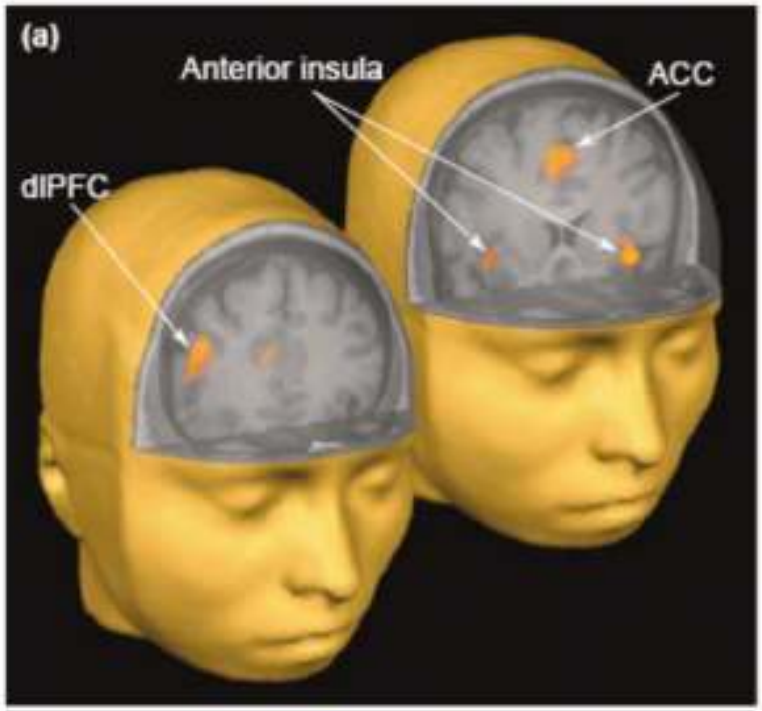
Average offers are typically around 50% of the total amount.

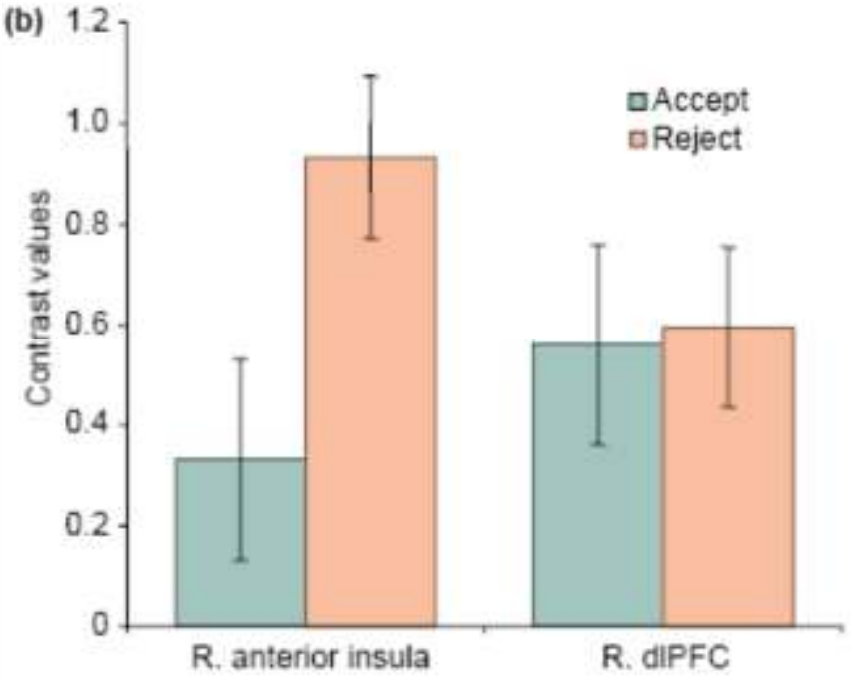
Study conducted in Tanzania, the more individualistic Pimbwe group made low offers in the Ultimatum Game, whereas the highly cooperative Sukuma group consistently made generous offers. Paciotti et all (2005).

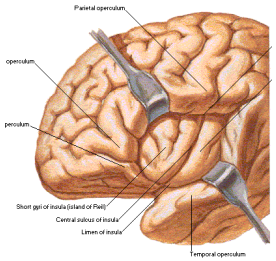
Hypothesis

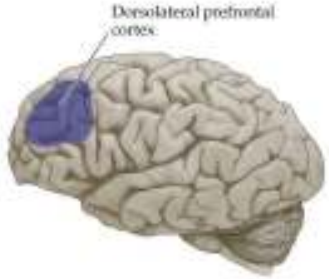
- Thus unfair offers induce a conflict in the responder:
  - between selfish motive ("it is economically rational to **accept any offer**")
  - and inequity aversions ("reject the offer because **it is unfair**").

An unfair offer in the Ultimatum Game leads to conflict between emotional, ‘reject’, and cognitive, ‘accept’, systems.

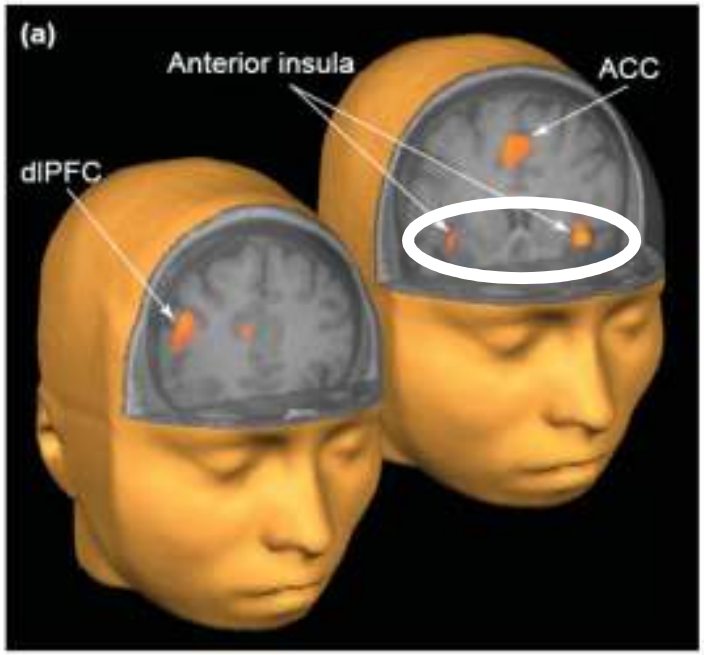


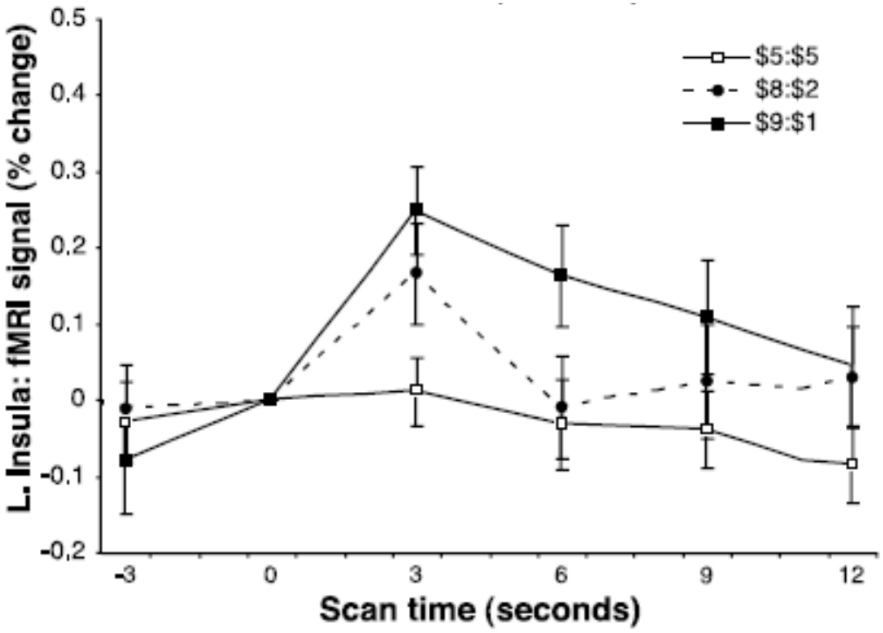


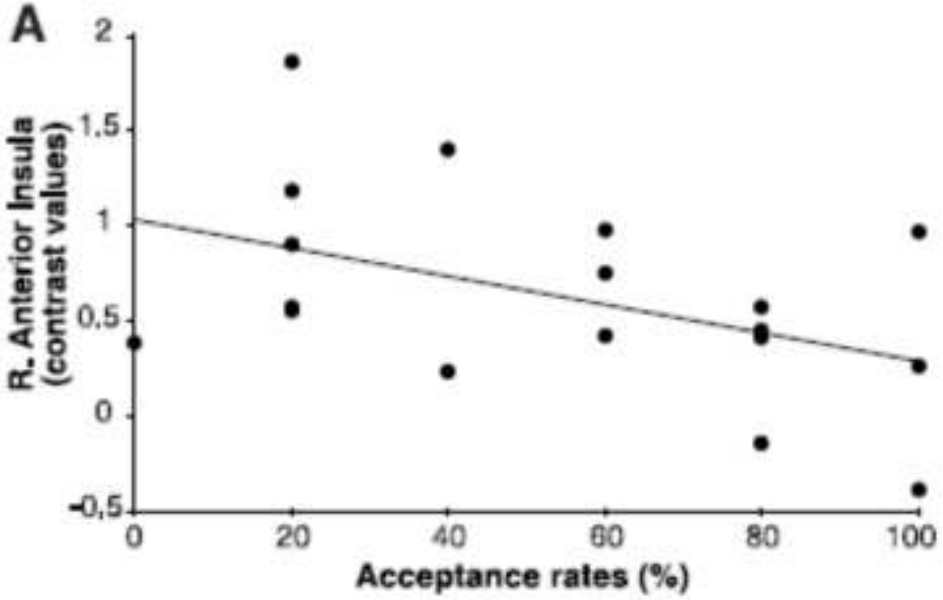




Sanfly et al 2003


(a)
Anterior insula
ACC
dlPFC


L. Insula: fMRI signal (% change)
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-3
0
3
6
9
12
Scan time (seconds)
$5:$5
$8:$2
$9:$1


A
R. Anterior Insula (contrast values)
2
1.5
1
0.5
0
-0.5
0
20
40
60
80
100
Acceptance rates (%)

Summary

The brain areas showing greatest activation for unfair offers:

- anterior insula (an area involved in negative emotions and disgust)
- dorsolateral prefrontal cortex (DLPFC, an area involved in cognitive self-control)
- cingulate cortex (an area involved in conflict monitoring).

TMS – Transcranial Magnetic Stimulation

TMS - rapidly changing magnetic fields (electromagnetic induction) induce weak electric currents in the brain, i.e. affect neurons.

fmri.uib.no

DLPFC - dorsolateral prefrontal cortex

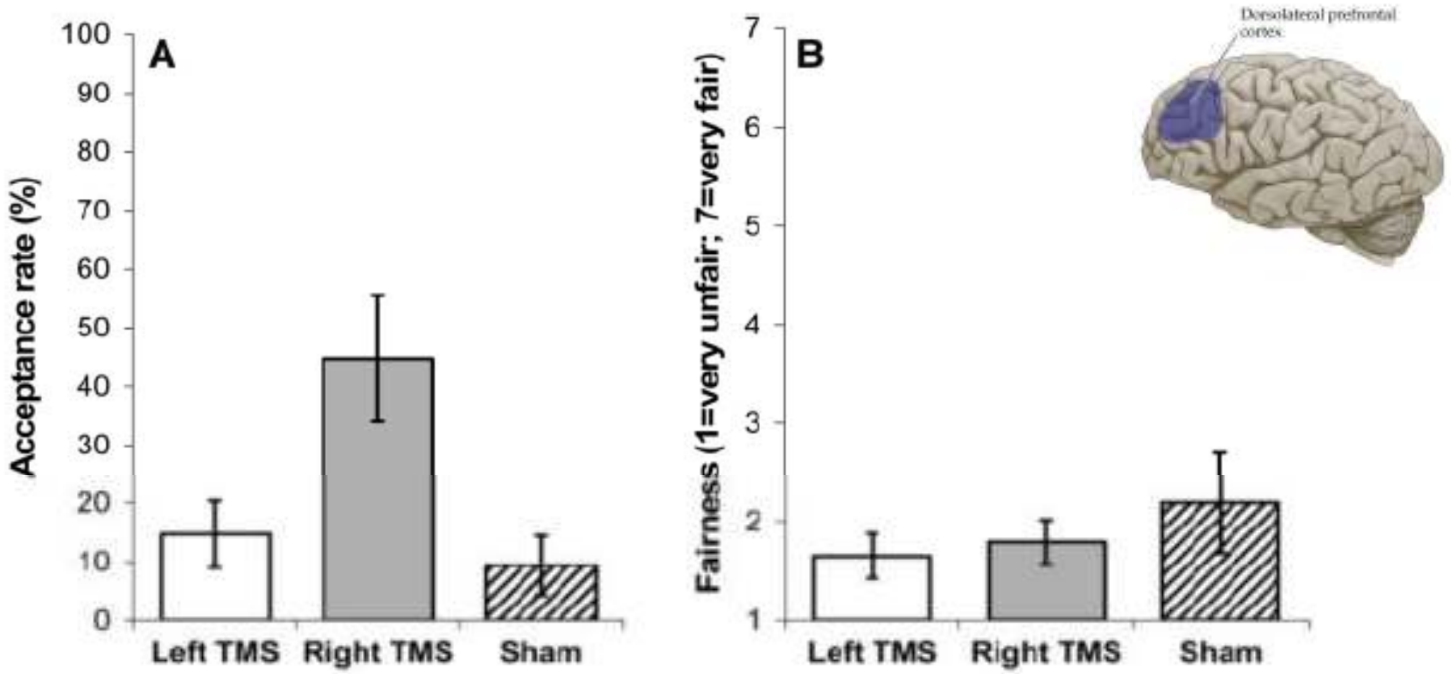


Fig. 1. Behavioral responses and fairness judgments (means ± SEM) related to the most unfair offer of CHF 4 in the human offer condition. (**A**) Acceptance rates across treatment groups. Subjects whose right DLPFC is disrupted exhibit a much higher acceptance rate than those in the other two treatment groups (Mann-Whitney *U* tests, two-tailed, $P < 0.05$). (**B**) Perceived unfairness across treatments (1 = very unfair; 7 = very fair). Subjects in all three treatment groups perceive an offer of 4 as very unfair, and there are no significant differences across groups.

Knoch et al 2006

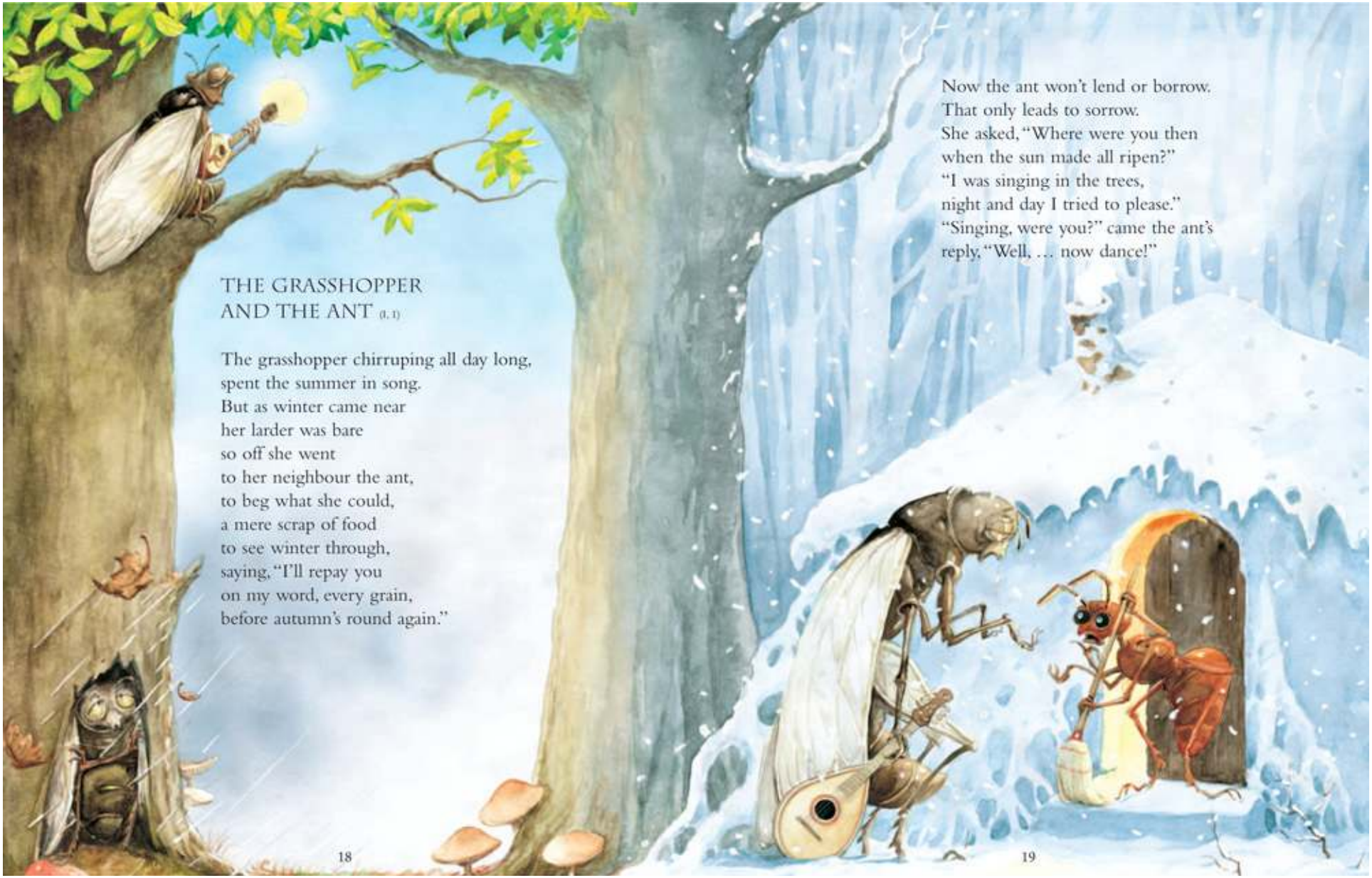
Summary

- TMS of the right DLPFC substantially reduces subjects' willingness to reject unfair offers, which suggests that subjects are less able to resist the economic temptation to accept.

- Right DLPFC plays a key role in the implementation of fairness-related behaviors.

- Interestingly, subjects still judged such offers as very unfair.

Example N4: Intertemporal choice

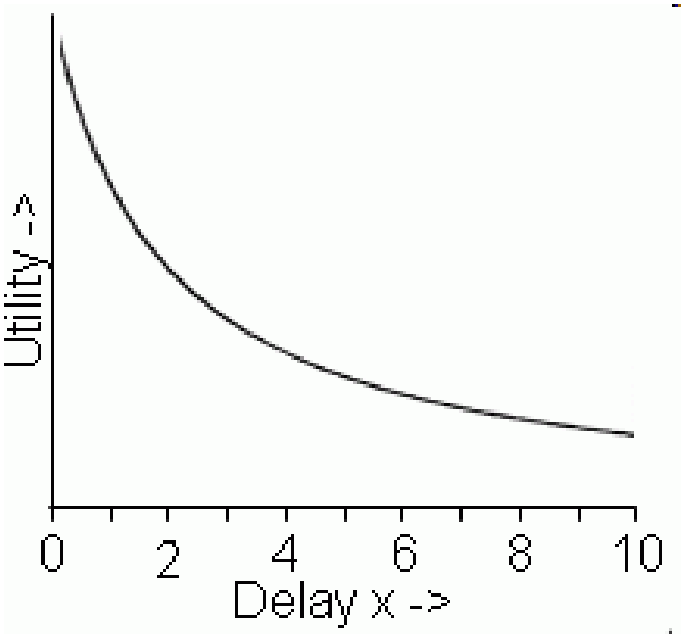


Intertemporal choice

"Temporal discounting" – the tendency to discount rewards which are distant in time.

There is a strong tendency to give greater value to rewards that can be obtained soon (a preference for immediate rewards vs. delayed rewards).

- €10 today and €11 tomorrow
- €10 in a year and €11 in a year and a day



Given a choice between small immediate reinforcers and large delayed ones, nonhuman animals usually show a preference for the former (e.g., Ainslie, 1974; Logue, 1995; Rachlin, 1995a; Rachlin & Green, 1972).

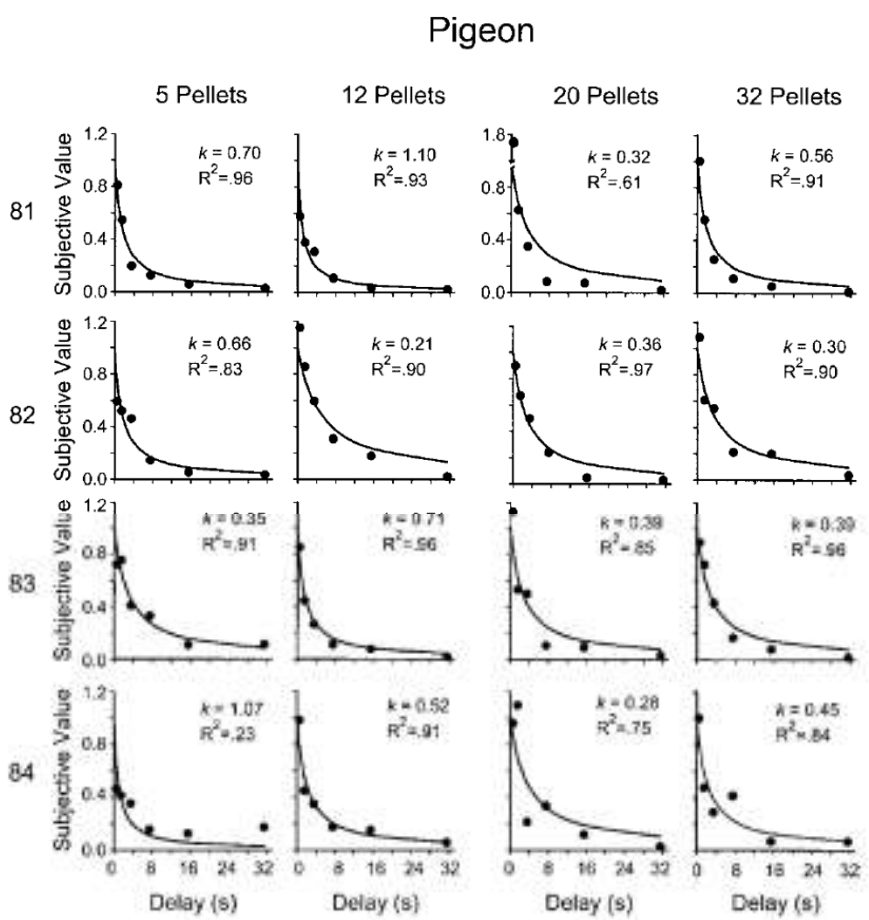


Fig. 1. Discounting functions for individual pigeons. Subjective value was calculated based on the number of pellets delivered immediately that was equivalent in value to the standard, delayed amount. So as to compare behavior in different amount conditions, subjective value is expressed as a proportion of the standard, delayed amount. Each curve represents the hyperbola (Equation 1) that best fit the individual data for each amount condition.

The adjusting-amount procedure accomplishes the same goal by adjusting the amount of the immediate reward, holding the amount of the larger reward and the delay until its receipt constant, until both the immediate and delayed rewards are equally likely to be chosen (Rachlin et al., 1991).

Green et al., 2004

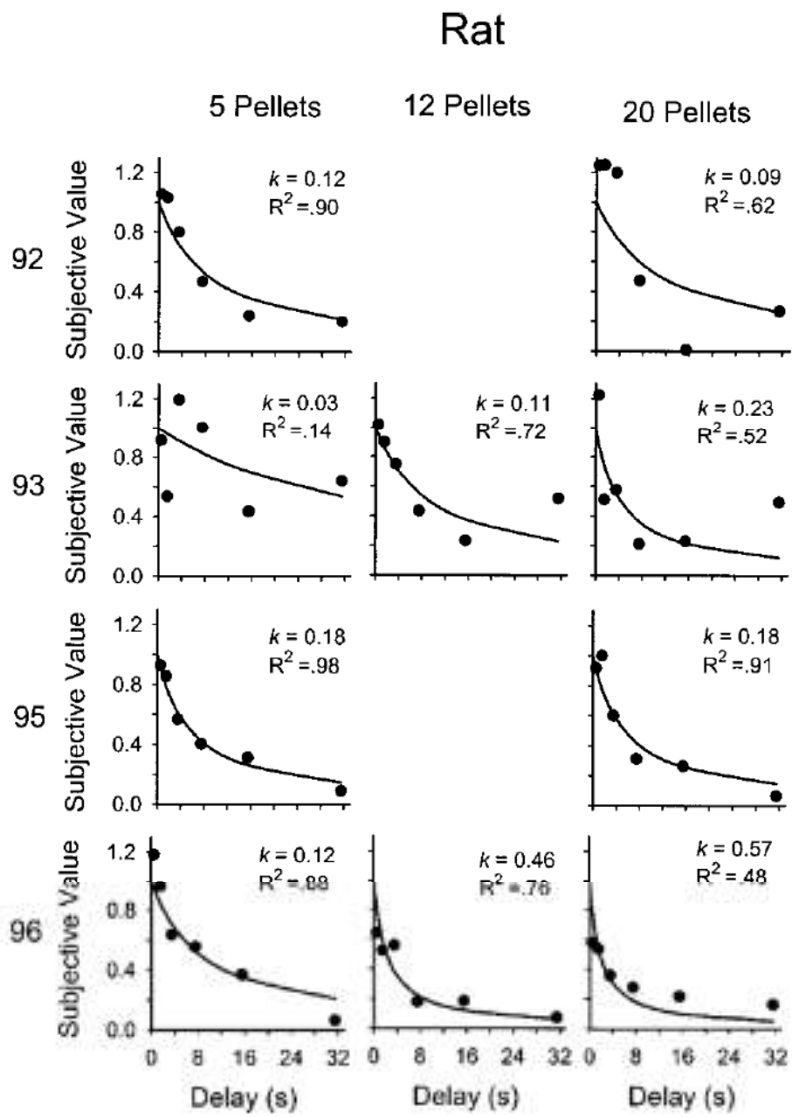


Fig. 2. Discounting functions for individual rats. Subjective value was calculated based on the number of pellets delivered immediately that was equivalent in value to the standard, delayed amount. So as to compare behavior in different amount conditions, subjective value is expressed as a proportion of the standard, delayed amount. Each curve represents the hyperbola (Equation 1) that best fit the individual data for each amount condition.

Green et al., 2004

Dual-processing hypothesis

The Dual-processing hypothesis could assume a tension between short-run (System 1) and long-run (System 2) preferences:

- the short-run preference favors immediate rewards and is less sensitive to future ones.
- the long-run preference is more able to trade off the advantages of payments at different points in time.

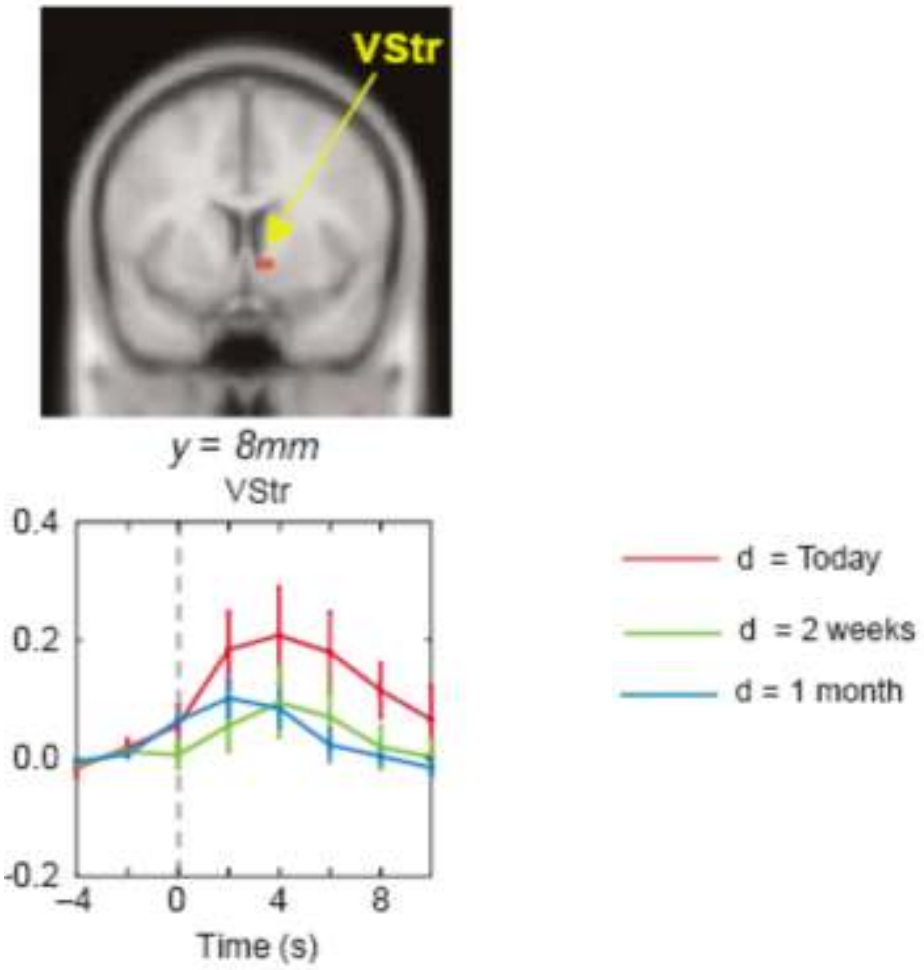
Two parameters (McClure et al., 2004)

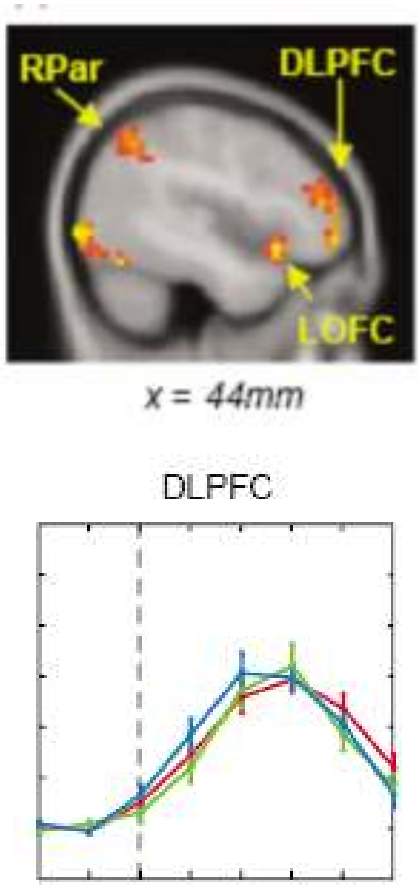
- β — the special (emotional) weight placed on outcomes that are immediate (ventral striatum).
- δ — a more consistent (rational) weighting of time periods by the lateral prefrontal cortex (DLPFC) and associated structures supporting higher cognitive functions.

Beta-delta model.

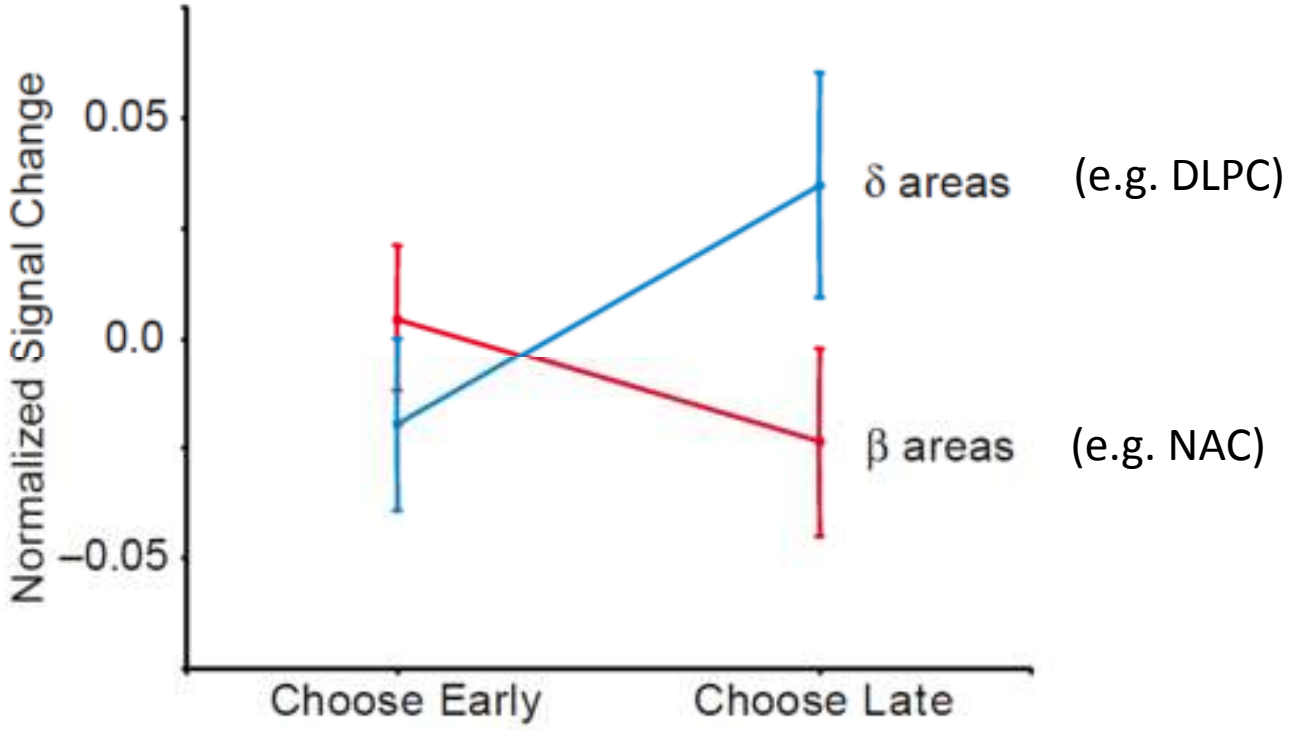
Brain regions that are preferentially activated for choices of immediately available reward (β areas).

Brain regions that are active independently of the delay (d) (δ areas).





McClure et al., 2004



Greater activity in δ than β areas is associated with the choice of later larger rewards.
Relative activity in δ and β brain regions correlates with subjects' choices.

McClure et al., 2004

Summary

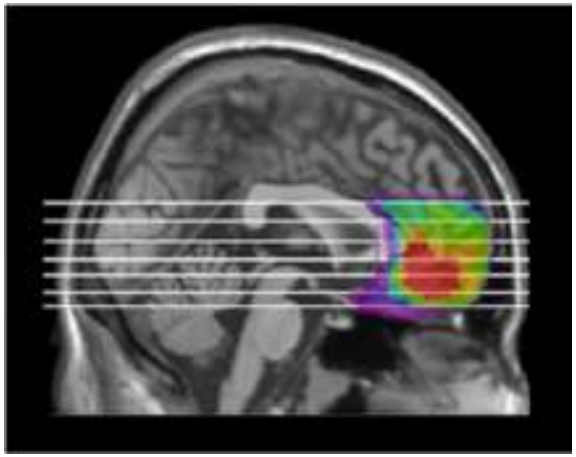
β **areas** – ventral striatum and medial orbitofrontal cortex, both classic limbic (emotional) structures disproportionately activated by choices involving an immediate outcome.

δ **areas** – DLPFC that were not preferentially activated by an option for a reward today.

Choices between immediate and delayed outcomes decisions are determined by the relative activation of the β- and δ-systems.

Criticism

- β **areas** tracks the revealed subjective value of delayed monetary rewards (Kable & Glimcher, 2007).
- Damage to mOFC resulted in steeper Temporal Discounting of future rewards (Sellitto et al., 2010).



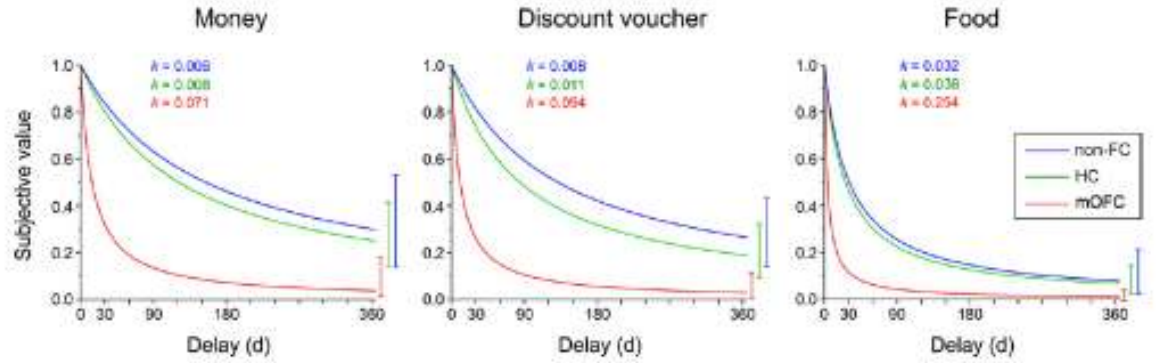


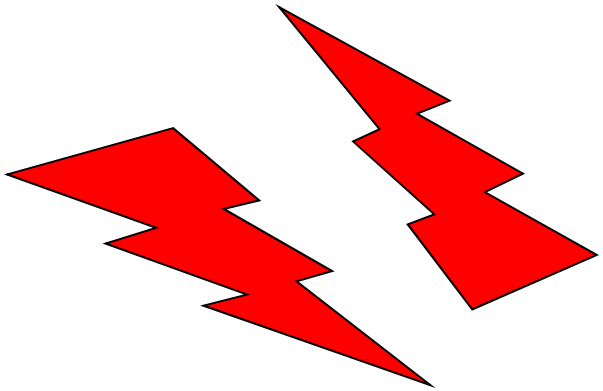
Figure 3. Temporal discounting functions by participant group (mOFC, non-FC, HC) and type of reward. The hyperbolic curves describe the discounting of subjective value (expressed as a proportion of the delayed amount) as a function of time (days). The discounting parameter *k* reflects the geometric mean of the group (mean of the log-transformed values). Confidence intervals are 95% intervals.

mOFC patients (n = 7)
nonfrontal (non-FC) patients (n = 9)
healthy control (HC) group (n = 20)

Debate dual-system approach

Sam McClure
Stanford University

- Dual-processing



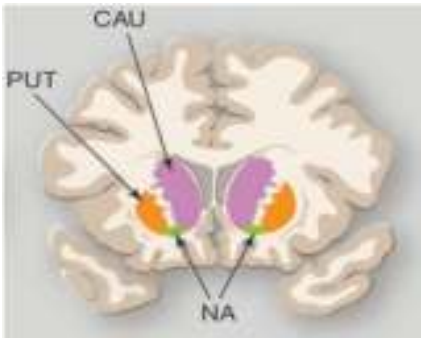
- Single system

Paul Glimcher
New York University

Process and Content in Two Cognitive Systems

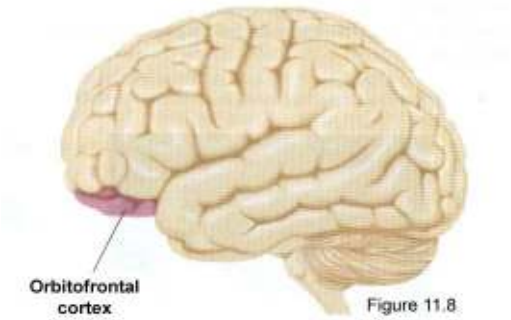
	PERCEPTION	INTUITION SYSTEM 1	REASONING SYSTEM 2
PROCESS	Fast Parallel Automatic Effortless Associative Slow-learning Emotional		Slow Serial Controlled Effortful Rule-governed Flexible Neutral
CONTENT	Percepts Current stimulation Stimulus-bound	Conceptual representations Past, Present and Future Can be evoked by language	

Daniel Kahneman September 2003 • American Psychologist



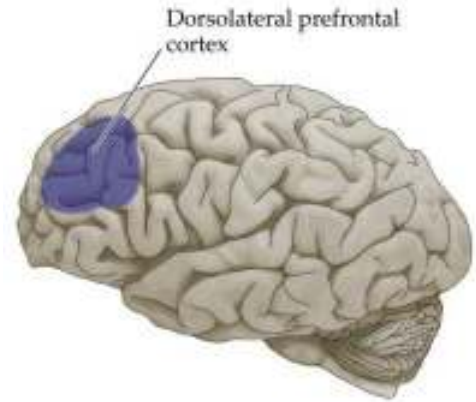
Nucleus accumbens (NAc) – subjective value / anticipated gain magnitude.

System 1



Orbitofrontal cortex (OFC) – compares / integrates multiple information regarding the reward outcome, learning.

System 1



Dorsolateral prefrontal cortex (DLPFC) – cognitive control & planning.

System 2

Thank you for your attention!