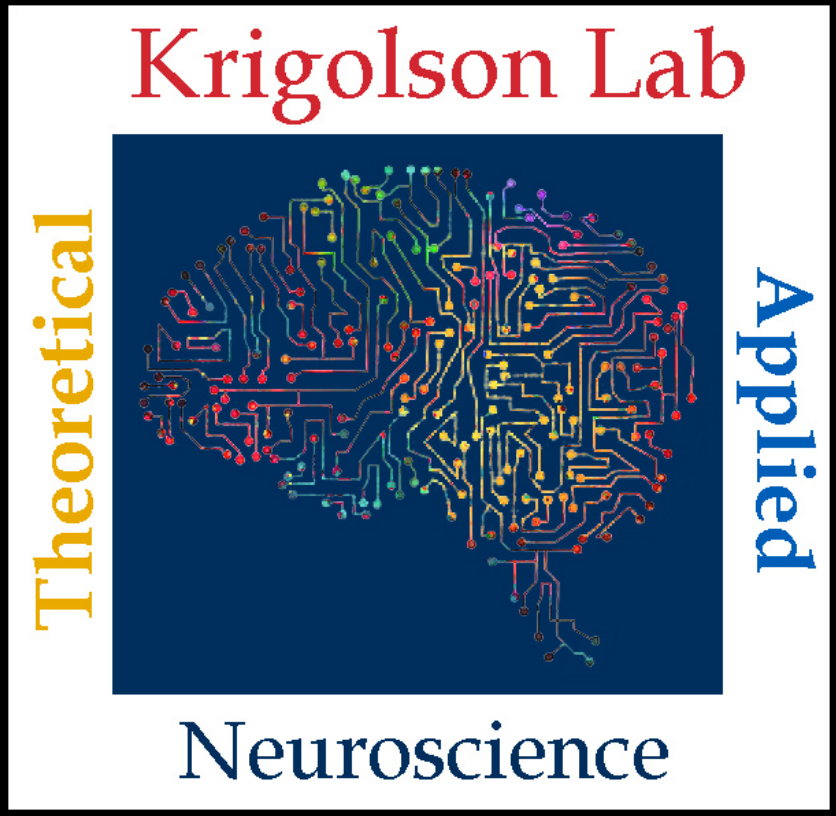
The Neuroscience of Human Decision Making

Dr. Olav E. Krigolson
Associate Director
Centre for Biomedical Research
University of Victoria



Course Outline

The Neuroscience of Human Decision Making
ASHI726 2018F C01
Dr. Olav E. Krigolson, PhD
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Course Overview
~~Week I: Decision Making Theory September 12th, 2018~~
Week II: Neural Evidence for Value September 19th, 2018
Week III: Neural Decision Systems September 26th, 2018 ???
Week IV: System I and System II October 10th, 2018
Week V: Emotional Decisions October 17th, 2018
Week VI: Current Research in Decision Making October 24th, 2018

OCT
15

Destination Mars: Using neuroscience to improve the safety of long term sp...

by The Centre for Biomedical Research, University of Victoria

Free

REGISTER

DESCRIPTION

Please join Olav Krigolson, PhD, Associate Professor, Neuroeconomics Laboratory, and Associate Director, Centre for Biomedical Research at UVic as he discusses:

Destination Mars: Using neuroscience to improve the safety of long term space flight

NASA has a set goal of sending astronauts to Mars in the near future.

As a part of the work up to that mission, NASA is conducting and supporting research to ensure mission success. A key area that is being targeted is "Human Factors" - how a crew will deal with the effects of an extended space mission. Working with the HISEAS Mars Habitat, the Krigolson Laboratory is developing mobile EEG ("brain wave") technology to monitor astronaut brain health and function during the Mars mission. During this talk Dr. Krigolson will discuss the HISEAS project and the work his laboratory has done to support the Mars mission."

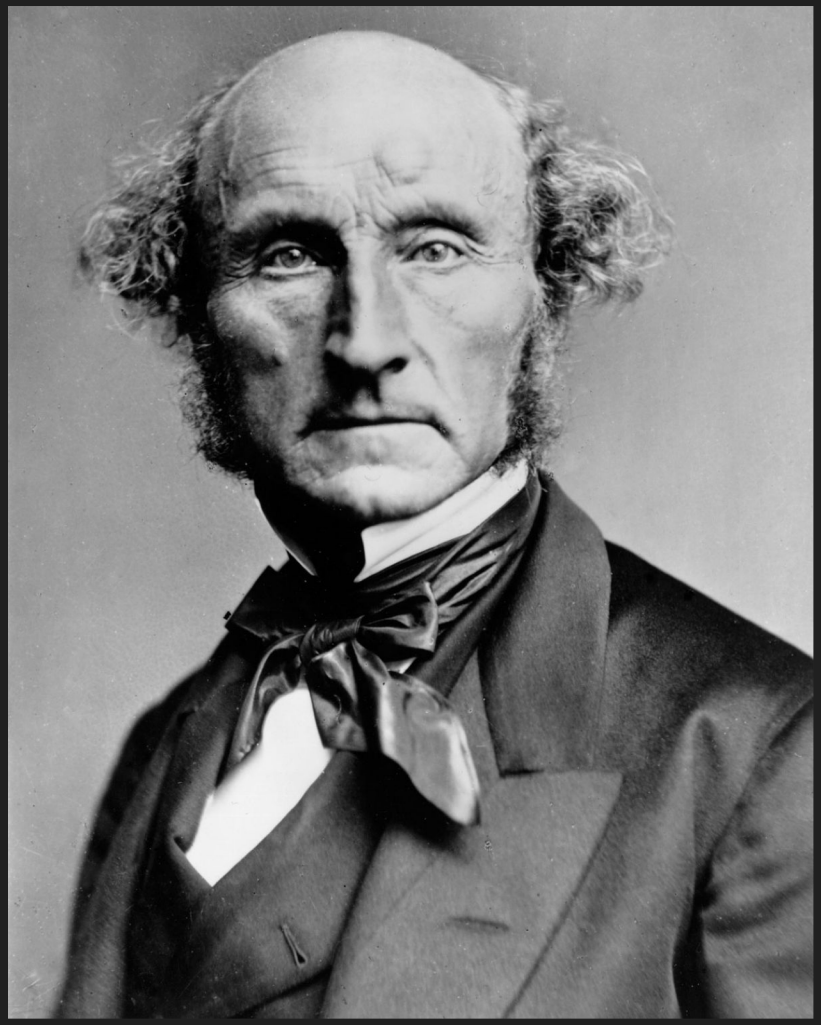
DATE AND TIME

Mon, 15 October 2018
7:00 PM – 9:00 PM PDT
Add to Calendar

LOCATION

MacLaurin Building, University of Victoria
David Lam Auditorium (MAC A144)
Parking Lots E and 6 (fees apply)
Victoria, BC V8P 5C2
View Map

Review



Utilitarianism

People seek actions
that increase utility
and avoid actions that
decrease utility

Mill, 1861

Decision Making

Our ability to process multiple alternatives and choose the option that maximizes utility

Expected Value = Value x Probability

A Sample Problem

Problem 1

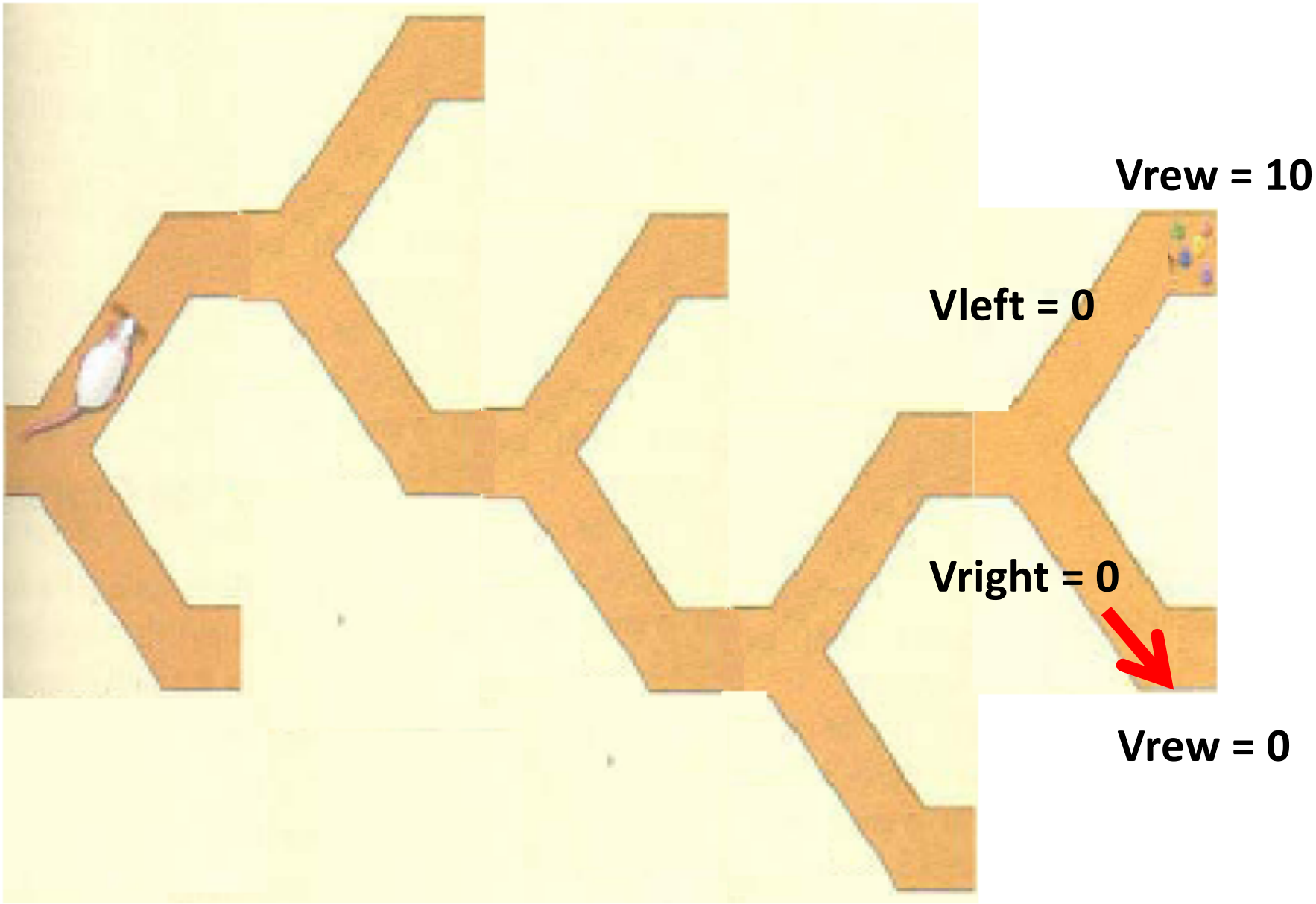
Would you play a gamble that has a 40% chance to win $1000 or a 70% chance to win $600?

Decision Making

1. Always Choose the Highest Value Option
2. Exploration versus Exploitation

BUT

3. Psychological factors have to be accounted for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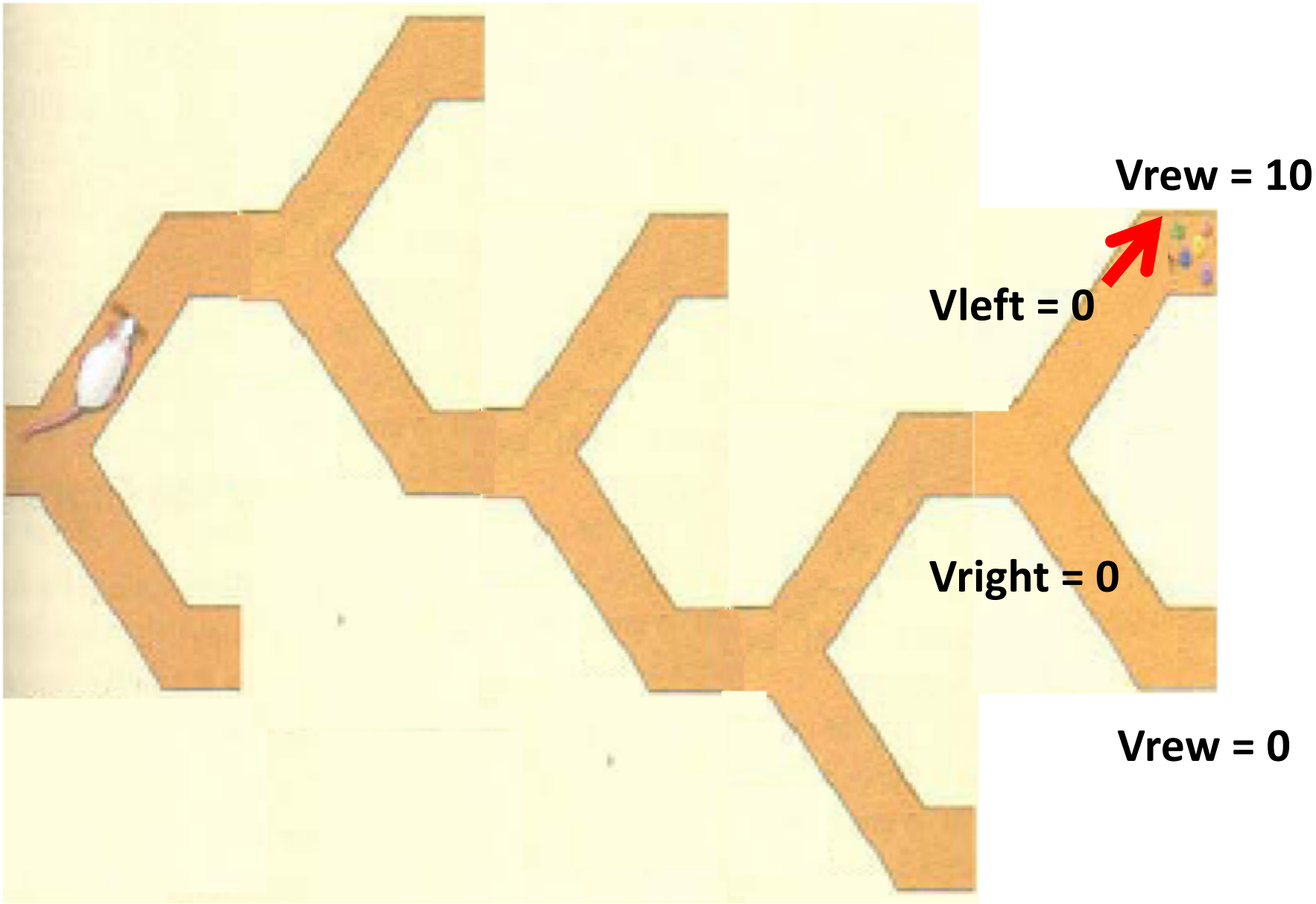
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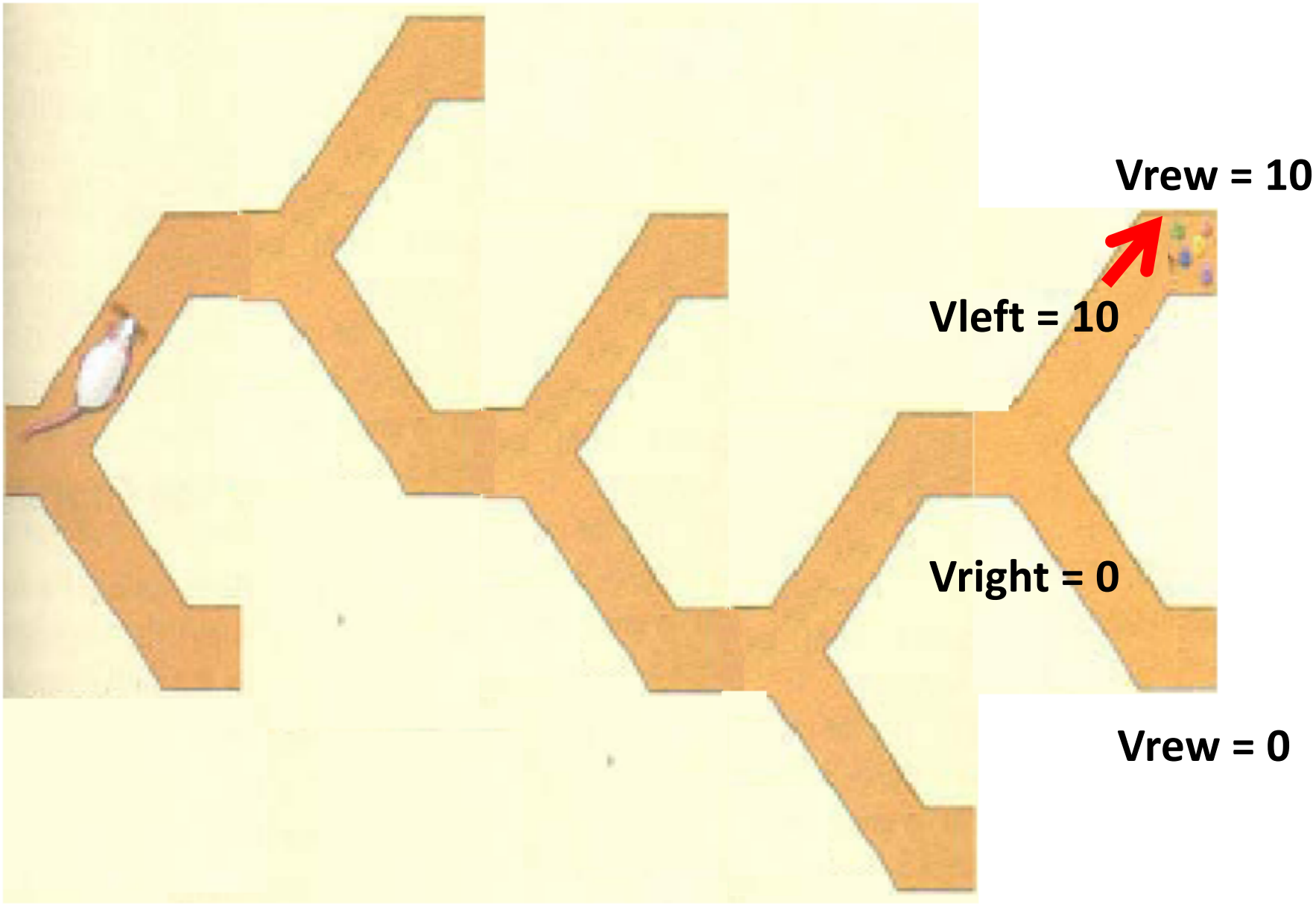
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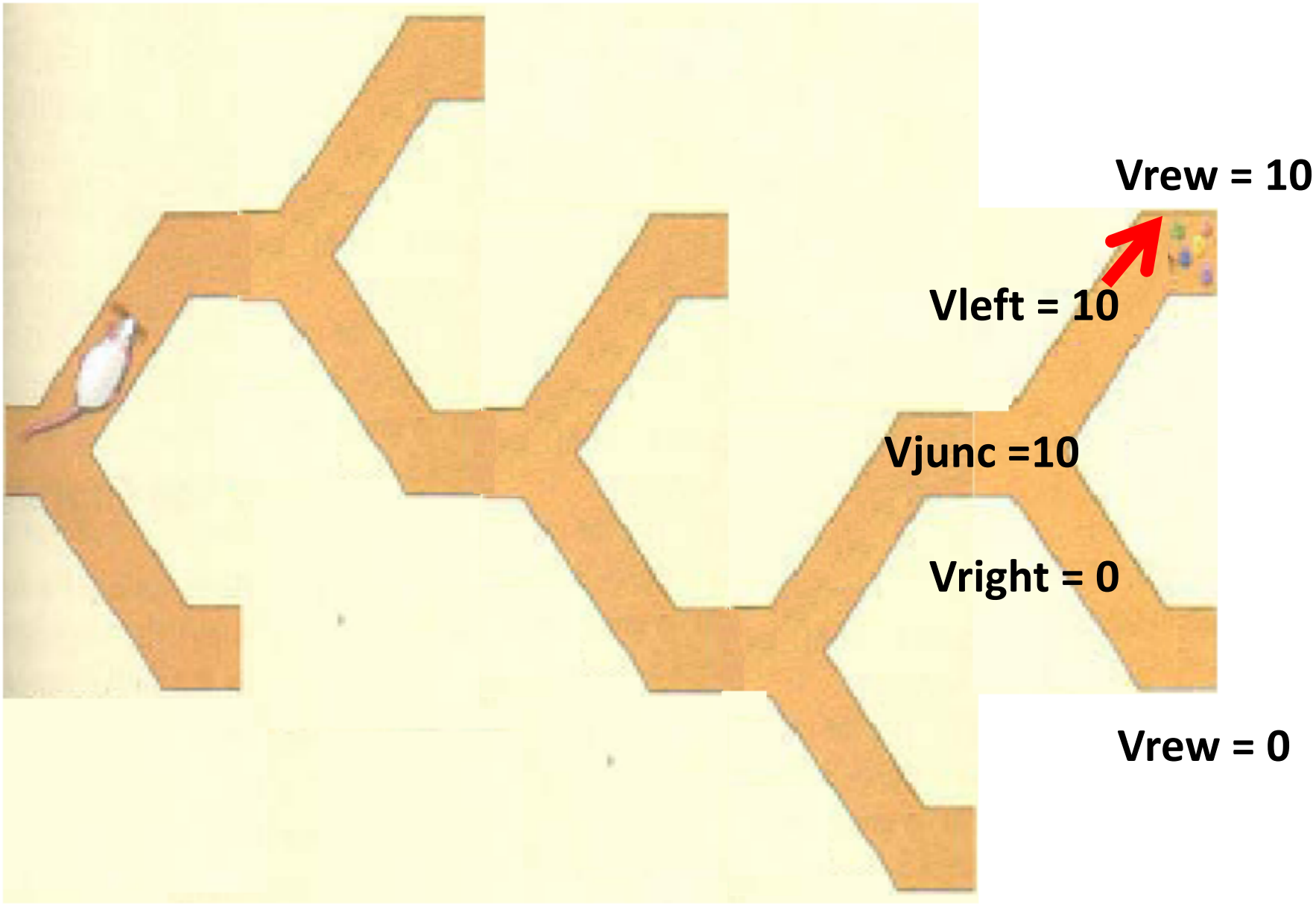
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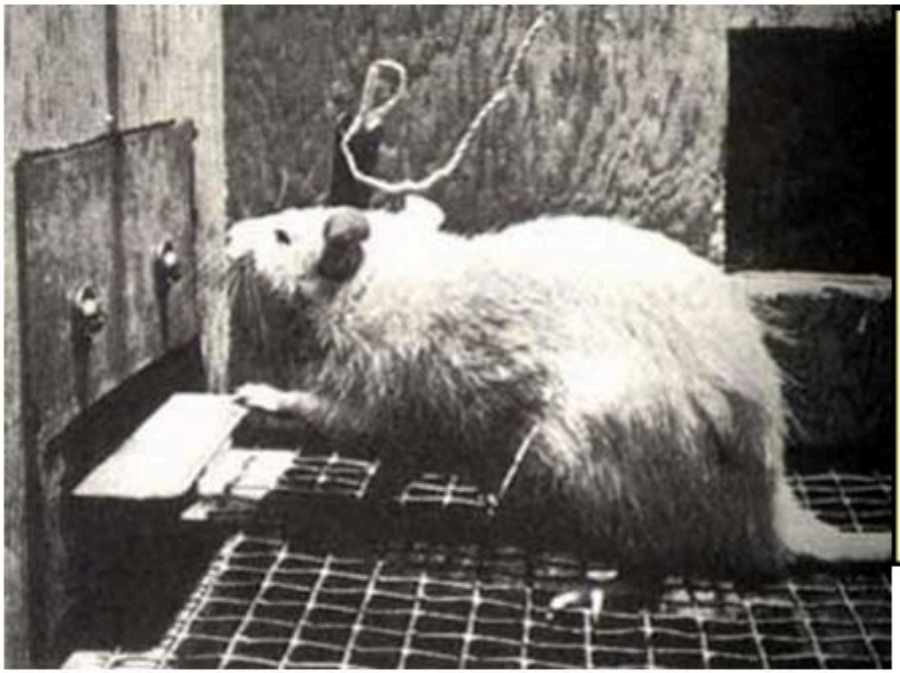
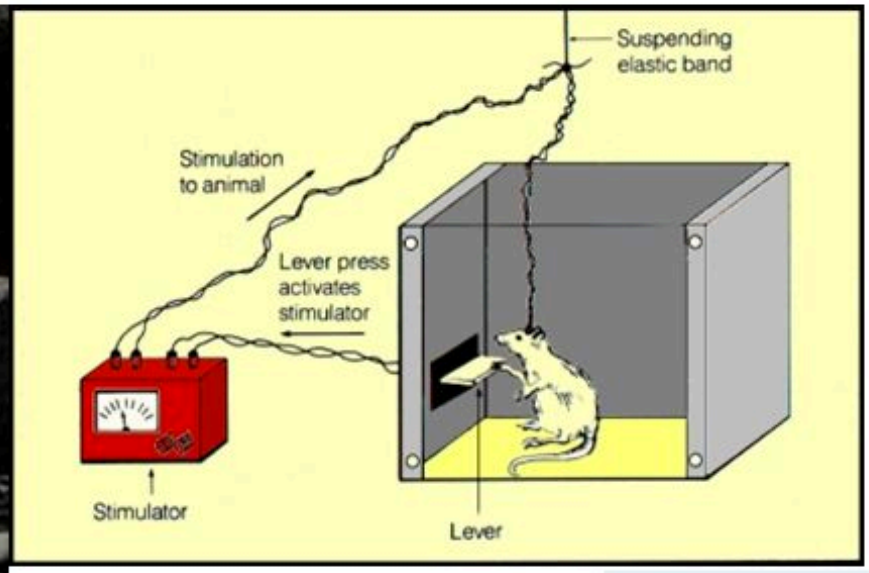
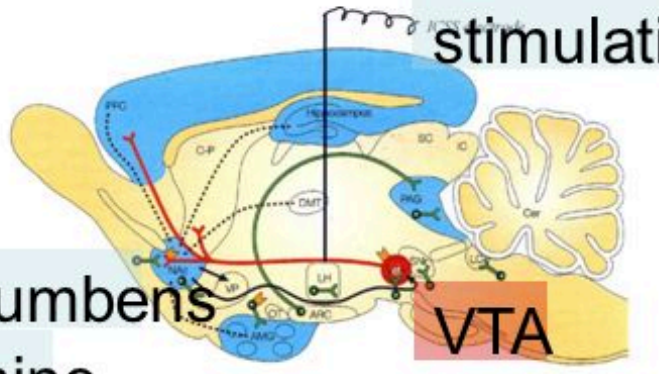
Encoding Value

Electrical intracranial self-stimulation





Olds & Milner (1954)

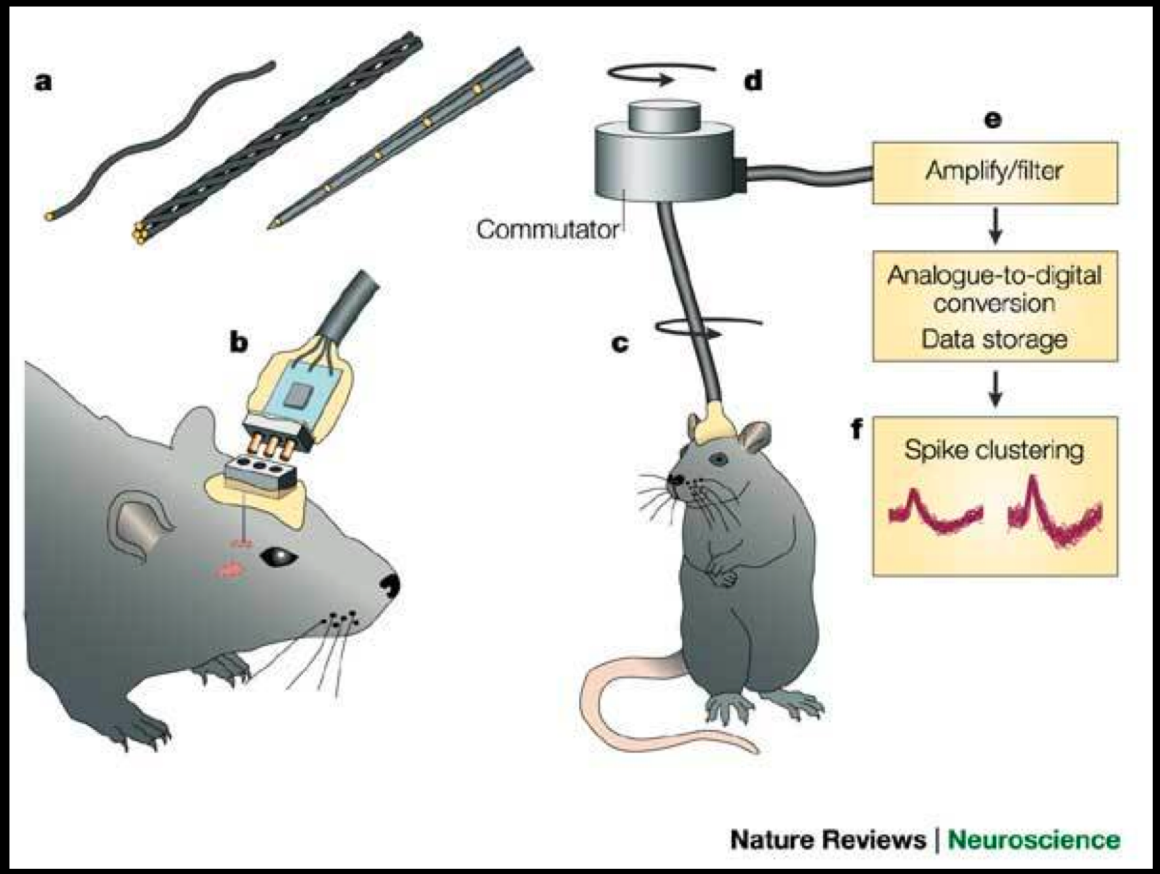


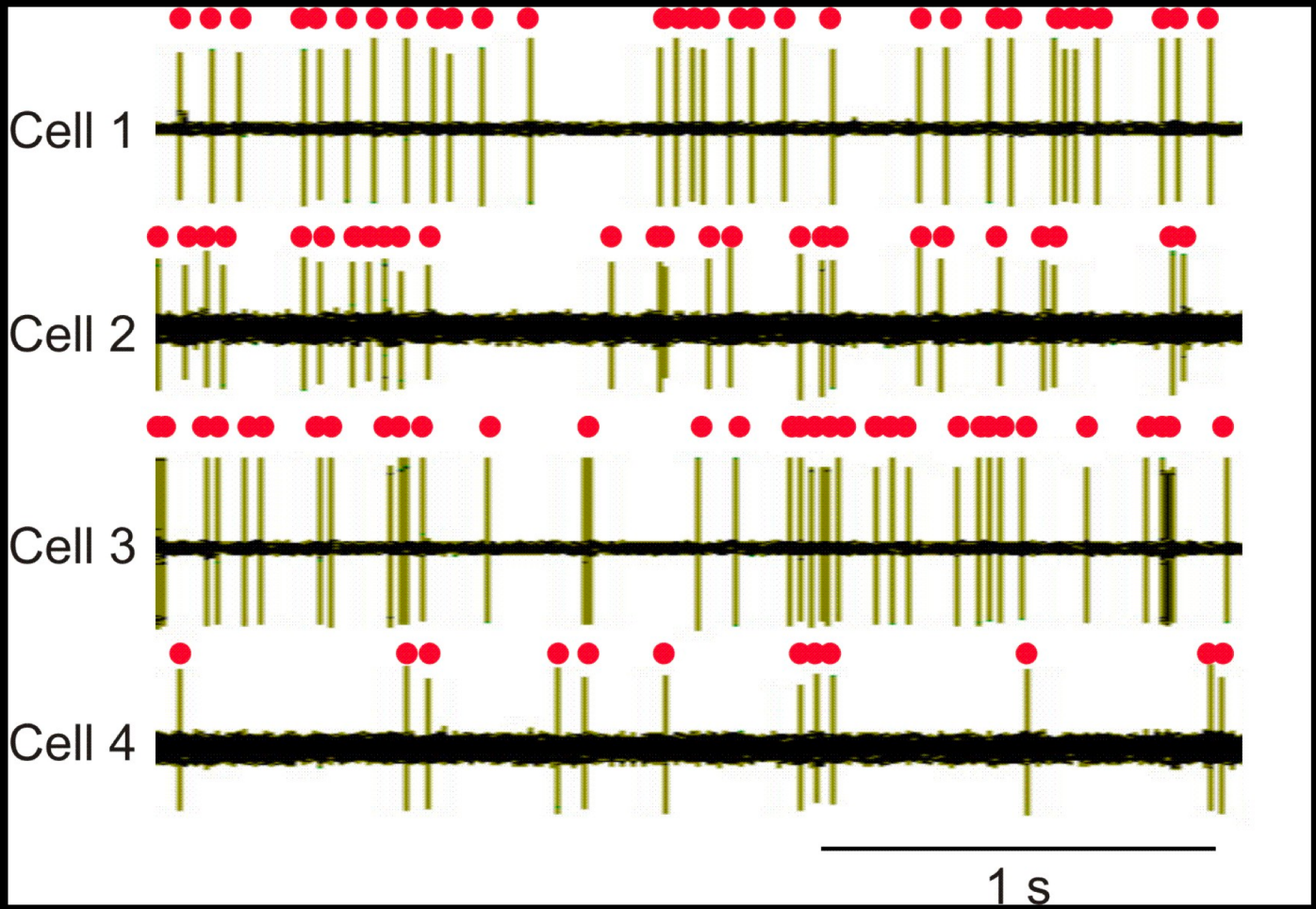
stimulation

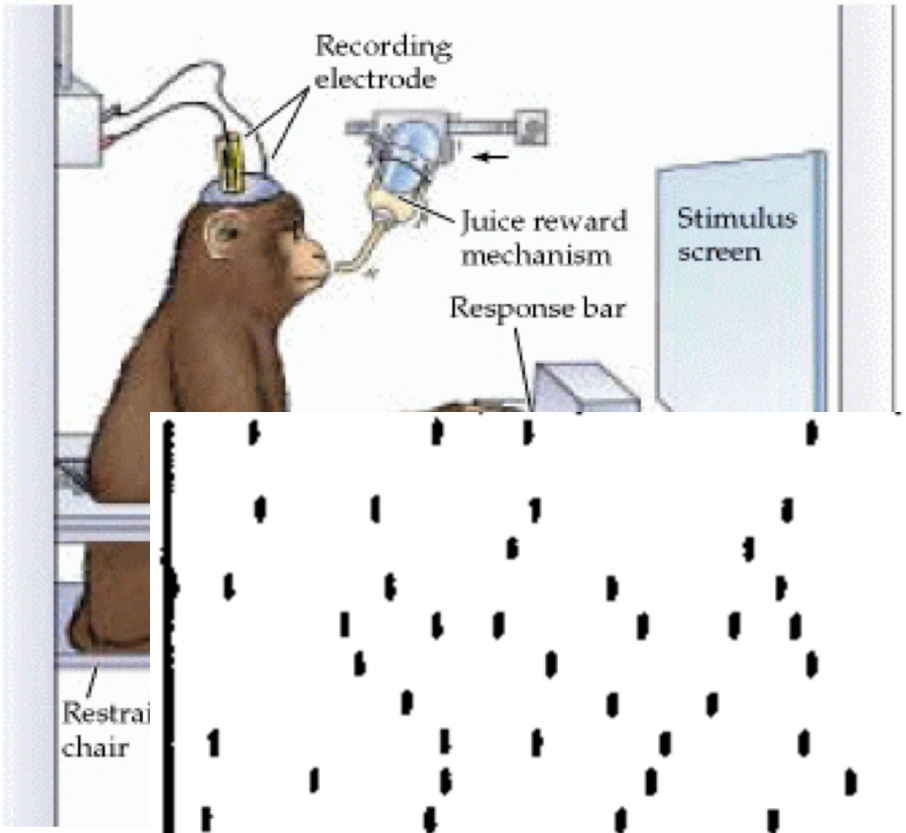
n. accumbens

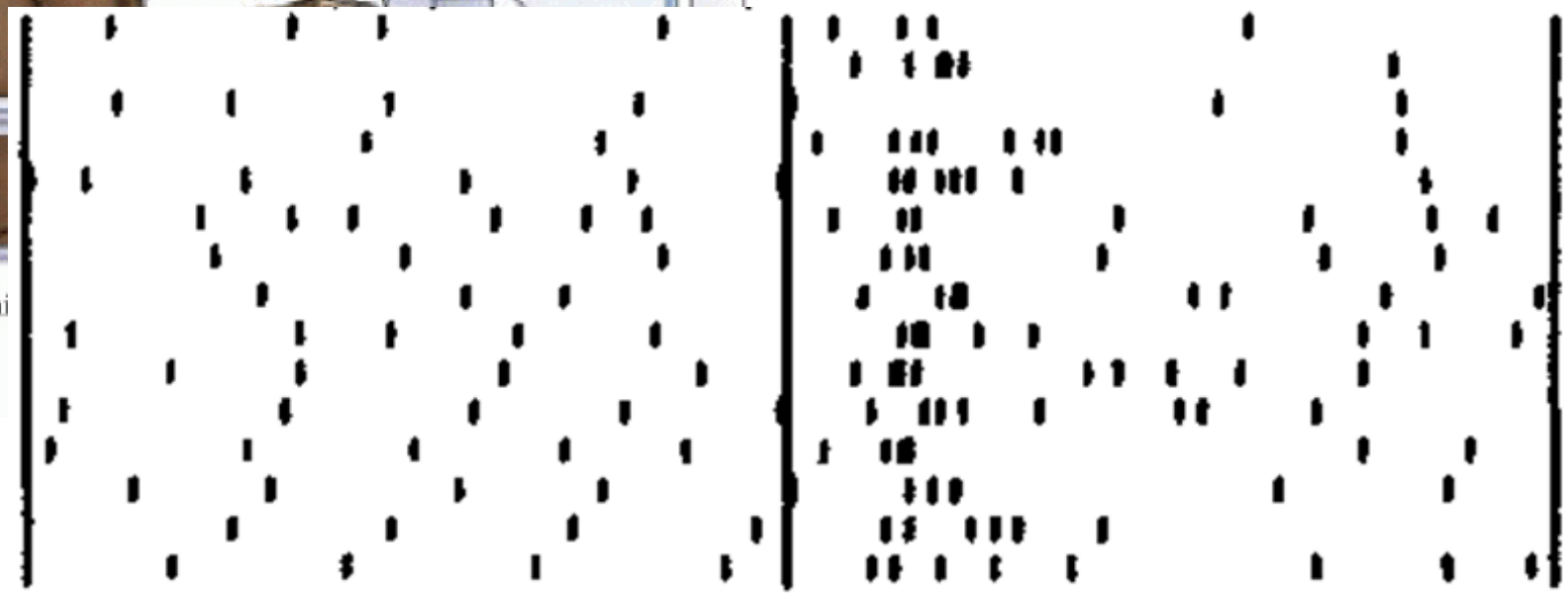
dopamine

VTA

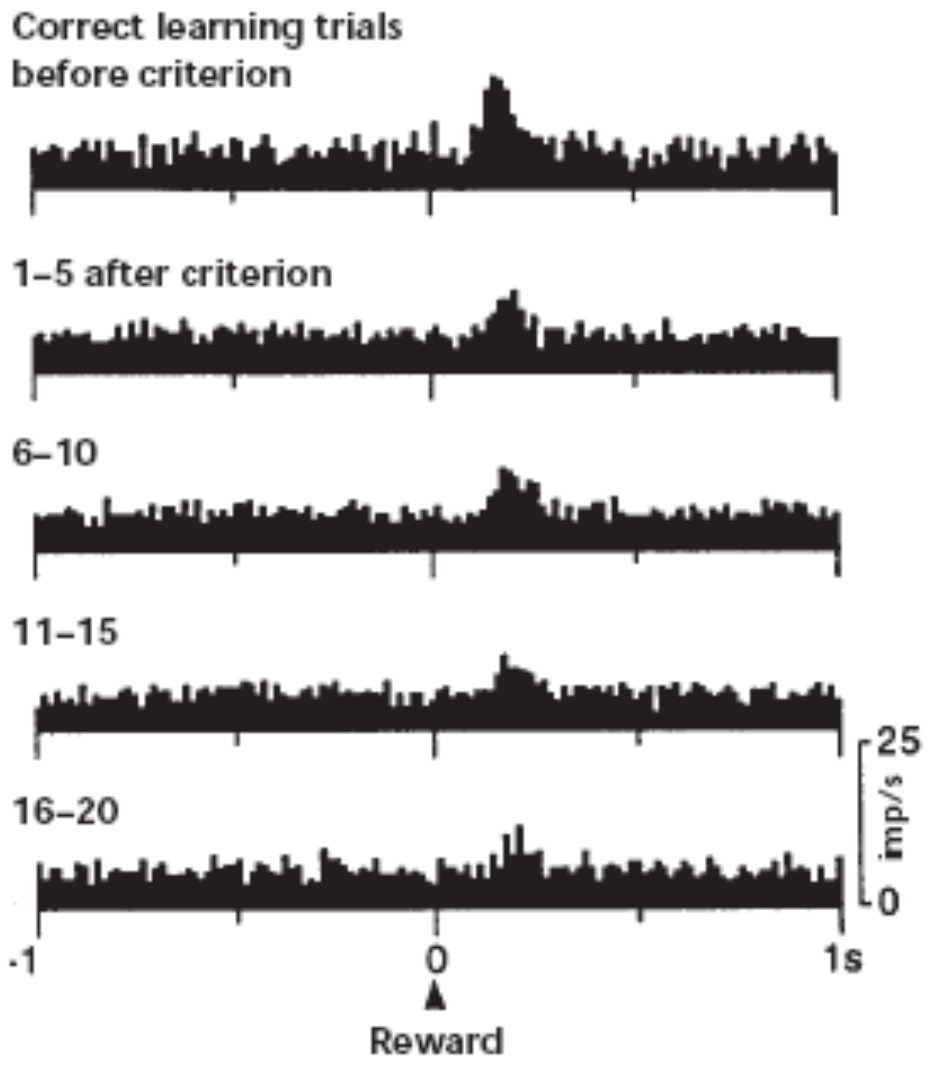

a
b
c
d
e
Amplify/filter
Commutator
Analogue-to-digital conversion
Data storage
f
Spike clustering
Nature Reviews | Neuroscience

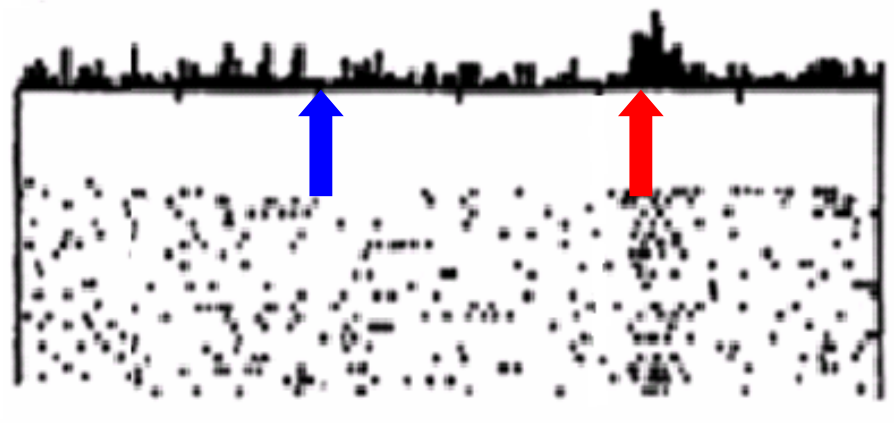

Cell 1
Cell 2
Cell 3
Cell 4
1 s

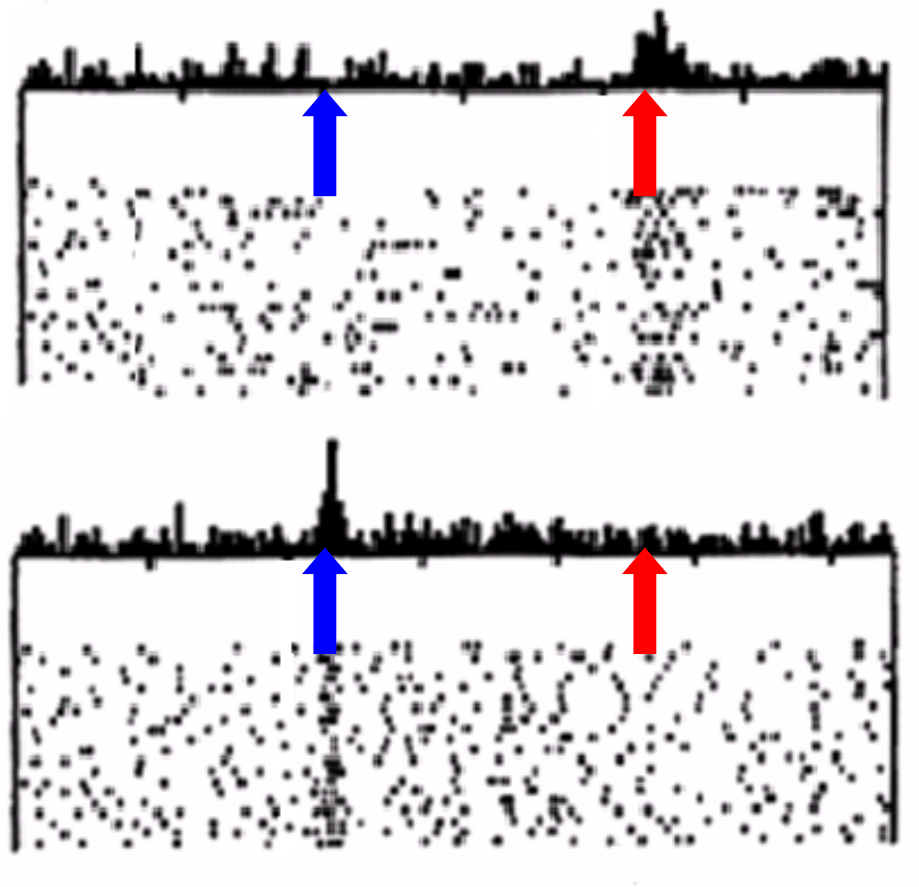

Recording electrode
Juice reward mechanism
Stimulus screen
Response bar
Restrai
chair

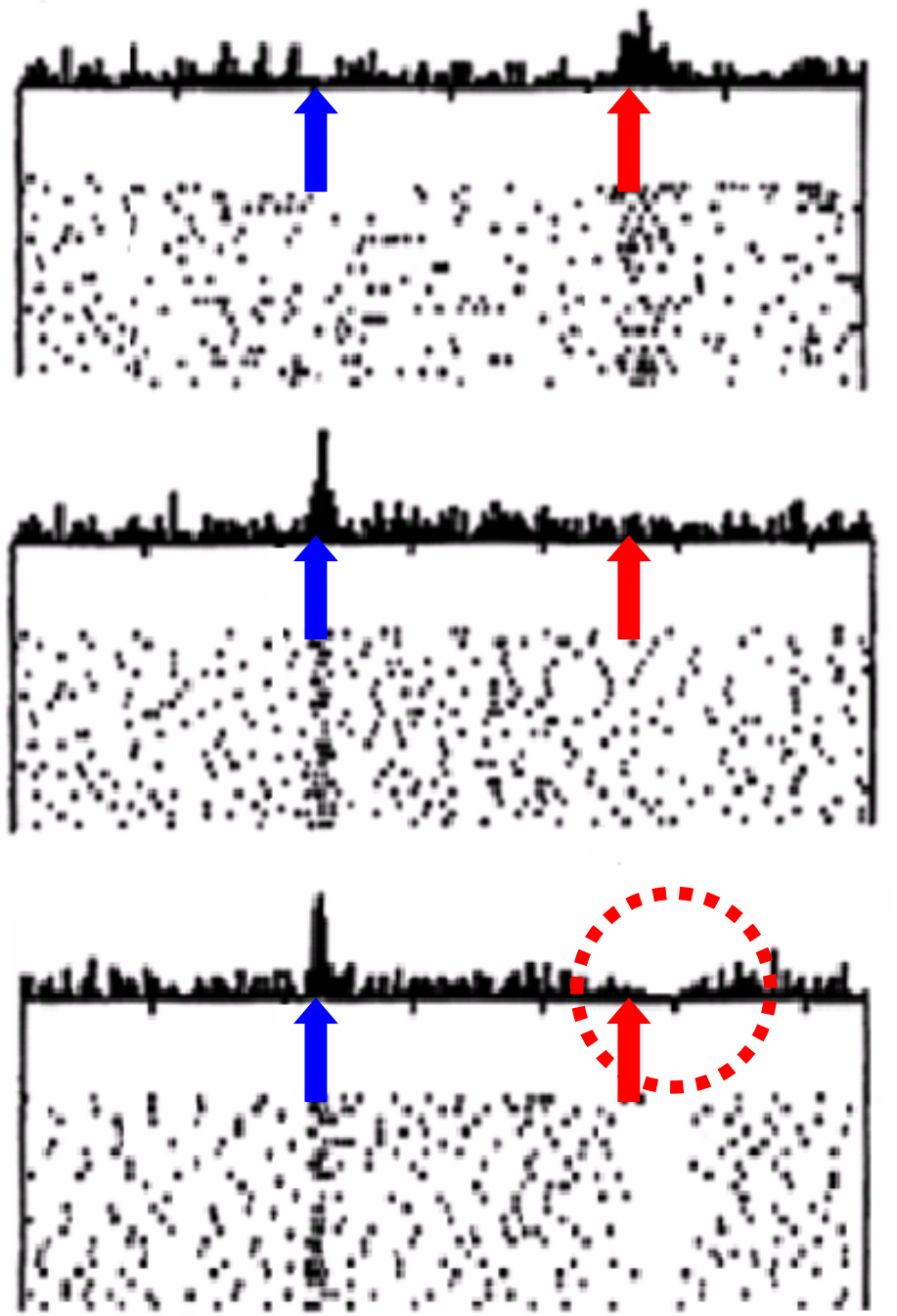


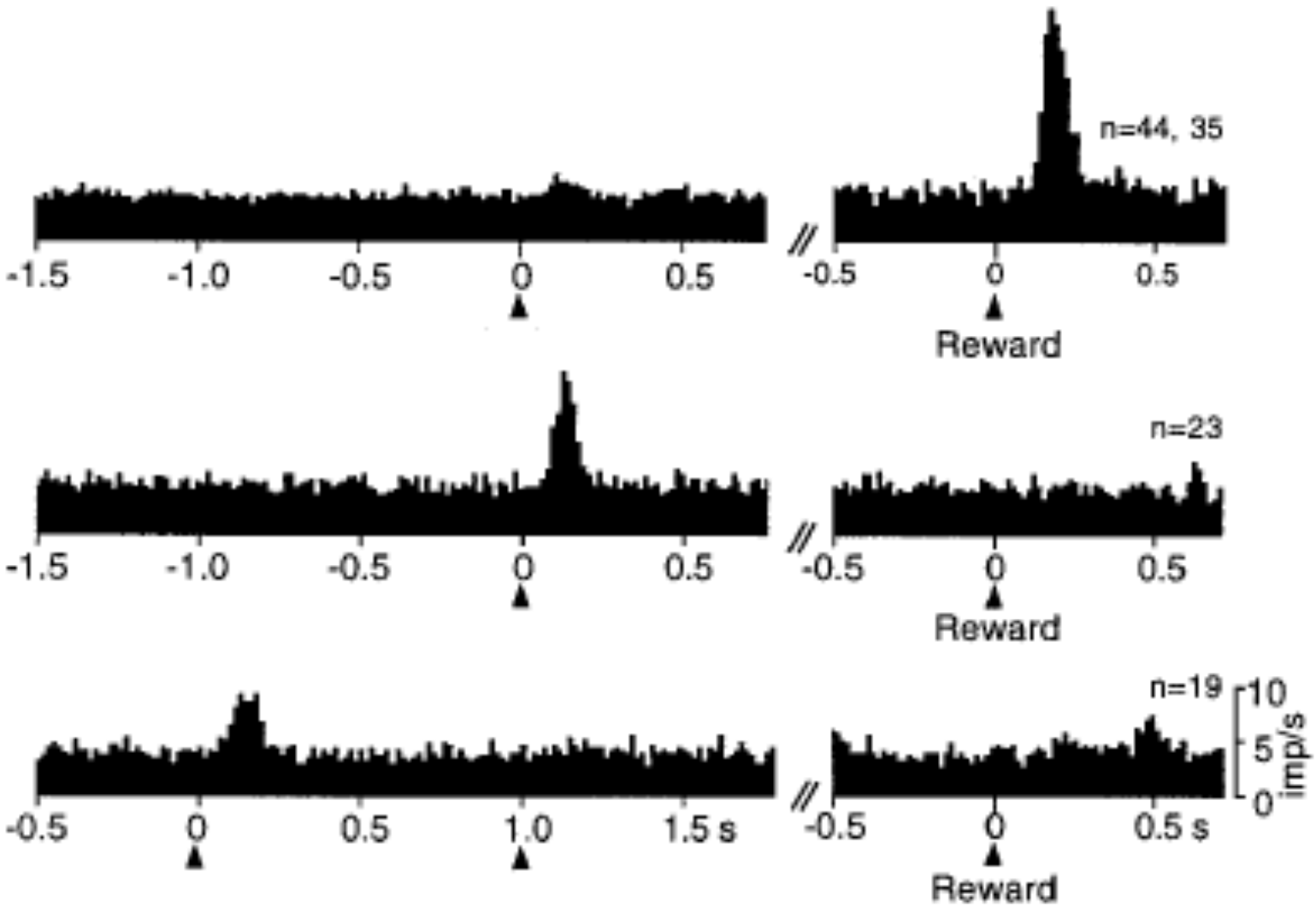

Juice

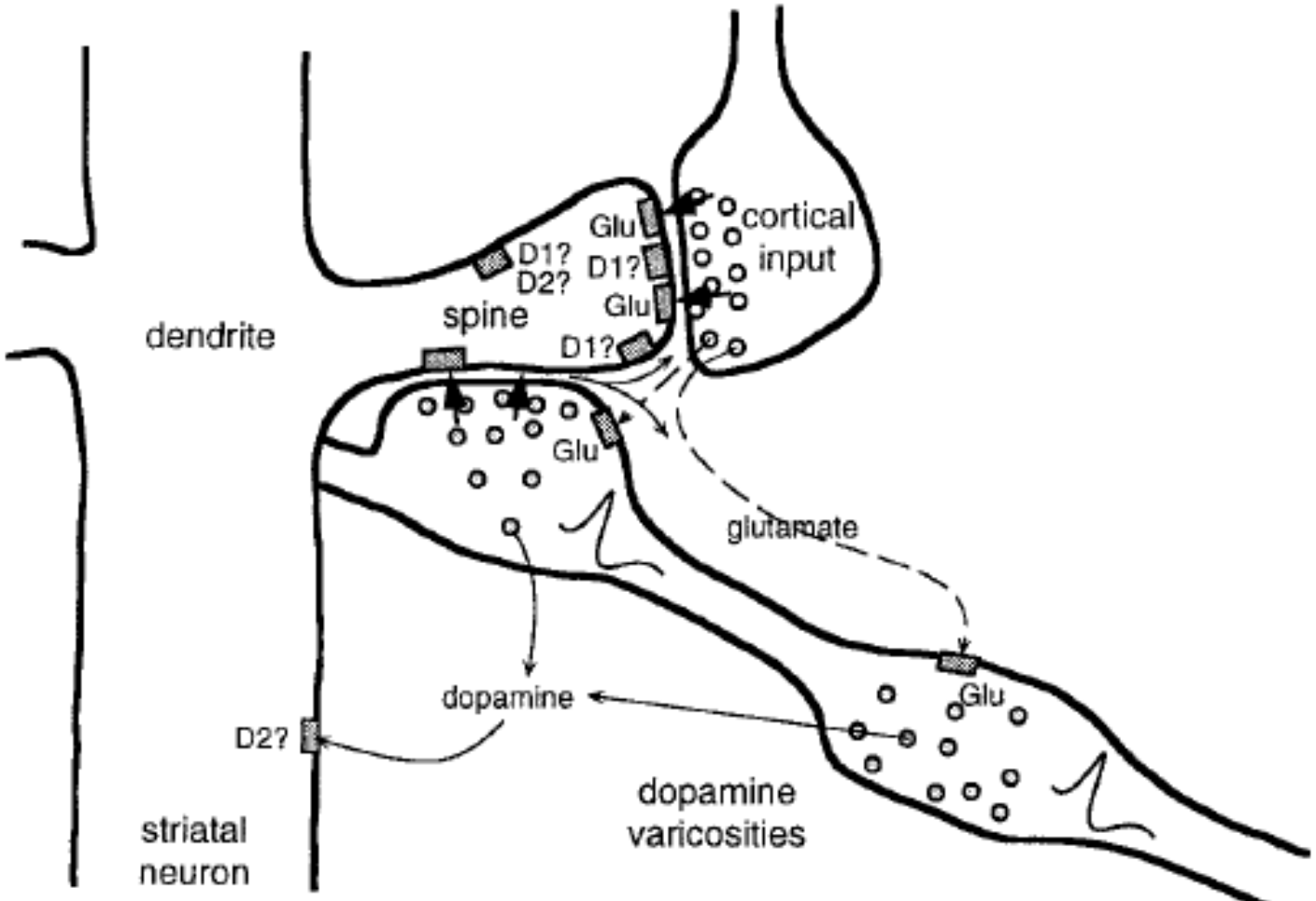

Correct learning trials
before criterion
1–5 after criterion
6–10
11–15
16–20
25
imp/s
0
-1
0
1s
Reward

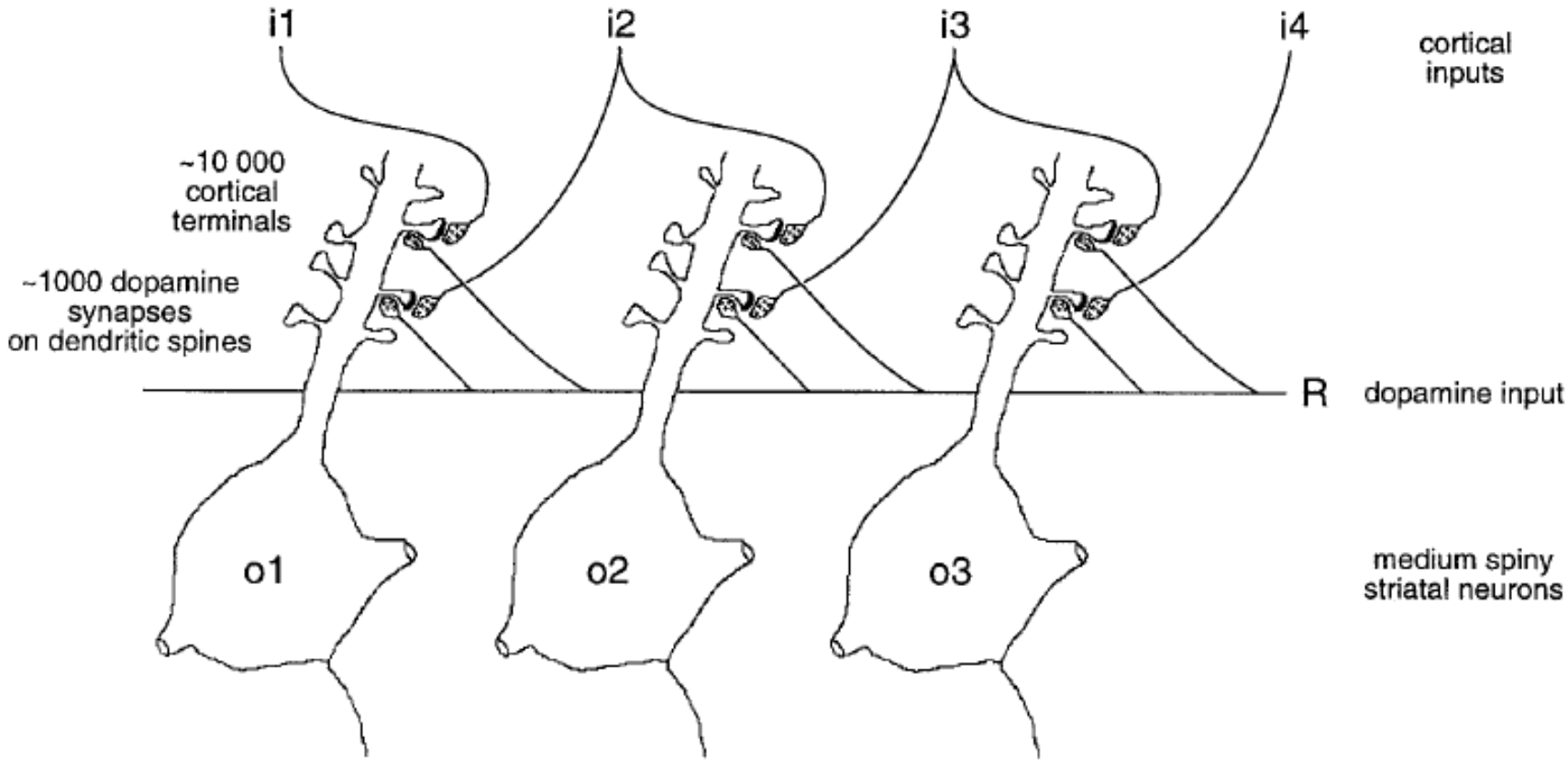






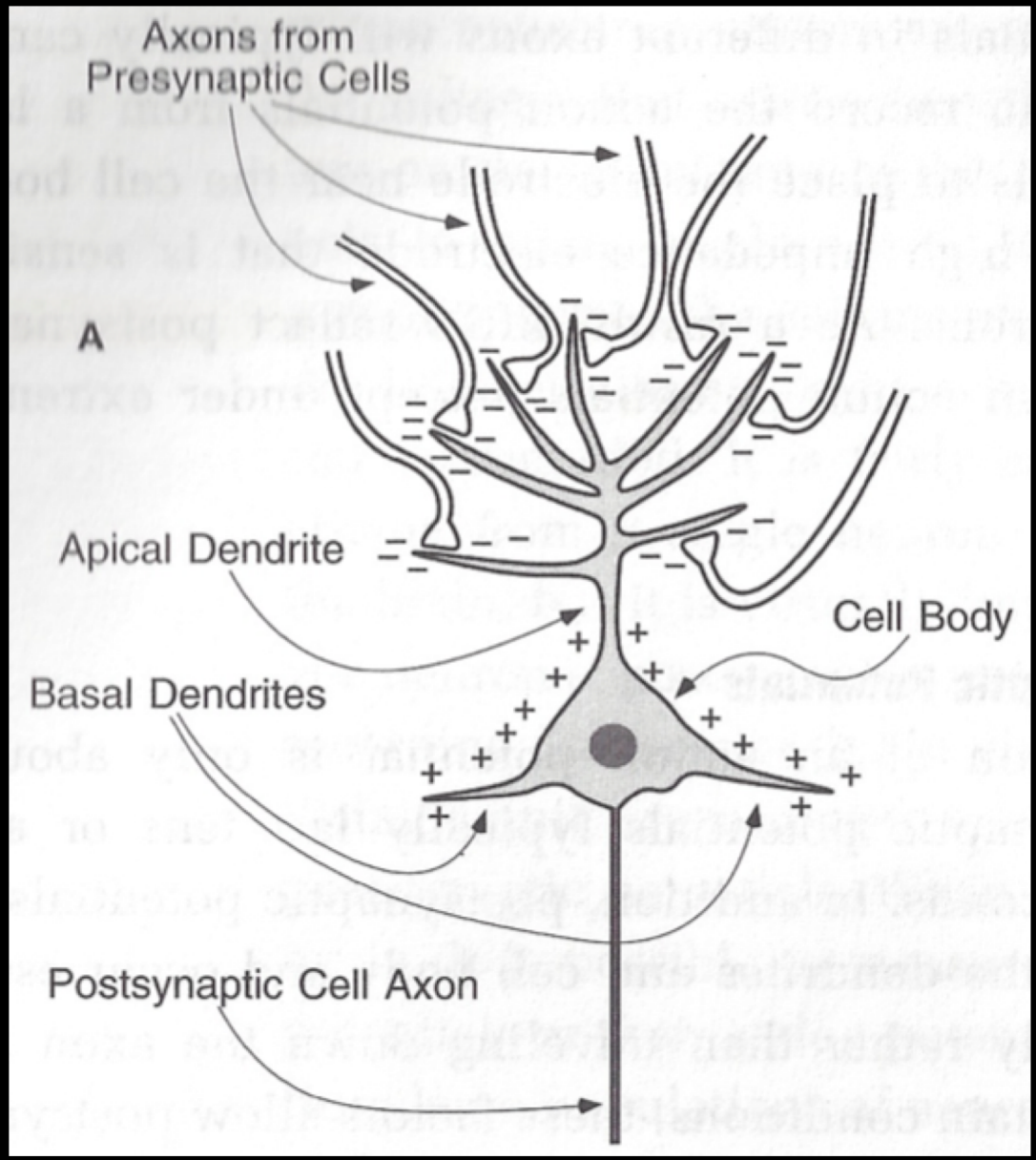

n=44, 35
-1.5
-1.0
-0.5
0
0.5
-0.5
0
0.5
Reward
n=23
-1.5
-1.0
-0.5
0
0.5
-0.5
0
0.5
Reward
n=19
10
5
0
imp/s
-0.5
0
0.5
1.0
1.5 s
-0.5
0
0.5 s
Reward

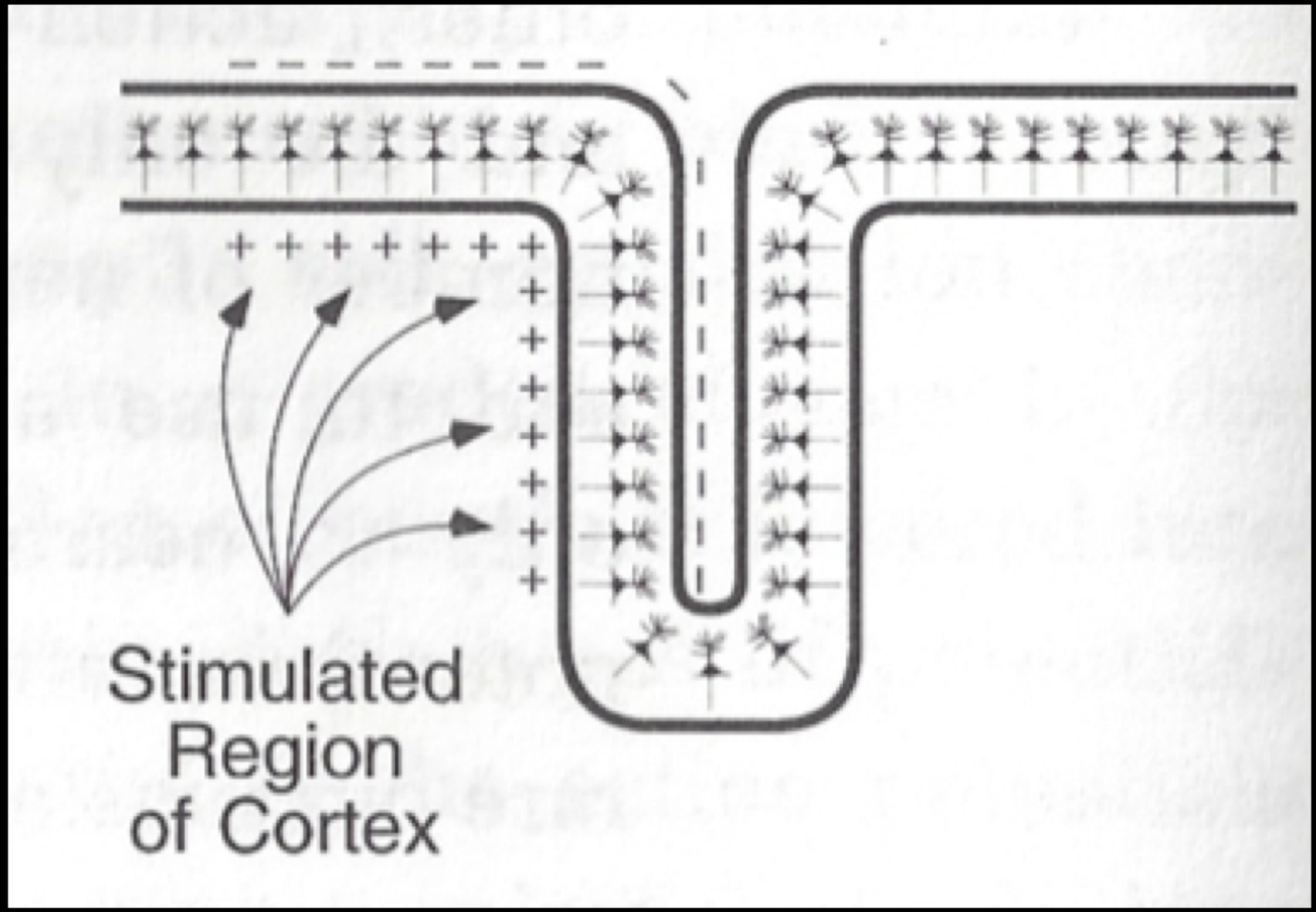

Glu
cortical
input
D1?
D2?
D1?
Glu
spine
dendrite
D1?
Glu
glutamate
dopamine
Glu
D2?
dopamine
varicosities
striatal
neuron

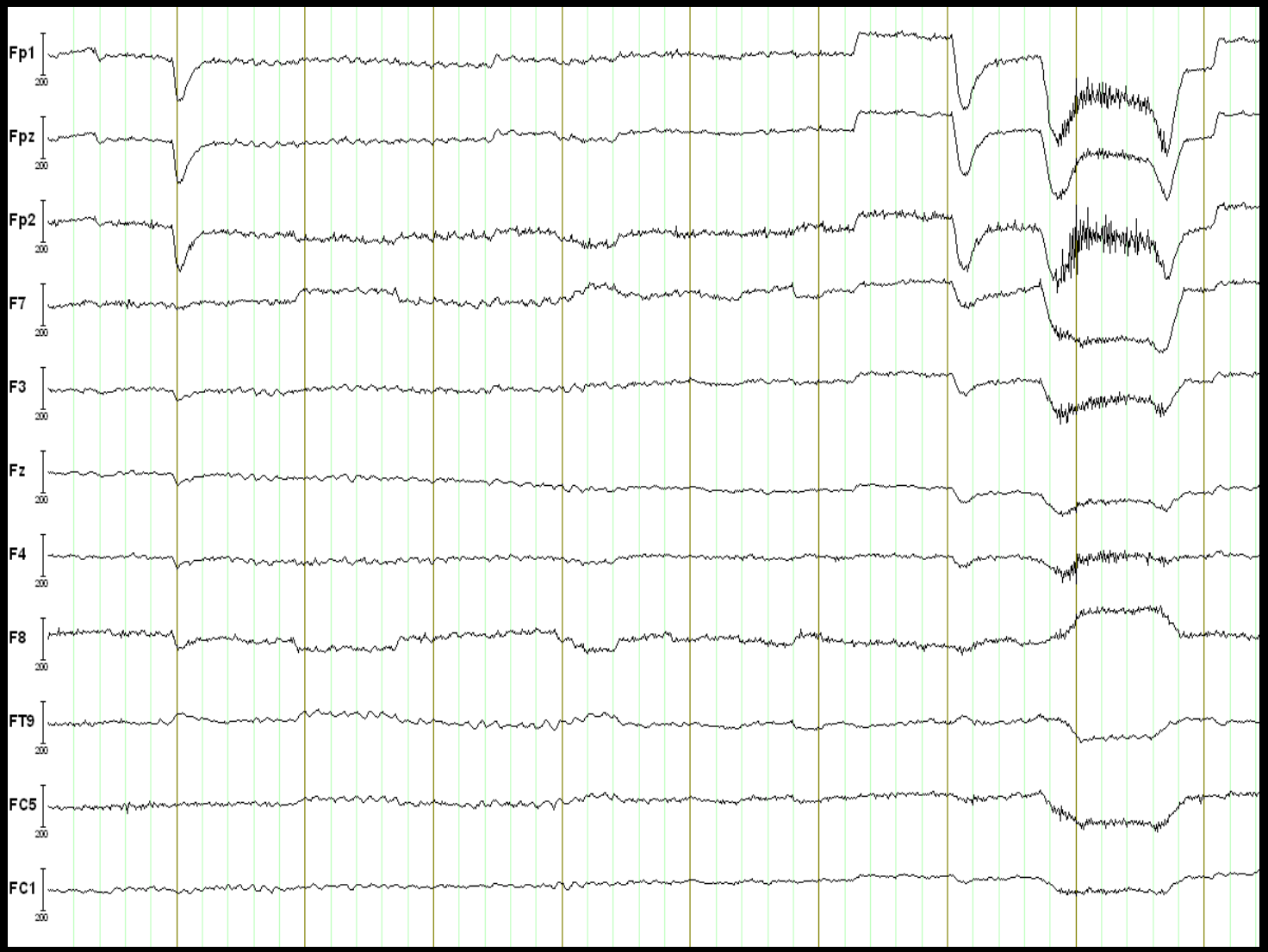

i1
i2
i3
i4
cortical inputs
~10 000 cortical terminals
~1000 dopamine synapses on dendritic spines
R
dopamine input
o1
o2
o3
medium spiny striatal neurons

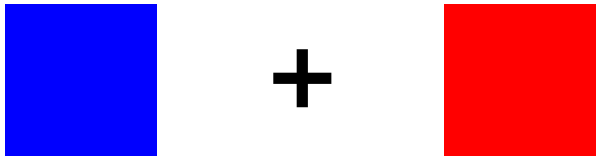

TOO SLOW

EEG reflects Post Synaptic Potentials

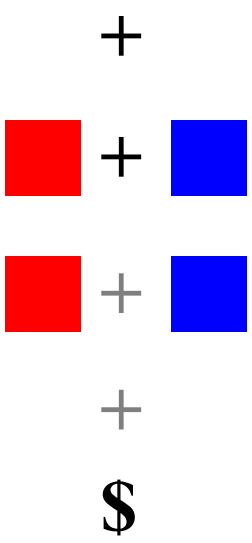



Stimulated
Region
of Cortex


Fp1
200
Fpz
200
Fp2
200
F7
200
F3
200
Fz
200
F4
200
F8
200
FT9
200
FC5
200
FC1
200



Krigolson et al., 2014



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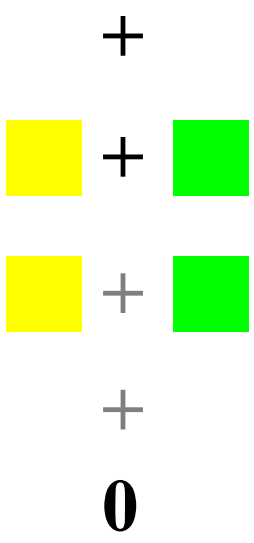

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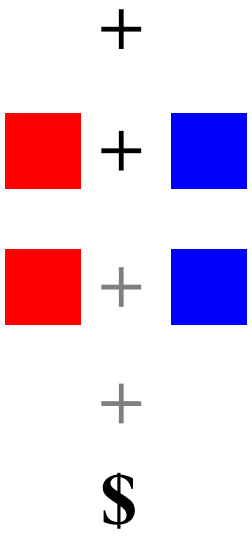

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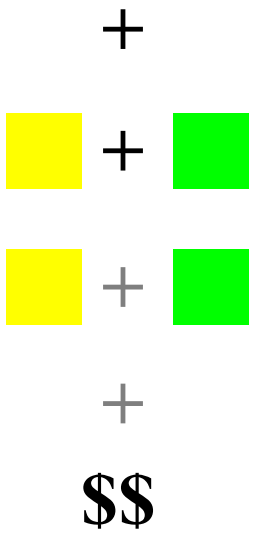
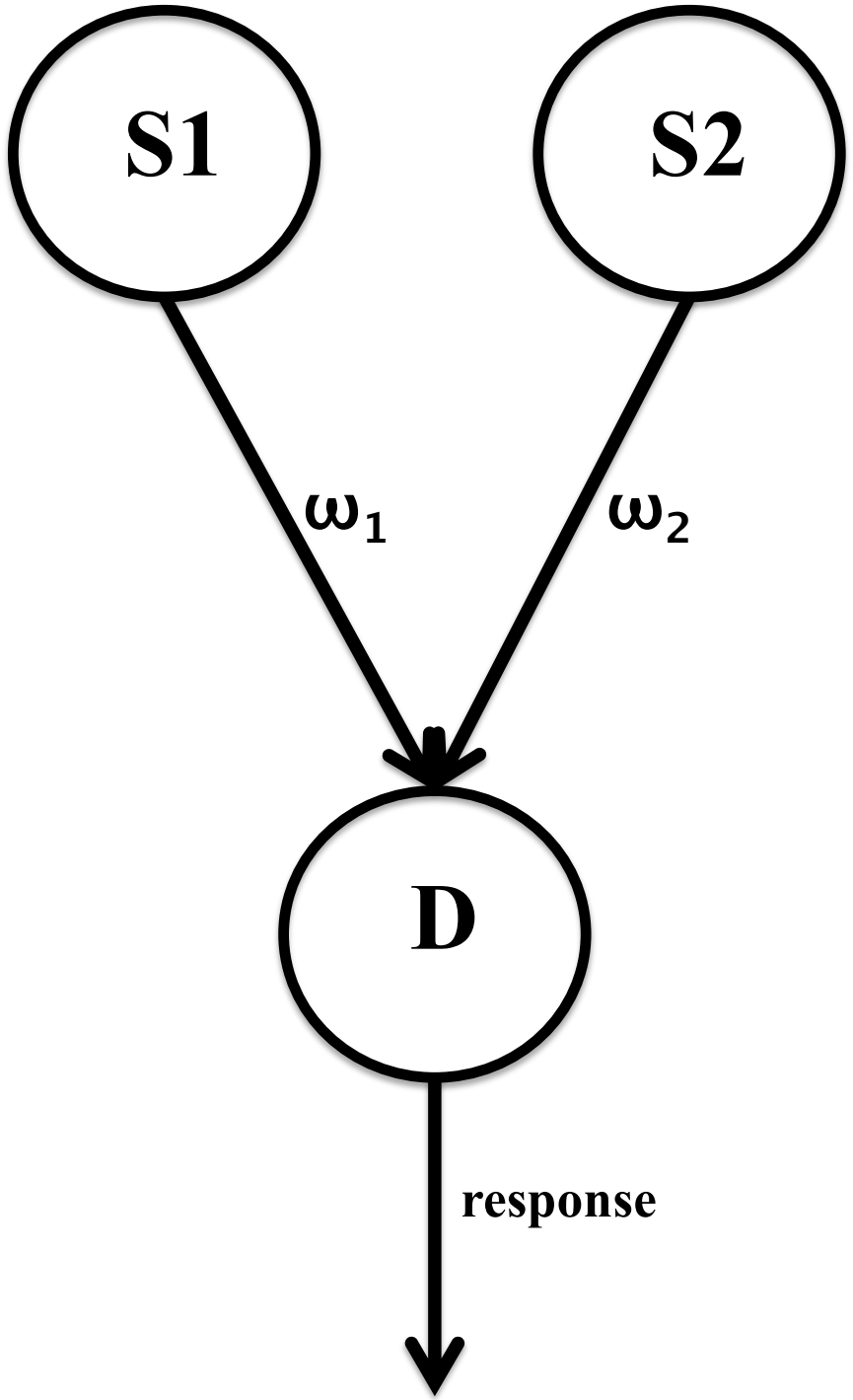
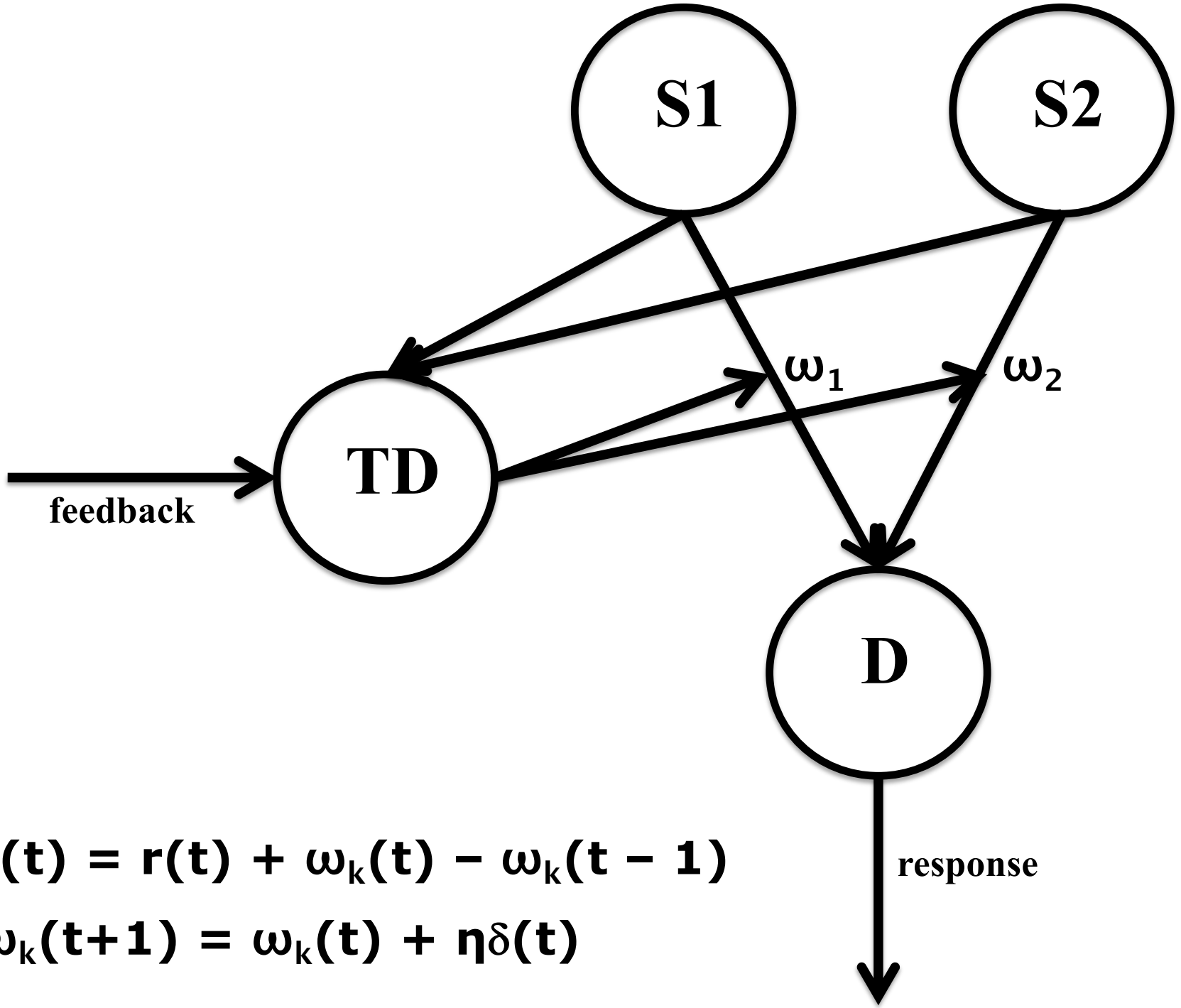


$$

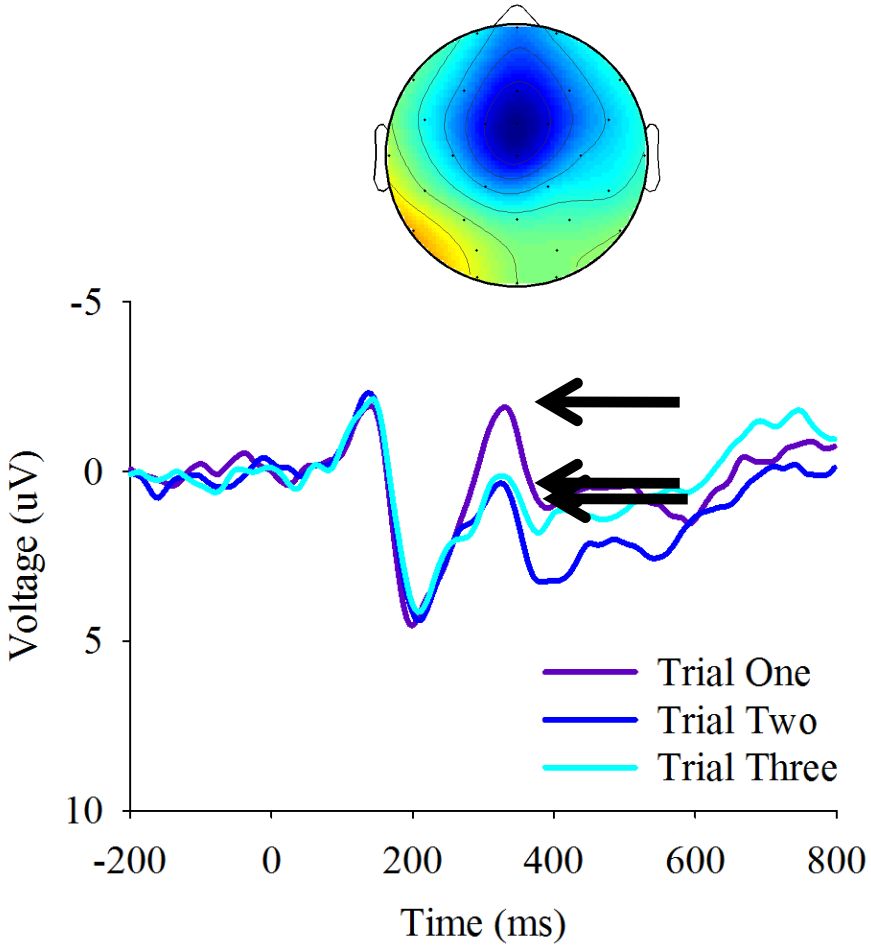
$$P_k = \frac{e^{w_k / t}}{\sum_{k=1}^{2} e^{w_k / t}}$$



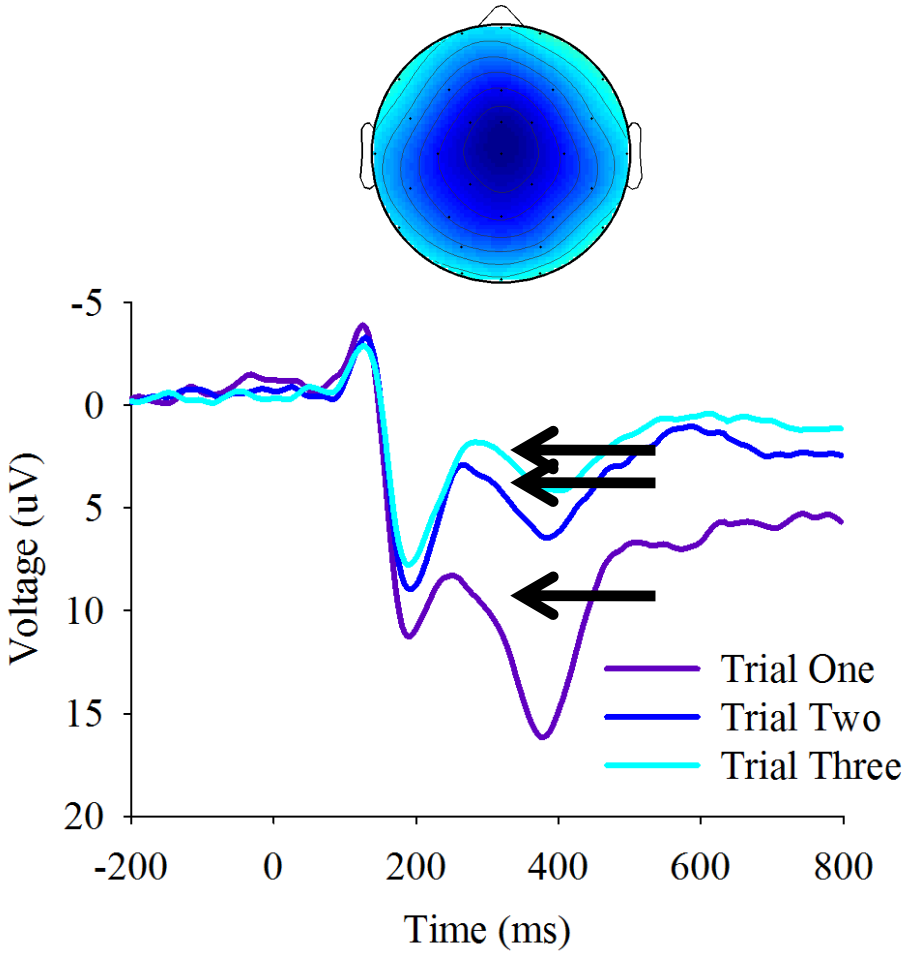


$$\delta(t) = r(t) + \omega_k(t) - \omega_k(t-1)$$

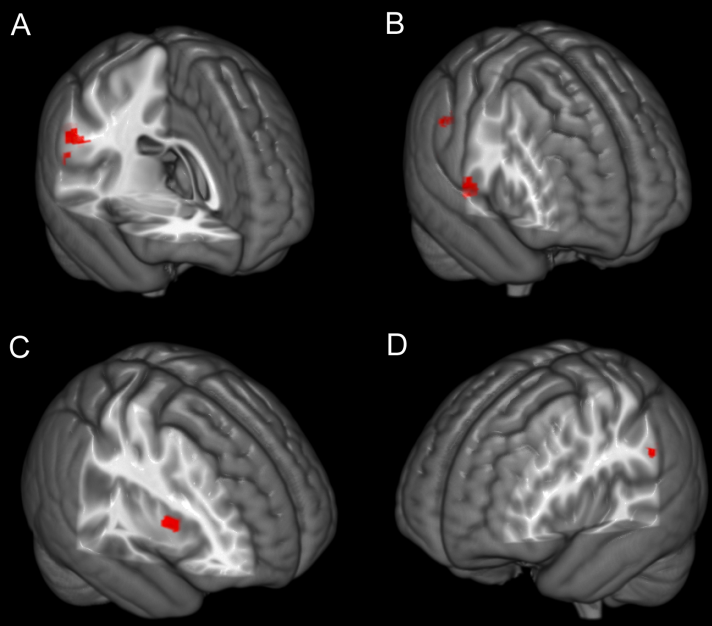
$$\omega_k(t+1) = \omega_k(t) + \eta\delta(t)$$

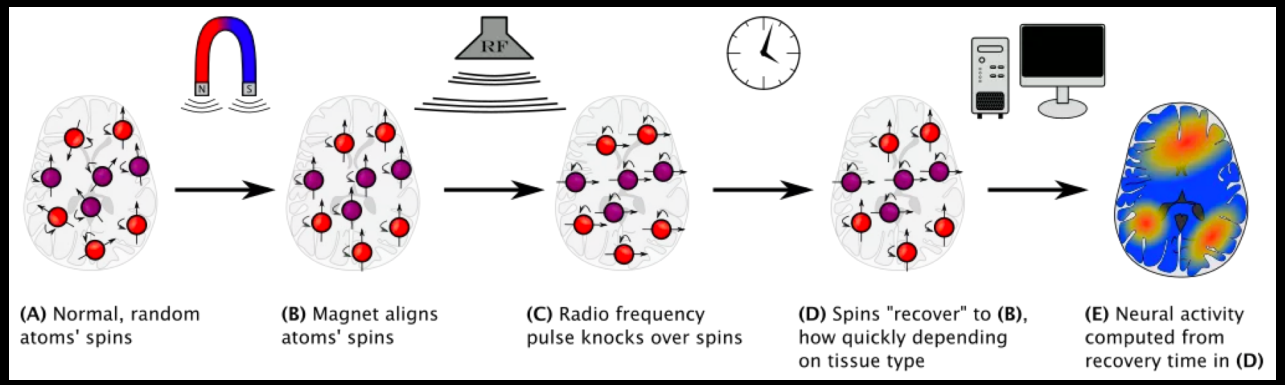


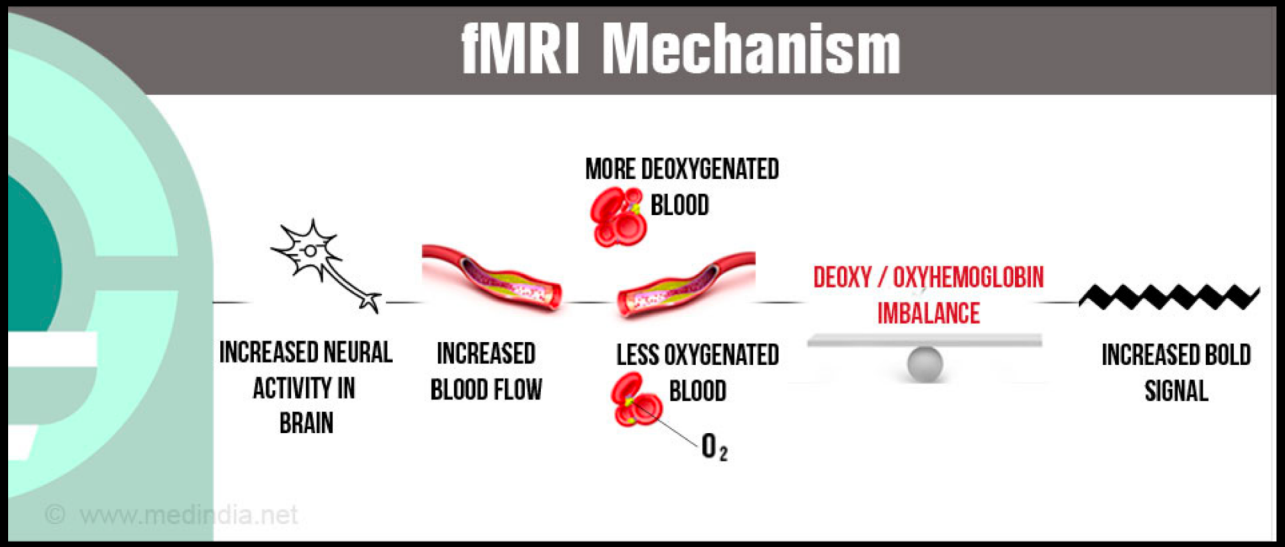
Stimulus Averaged ERP Waveforms



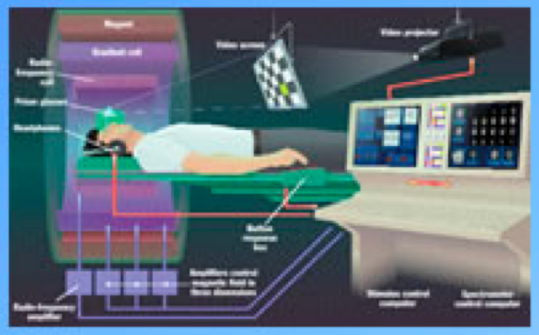
Feedback Averaged ERP Waveforms


A
B
C
D

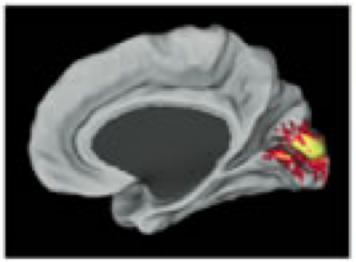

RF
(A) Normal, random atoms' spins
(B) Magnet aligns atoms' spins
(C) Radio frequency pulse knocks over spins
(D) Spins "recover" to (B), how quickly depending on tissue type
(E) Neural activity computed from recovery time in (D)

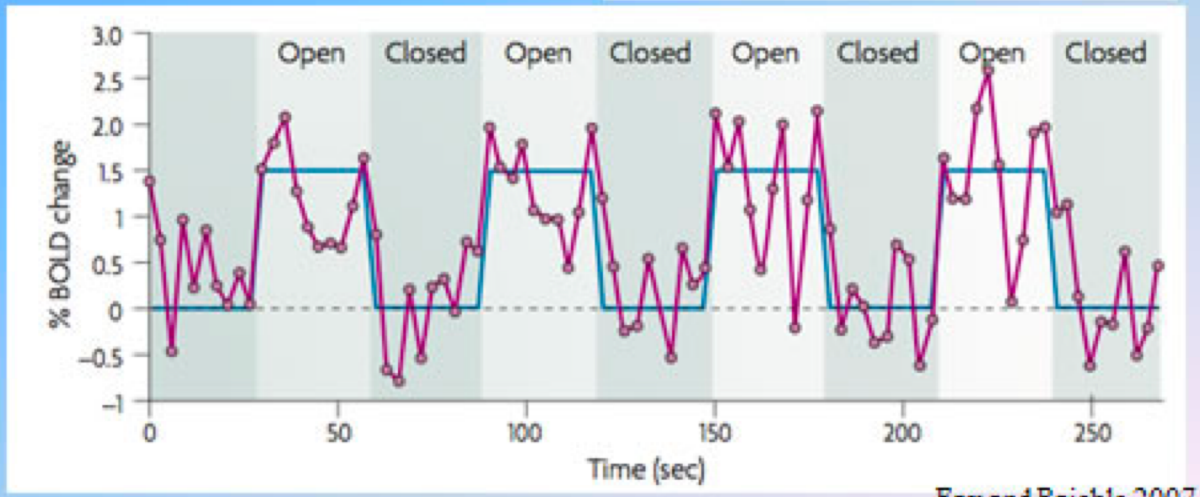

fMRI Mechanism
MORE DEOXYGENATED BLOOD
INCREASED NEURAL ACTIVITY IN BRAIN
INCREASED BLOOD FLOW
LESS OXYGENATED BLOOD
O_2
DEOXY / OXYHEMOGLOBIN IMBALANCE
INCREASED BOLD SIGNAL
© www.medindia.net

Functional MRI



Open – Closed =





Fox and Raichle 2007

Cultural objects modulate reward circuitry

Susanne Erk, Manfred Spitzer, Arthur P. Wunderlich,[1] Lars Galley[2] and Henrik Walter[CA]

Departments of Psychiatry and [1]Diagnostic Radiology, University Clinic Ulm, Leimgrubenweg 12, 89075 Ulm [2]Daimler Chrysler Research Center, Berlin, Germany

[CA]Corresponding Author: henrik.walter@medizin.uni-ulm.de

Received 22 October 2002; accepted 1 November 2002

DOI: 10.1097/01.wnr.0000048542.12213.60

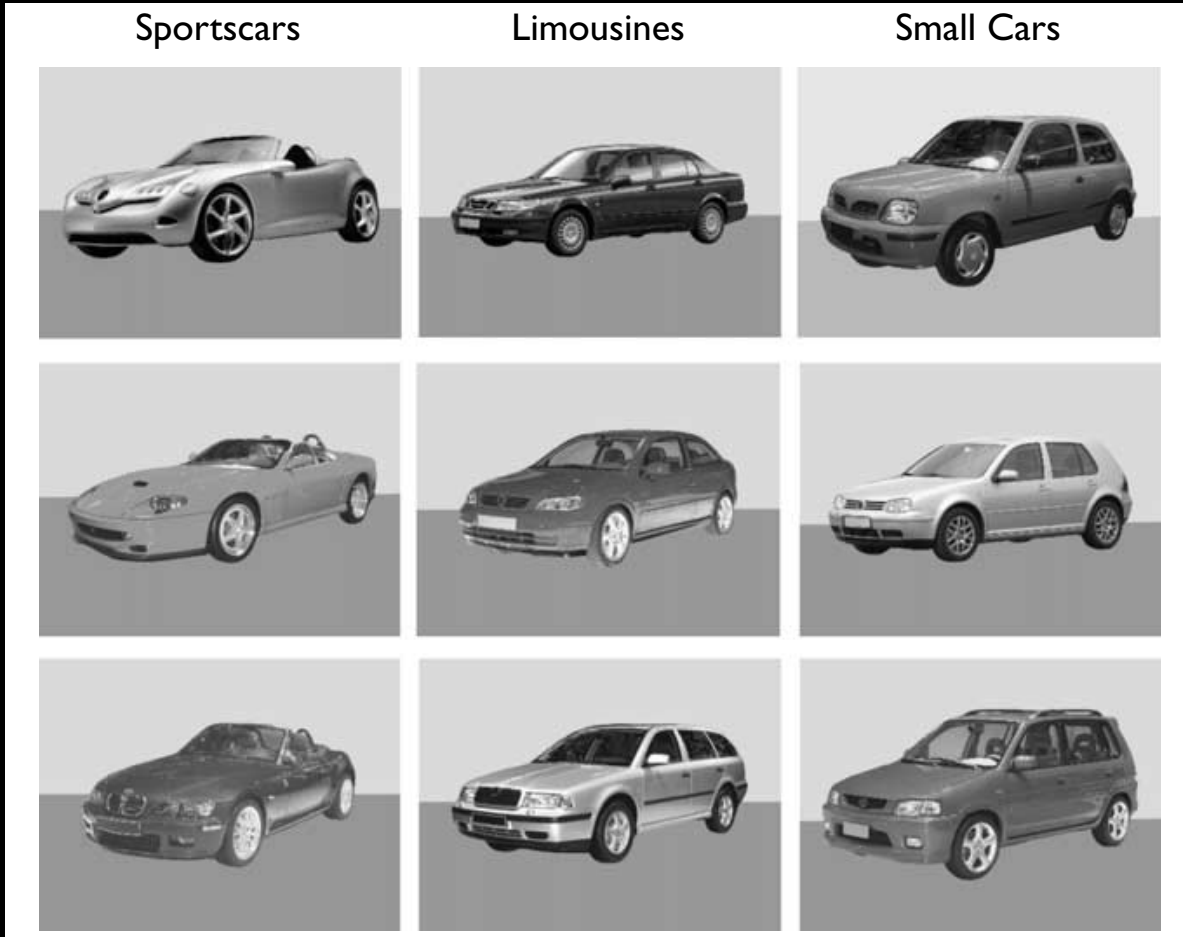
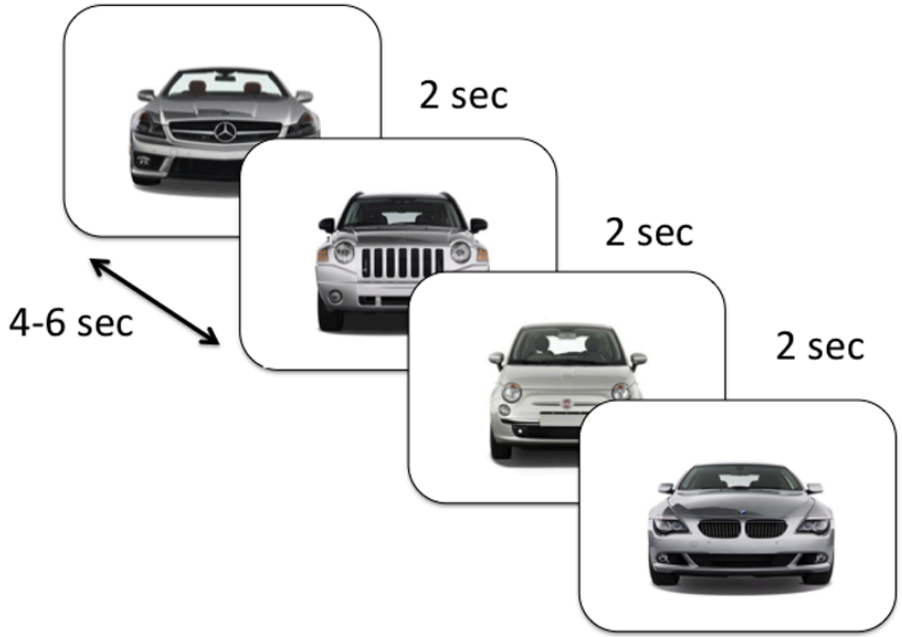
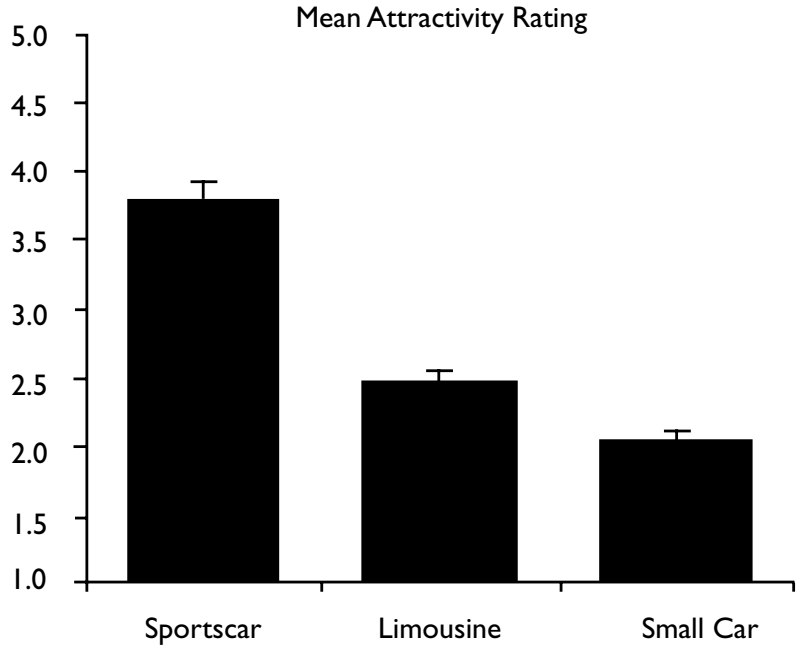


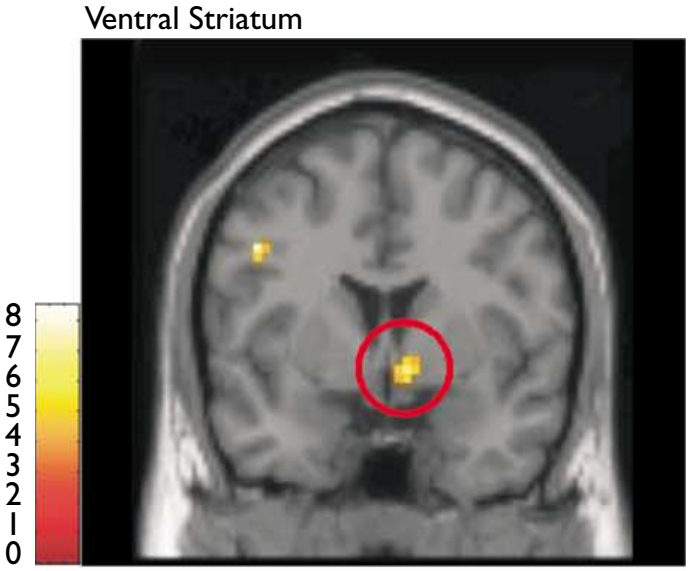
Fig. 1. Picture stimuli. Example of photographs of sports cars, limousines and small cars as used in the experiment.

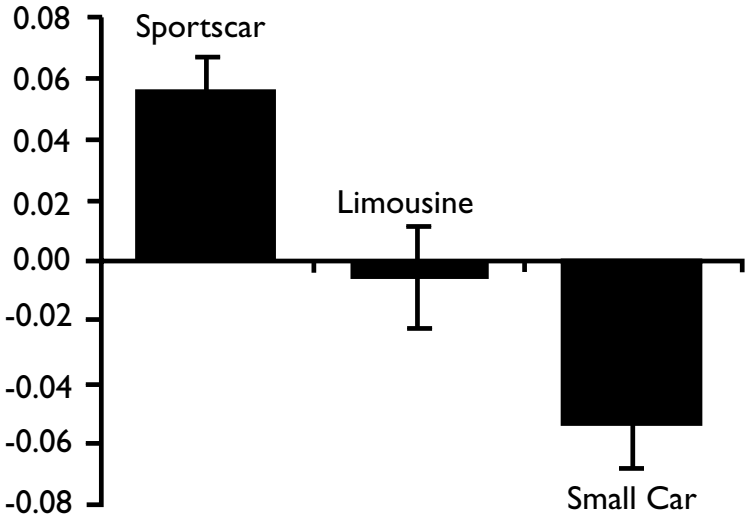
(A) Car fMRI task



(B) Post fMRI car rating task


Mean Attractivity Rating
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
Sportscar
Limousine
Small Car


Ventral Striatum
8
7
6
5
4
3
2
1
0


0.08
0.06
0.04
0.02
0.00
-0.02
-0.04
-0.06
-0.08
Sportscar
Limousine
Small Car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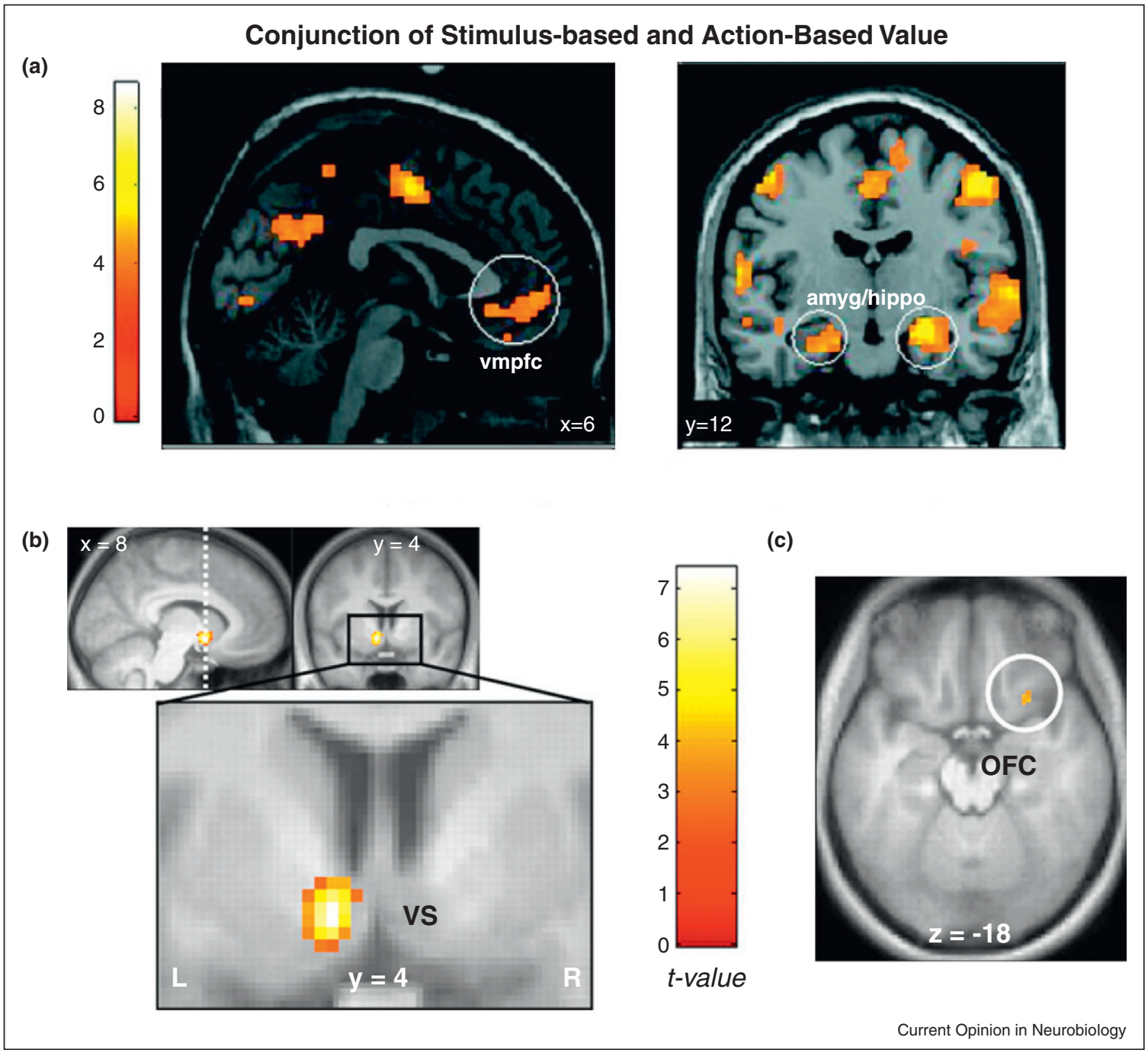
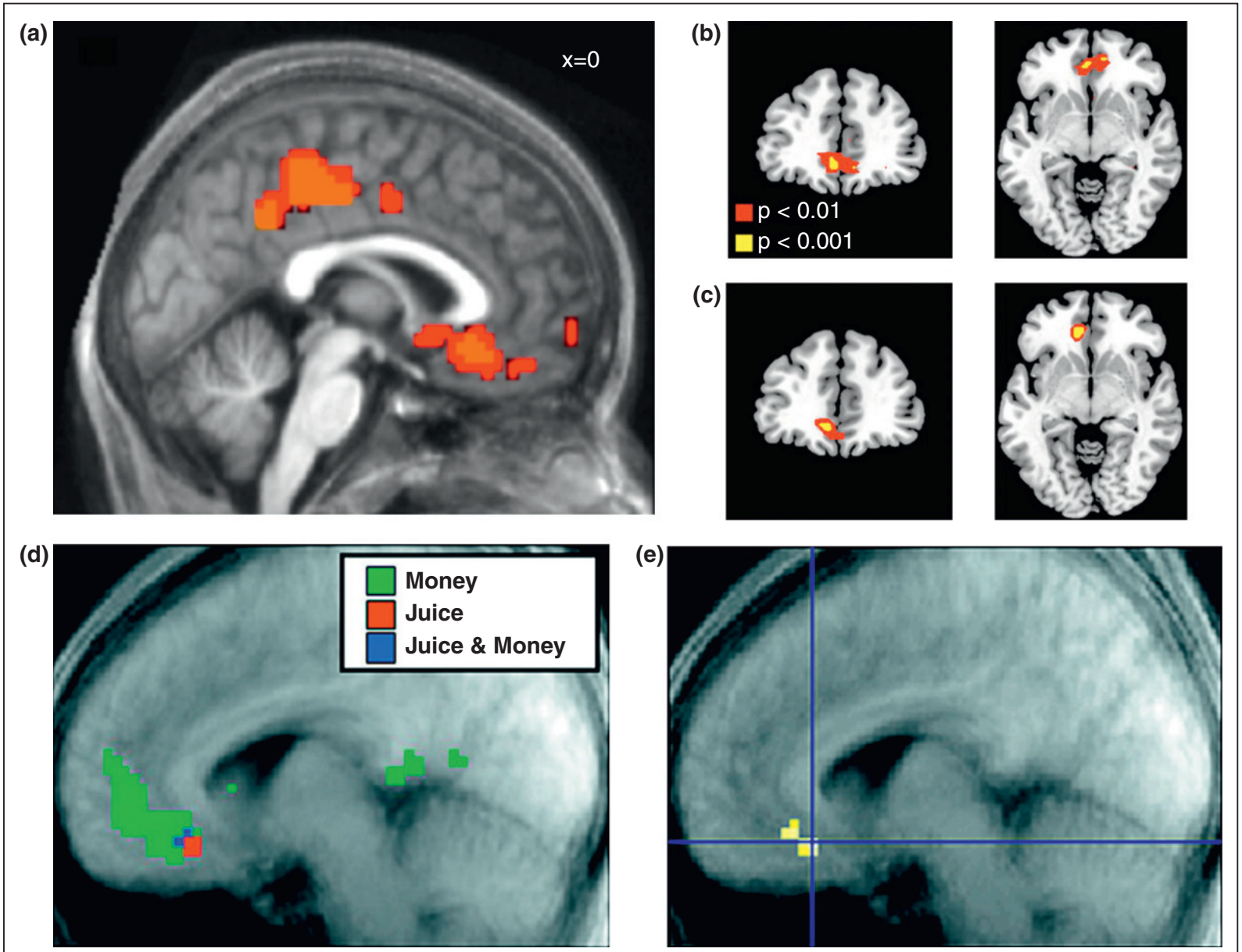
Current Opinion in Neurobiology

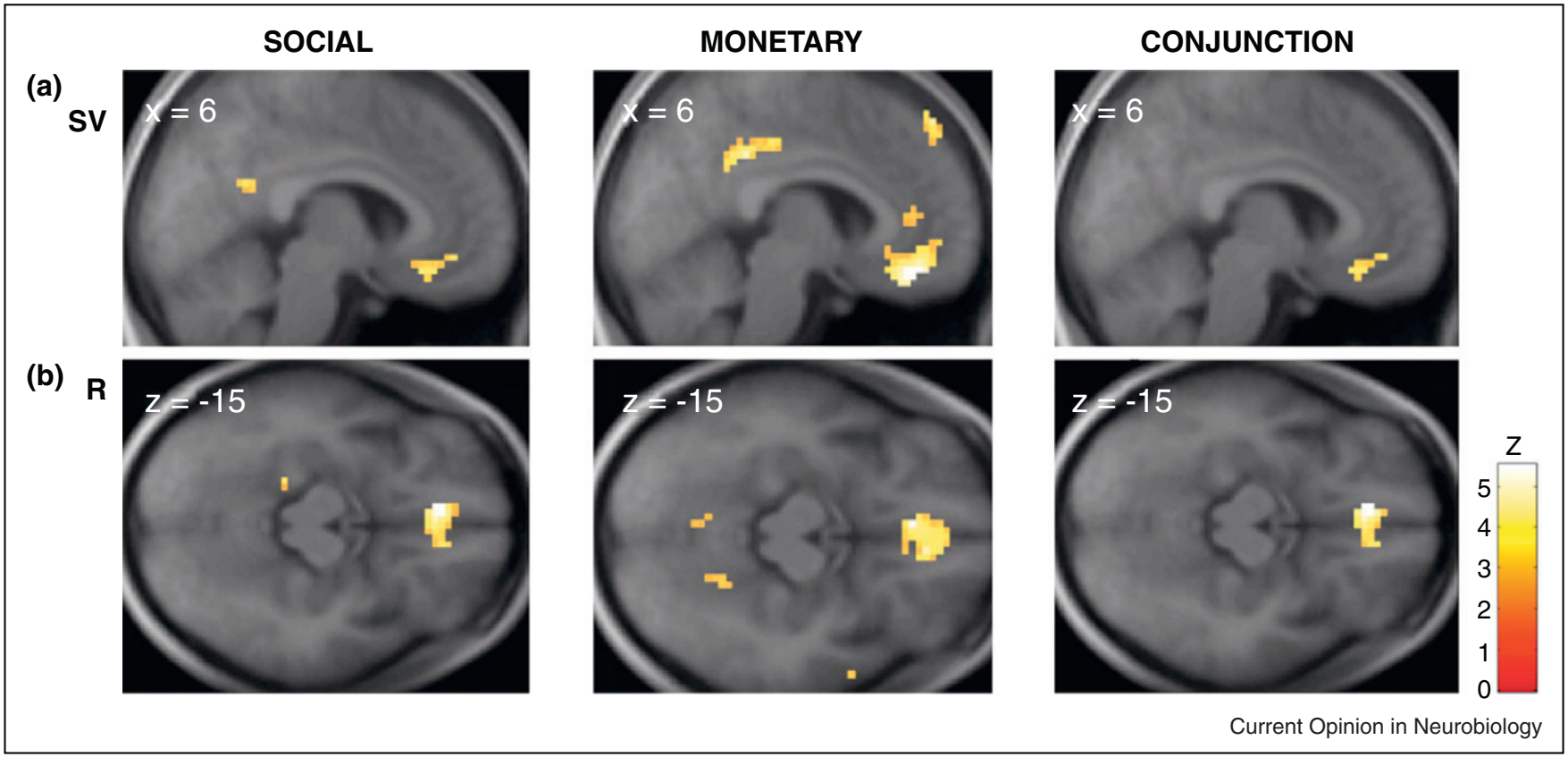
The root of all value: a neural common currency for choice

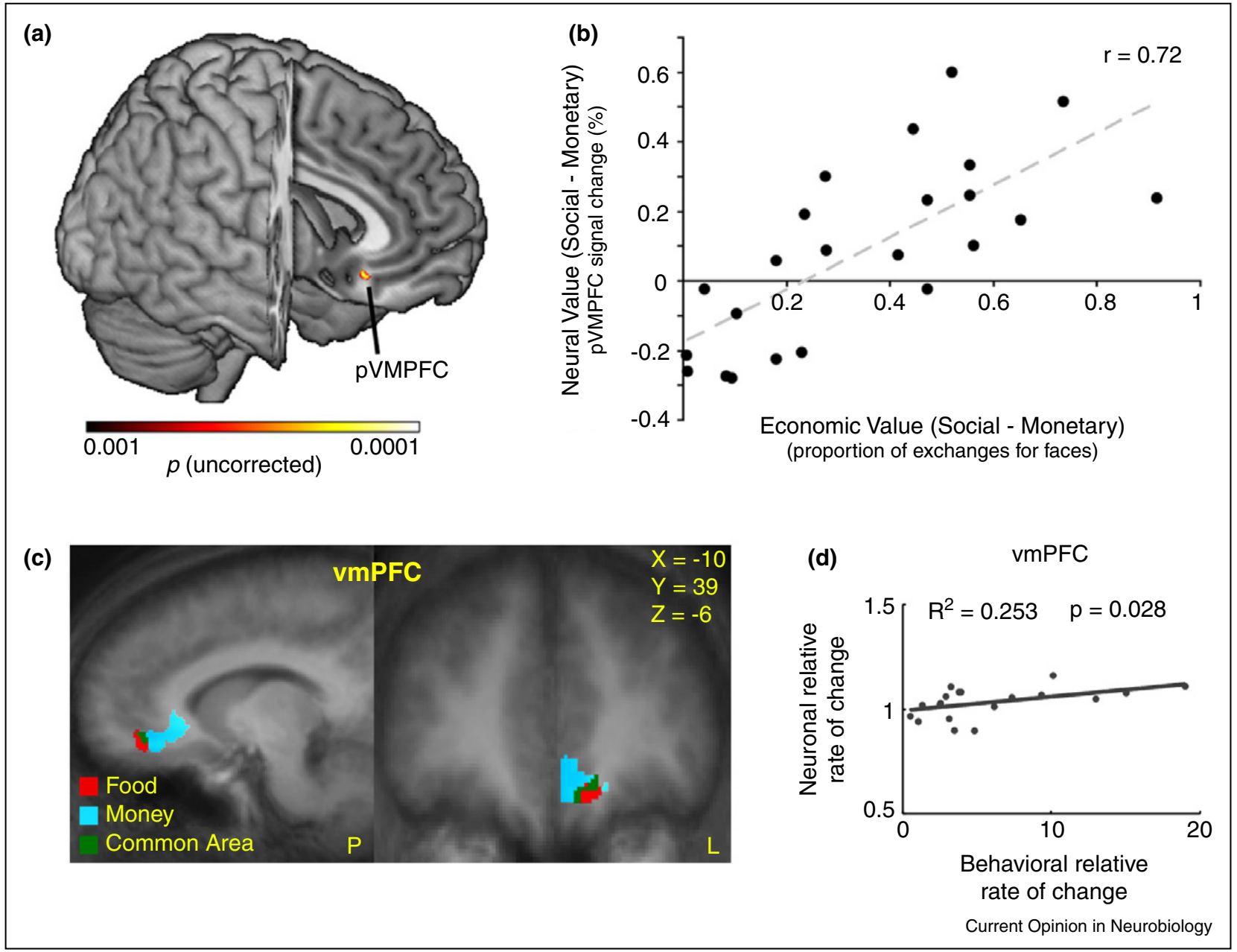
Dino J Levy and Paul W Glimcher

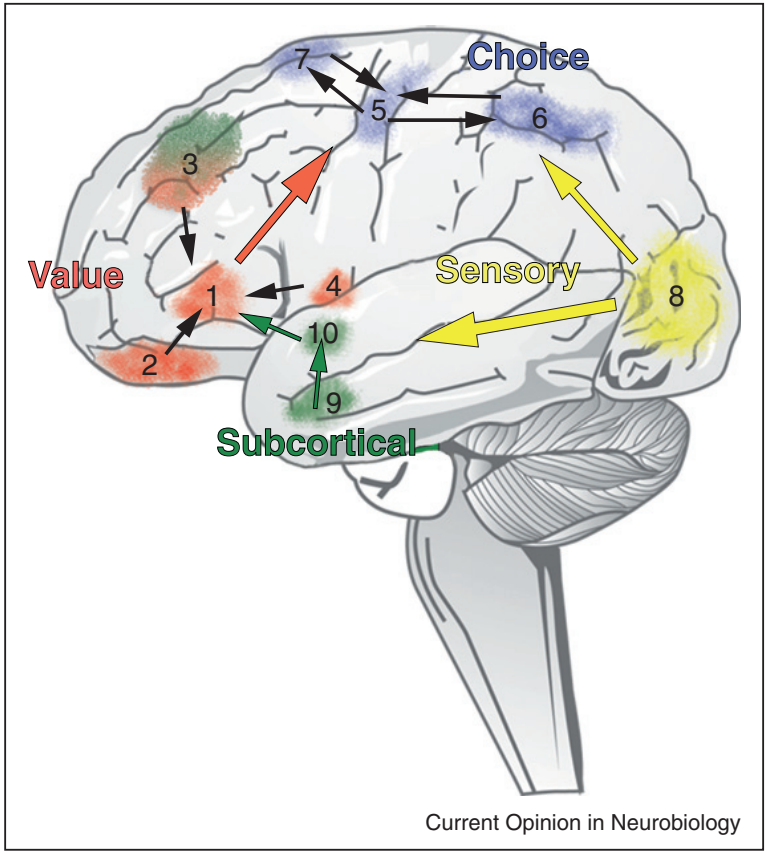

Conjunction of Stimulus-based and Action-Based Value
(a)
8
6
4
2
0
vmpfc
x=6
amyg/hippo
y=12
(b)
x = 8
y = 4
VS
L
y = 4
R
7
6
5
4
3
2
1
0
t-value
(c)
OFC
z = -18
Current Opinion in Neurobiology



Current Opinion in Neurobiology

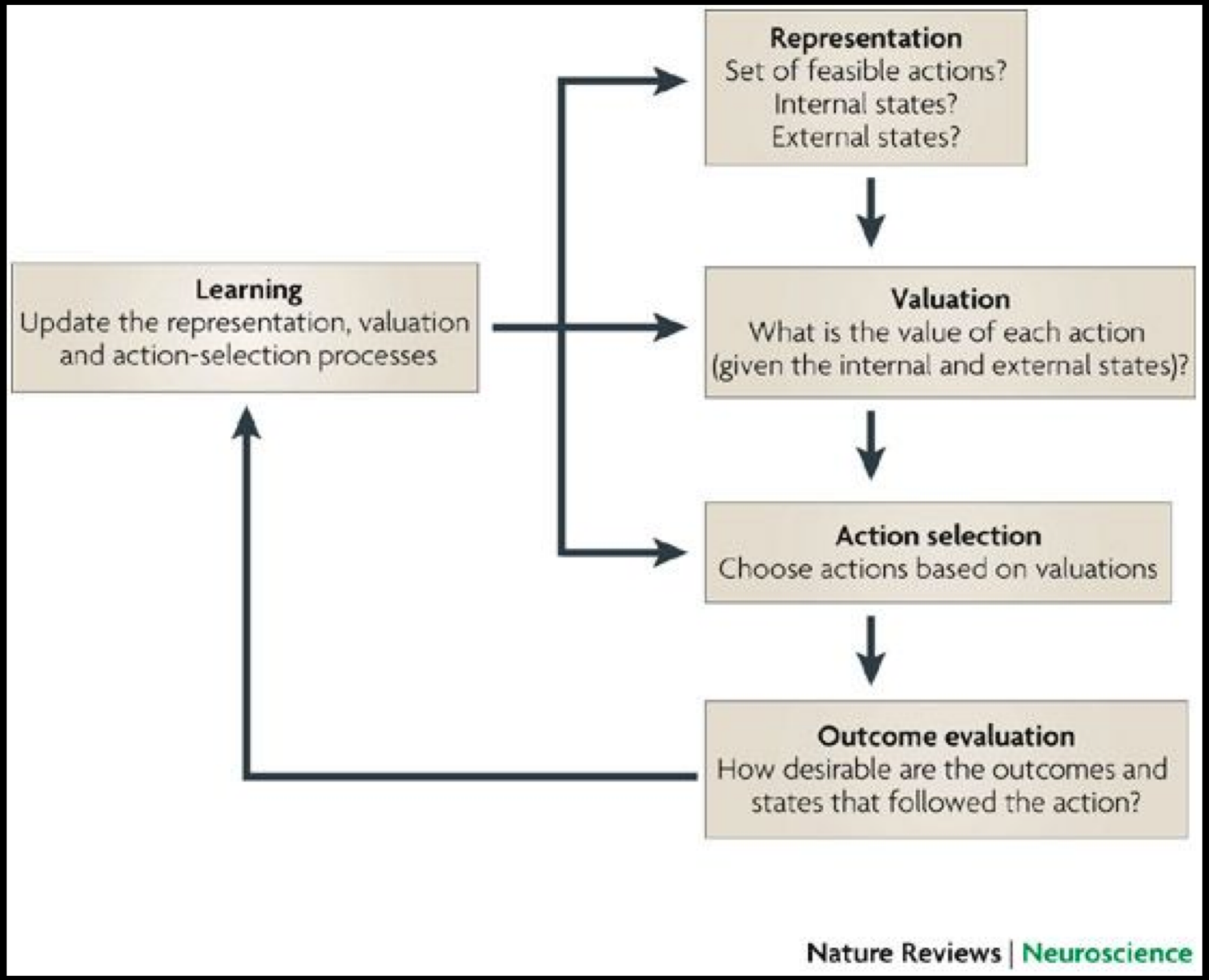

SOCIAL
MONETARY
CONJUNCTION
(a)
SV
x = 6
x = 6
x = 6
(b)
R
z = -15
z = -15
z = -15
Z
5
4
3
2
1
0
Current Opinion in Neurobiology


(a)
pVMPFC
0.001
0.0001
p (uncorrected)
(b)
r = 0.72
Neural Value (Social - Monetary)
pVMPFC signal change (%)
0.6
0.4
0.2
0
-0.2
-0.4
0.2
0.4
0.6
0.8
1
Economic Value (Social - Monetary)
(proportion of exchanges for faces)
(c)
vmPFC
X = -10
Y = 39
Z = -6
Food
Money
Common Area
P
L
(d)
vmPFC
R2 = 0.253
p = 0.028
Neuronal relative
rate of change
1.5
1
0.5
0
10
20
Behavioral relative
rate of change
Current Opinion in Neurobiology



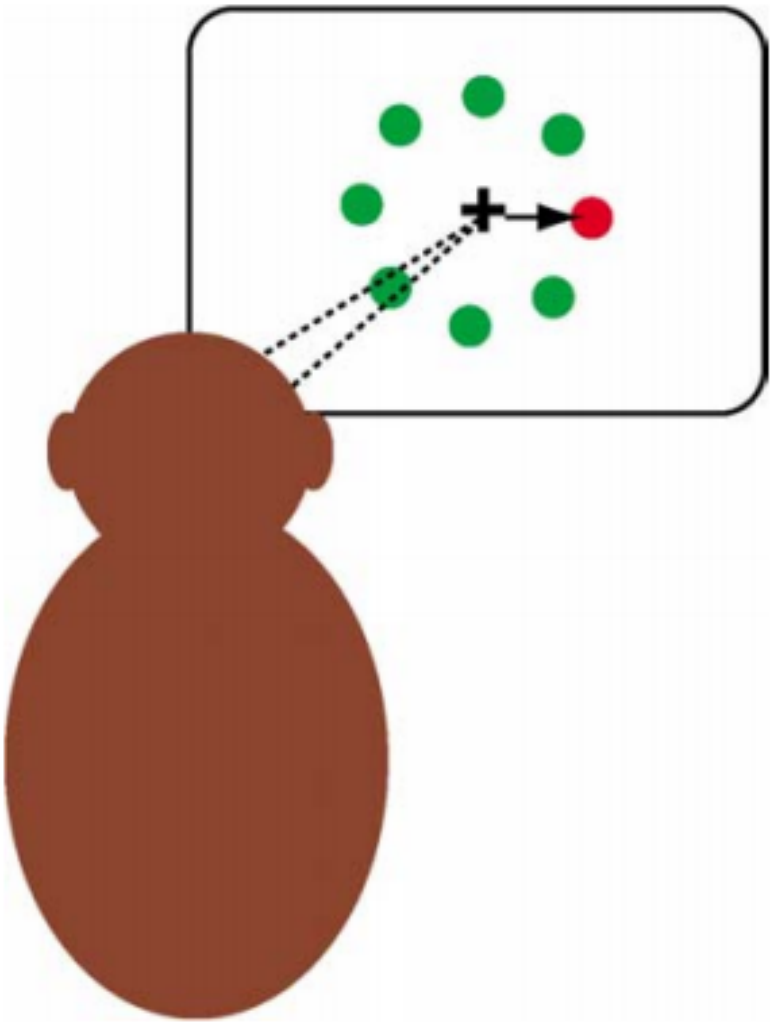
One possible schema for understanding the decision-making networks of the human brain. Current evidence suggests that information from cortical and subcortical structures converges toward a single common value representation before passing on to the choice-related motor control circuitry. Modulatory inputs play a critical role in establishing this final common representation with those inputs carrying signals related to arousal, internal state (satiety, thirst, hormonal levels, etc.) and emotional intensity. In this schema, sensory information from all modalities carries, among other things, the identity and location of the options. We use visual signals in this diagram to stand for information from all sensory modalities. (1) vmPFC, (2) OFC, (3) DLPFC, (4) Insula, (5) Primary motor cortex (M1), (6) Posterior parietal cortex, (7) frontal eye fields, (8) Visual cortex, (9) Amygdala, (10) Striatum.

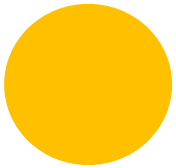
Decision Making

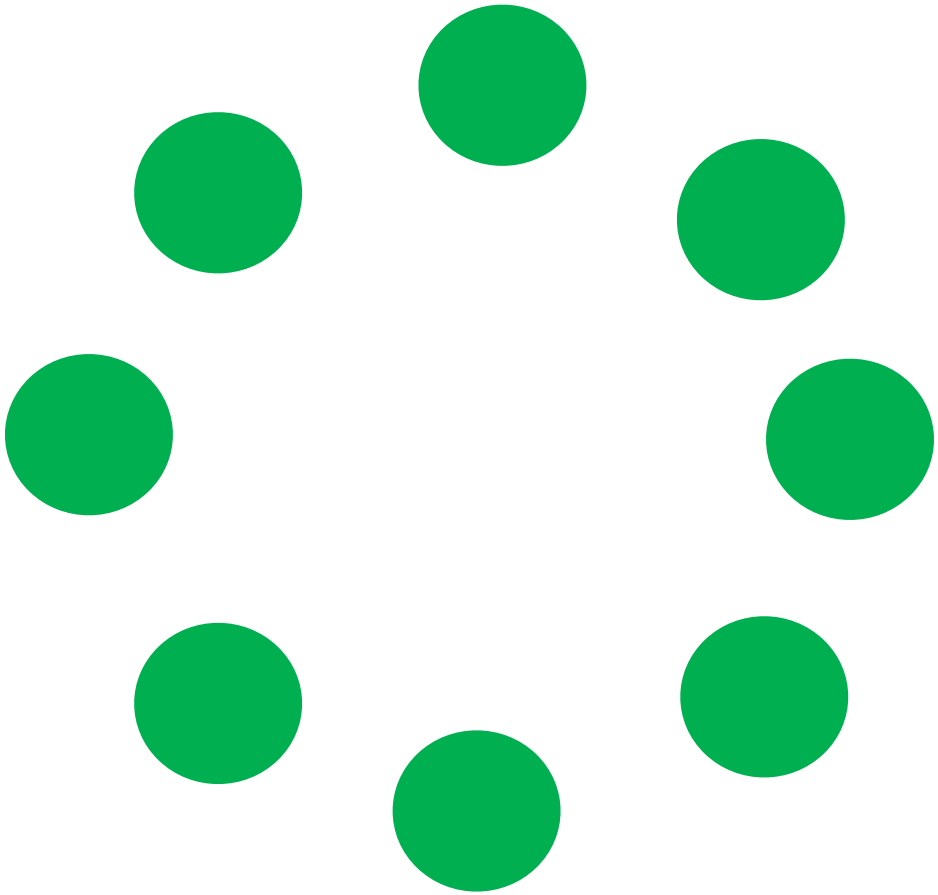

Representation
Set of feasible actions?
Internal states?
External states?
Learning
Update the representation, valuation and action-selection processes
Valuation
What is the value of each action (given the internal and external states)?
Action selection
Choose actions based on valuations
Outcome evaluation
How desirable are the outcomes and states that followed the action?
Nature Reviews | Neuroscience

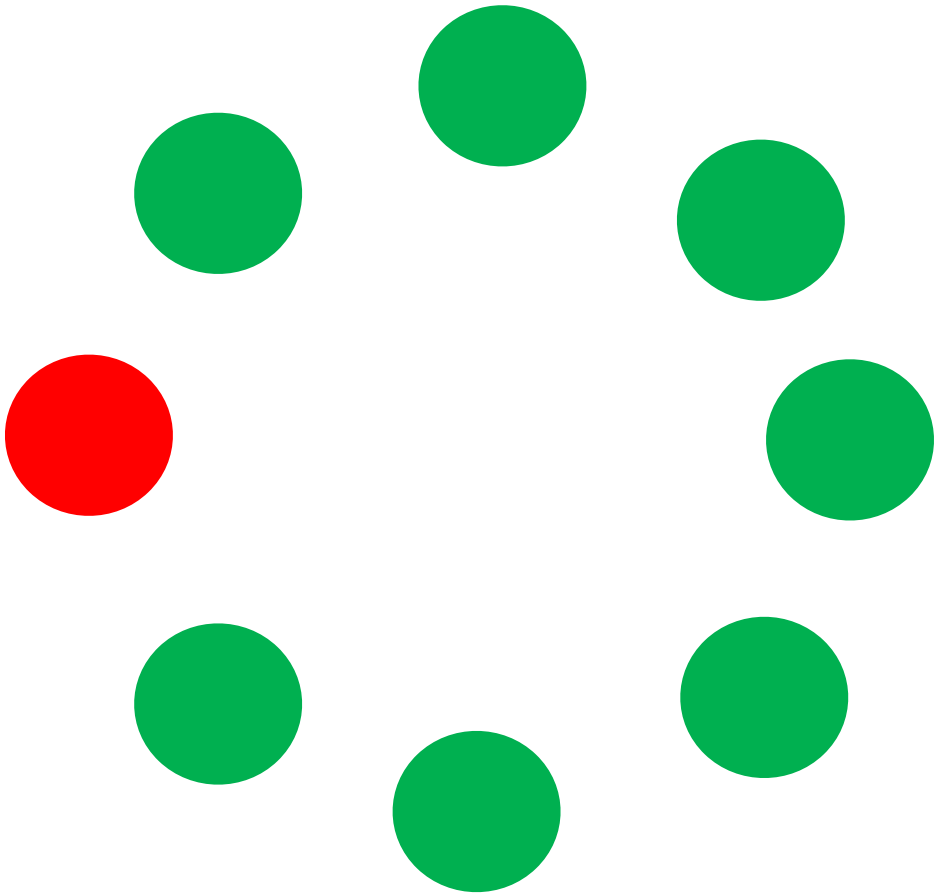
Hanes & Schall, 1996

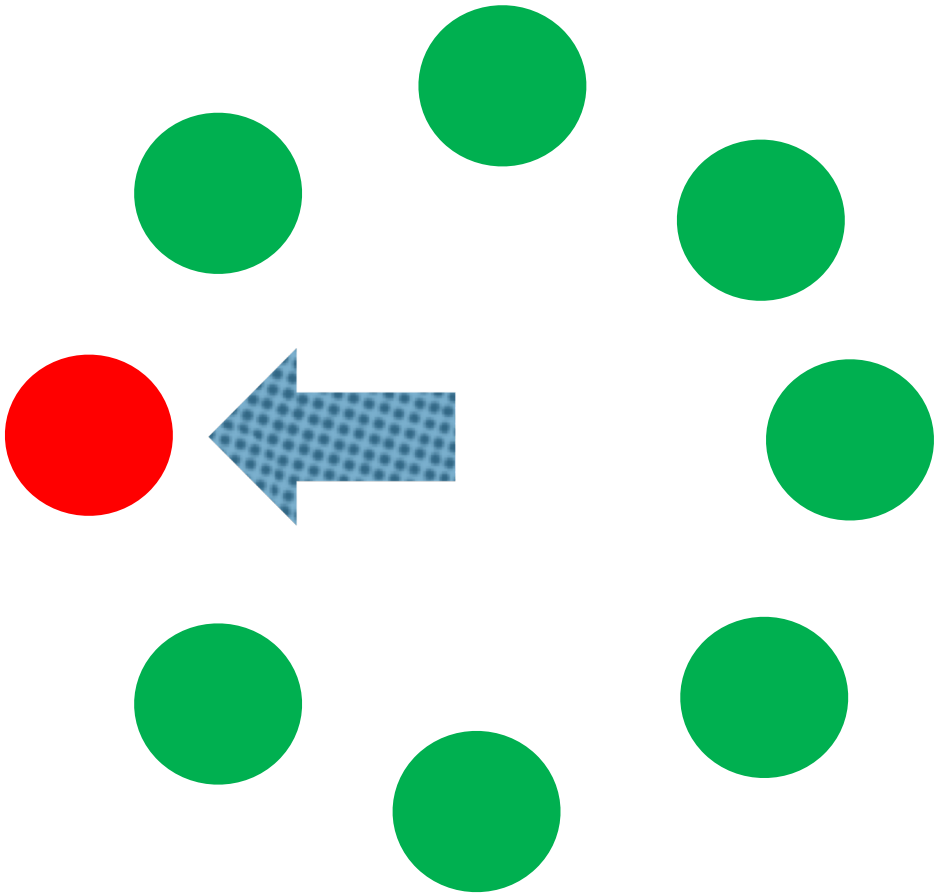
- Monkey is situated in a chair, trained to stare at a blank screen
- Recording of neuronal activity in PPC
- Stimulus onset (circle of green circles)
- Monkey chooses odd dot
- Monkey receives juice



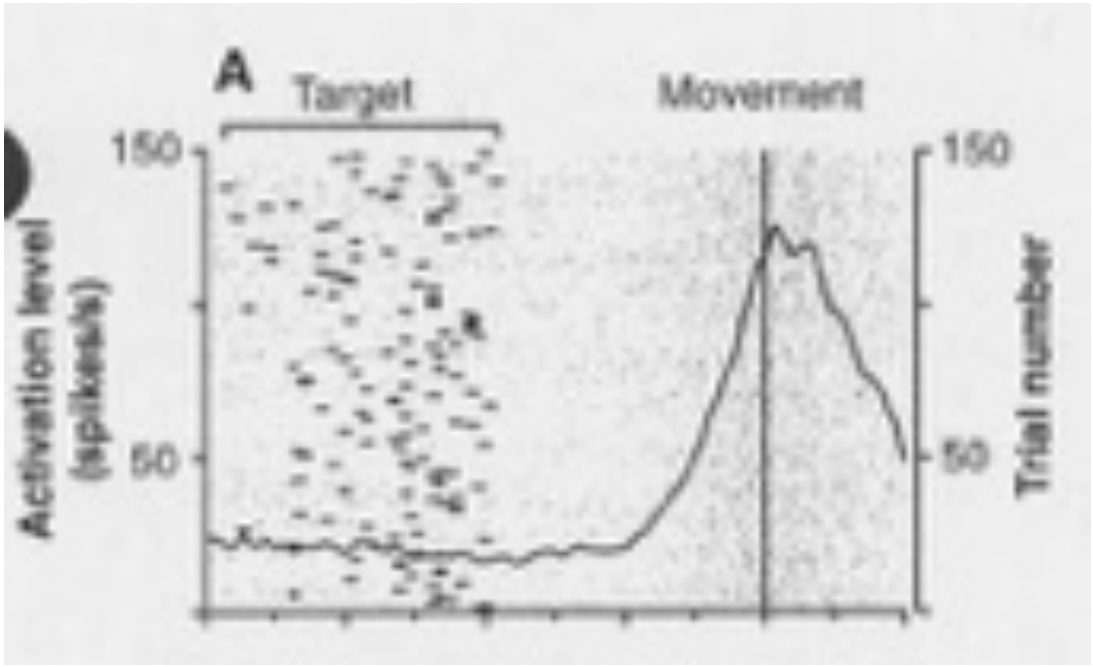


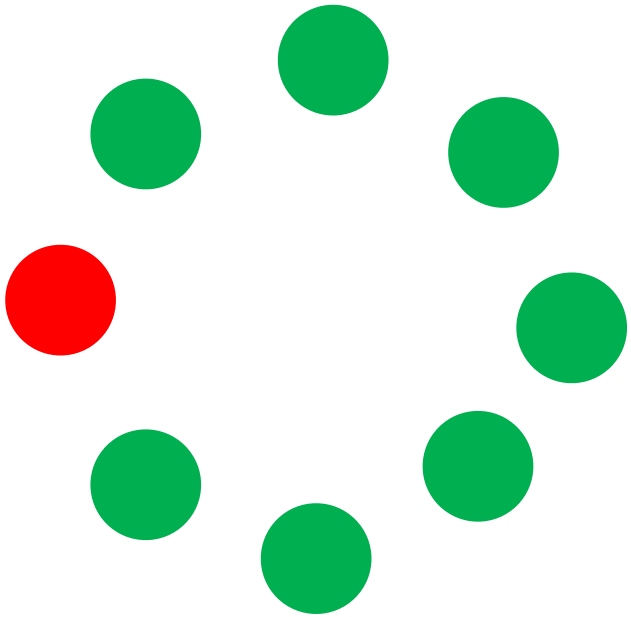






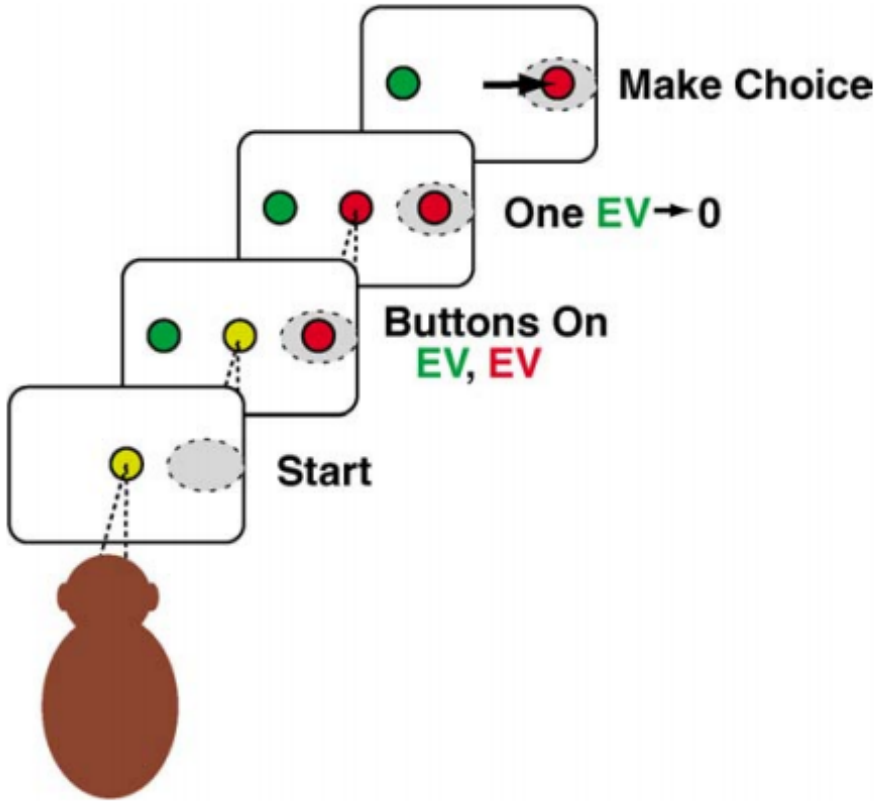
Hanes & Schall, 1996

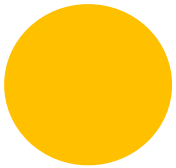


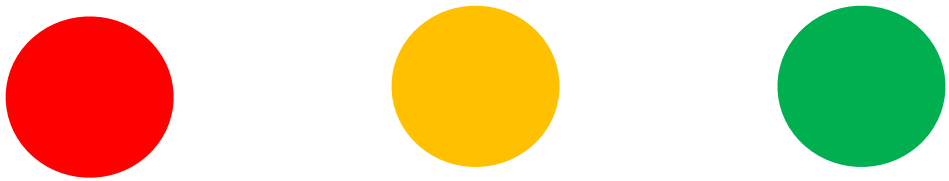


Glimcher at al. 2004

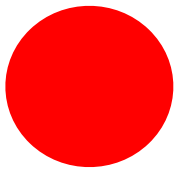
- do neurons encode choice values?



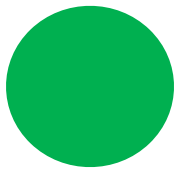





Minute Maid
100% JUICE
APPLE JUICE
FROM CONCENTRATE WITH ADDED INGREDIENTS
100
CALORIES
PER BOX



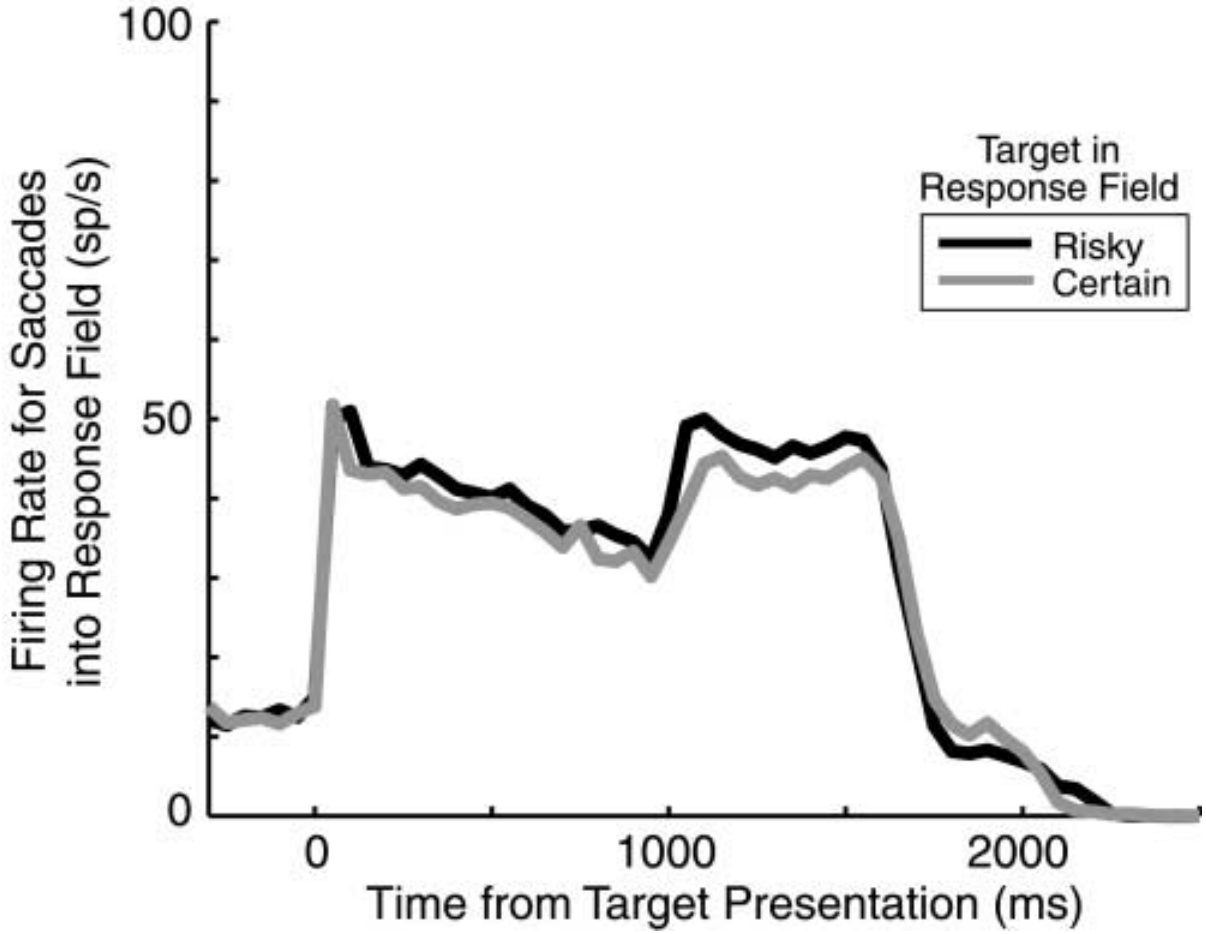
0.8 ml juice



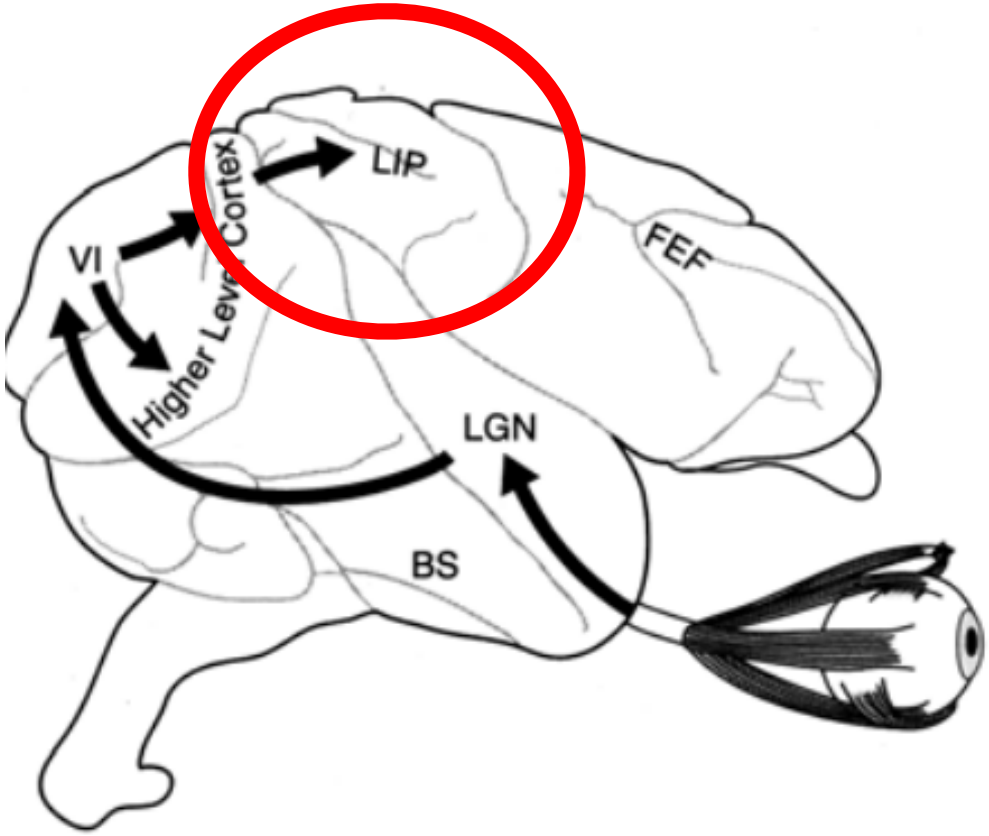
0.2 ml juice

Glimcher et al. 2004

$$\frac{LeftReward}{LeftReward + RightReward} = FiringRate.$$

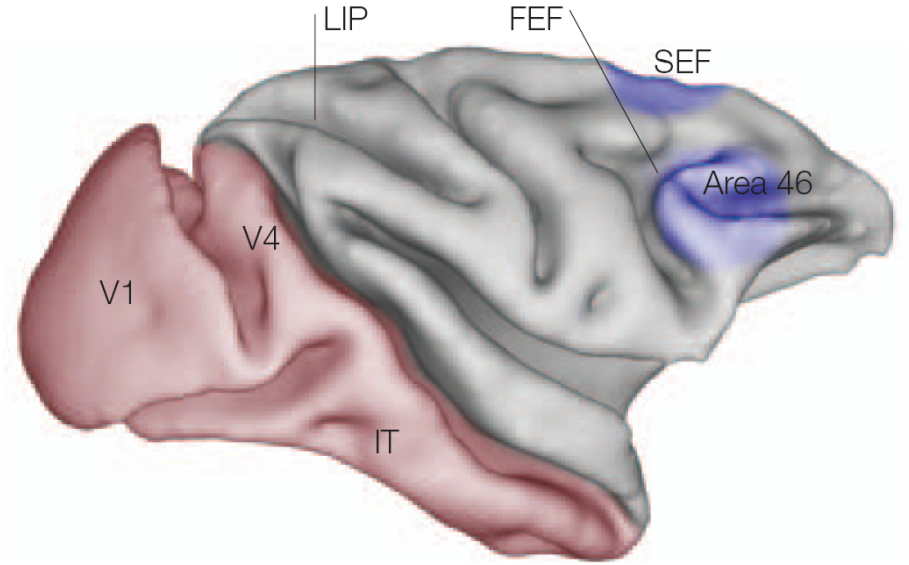

100
50
0
Firing Rate for Saccades into Response Field (sp/s)
Target in Response Field
Risky
Certain
0
1000
2000
Time from Target Presentation (ms)

Neurons in the the lateral intraparietal cortex (LIP) scaled in firing rate to expected utility



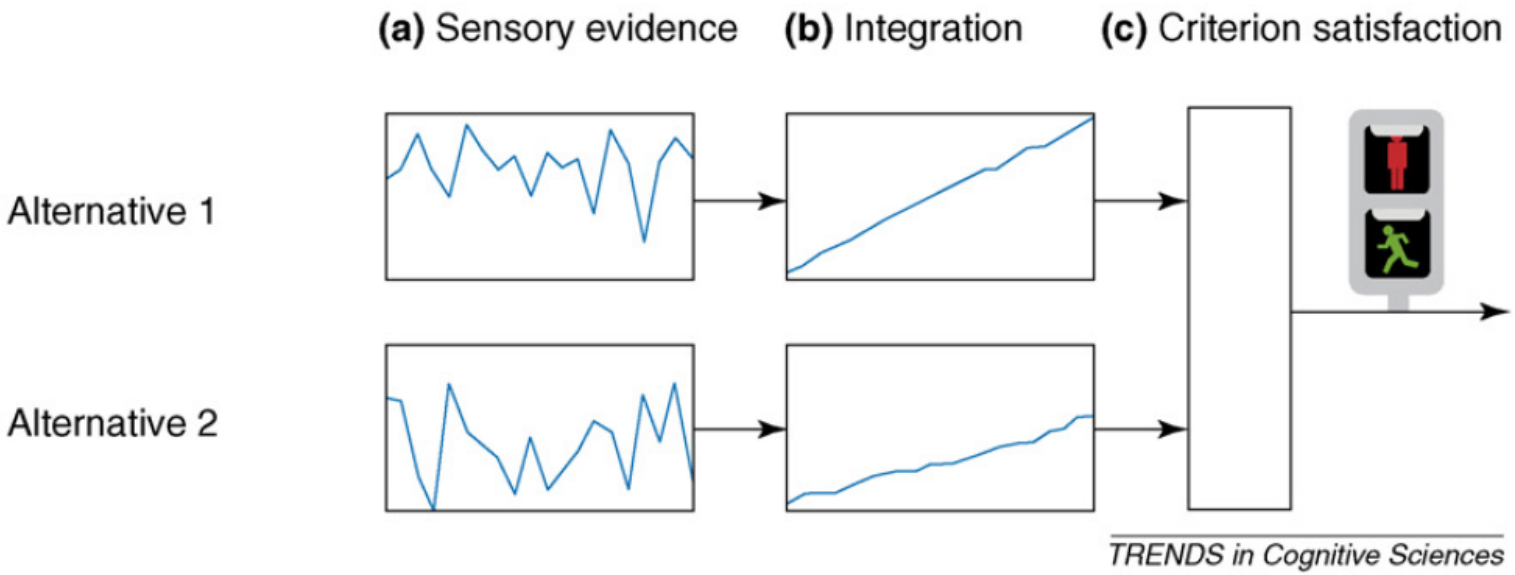
Glimcher *et al* (2004)

Monkey Brain



- LIP area – part of visuo-motor pathway
- Its activation is covaried with choice AND modulated by movement strength during motion
- not purely sensory (mistake trials);
- not purely decision oriented (modulated by strength of movement)
- LIP is where “deliberation” takes place

Three processes of choice



- Neurons in Visual cortex provide evidence for alternatives (noisy)
- Intergation takes place (in LIP), removes noise
- The choice is made once certain criterion is reached (confidence level)

In the human brain the story is more complex.

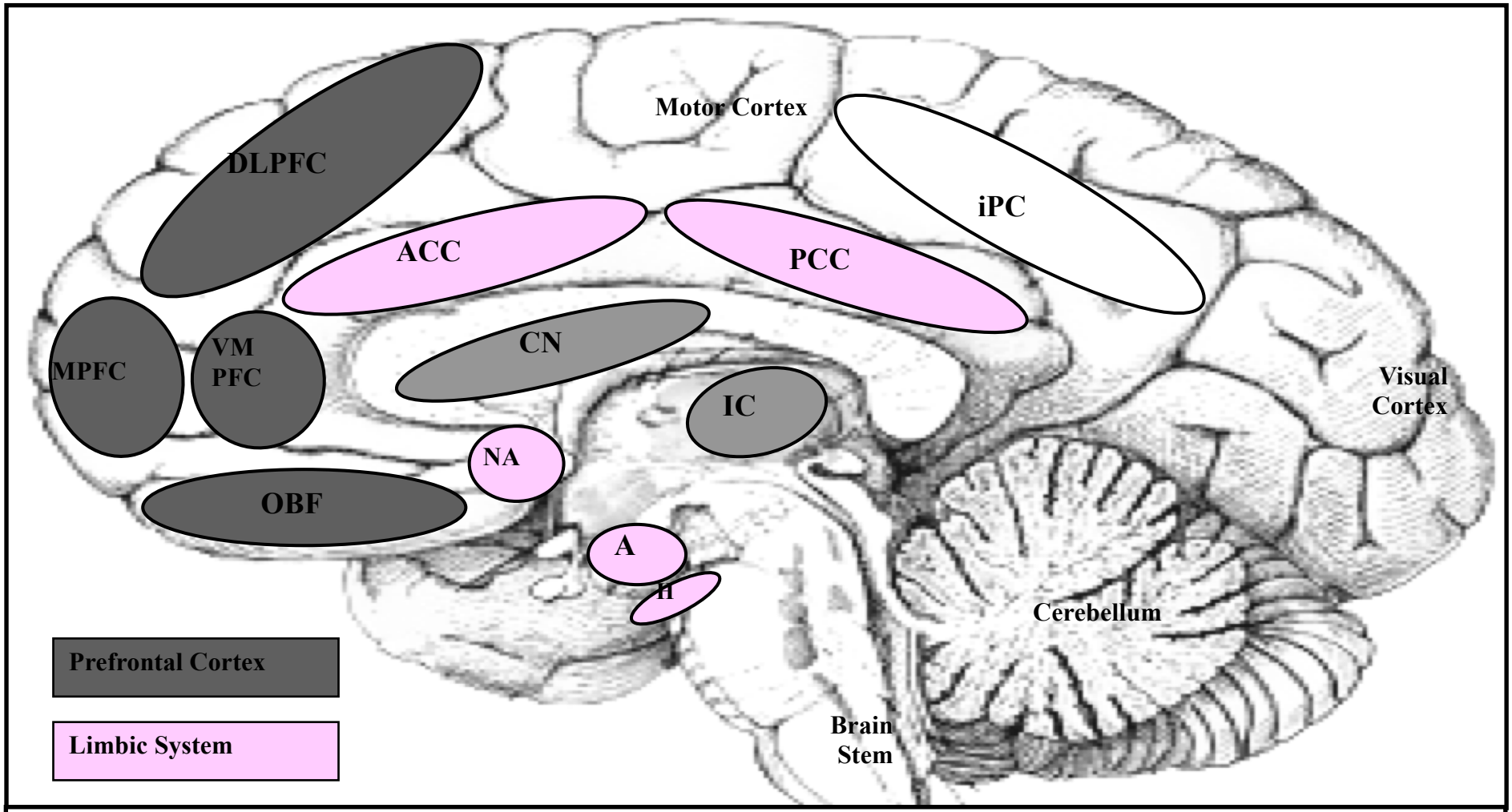
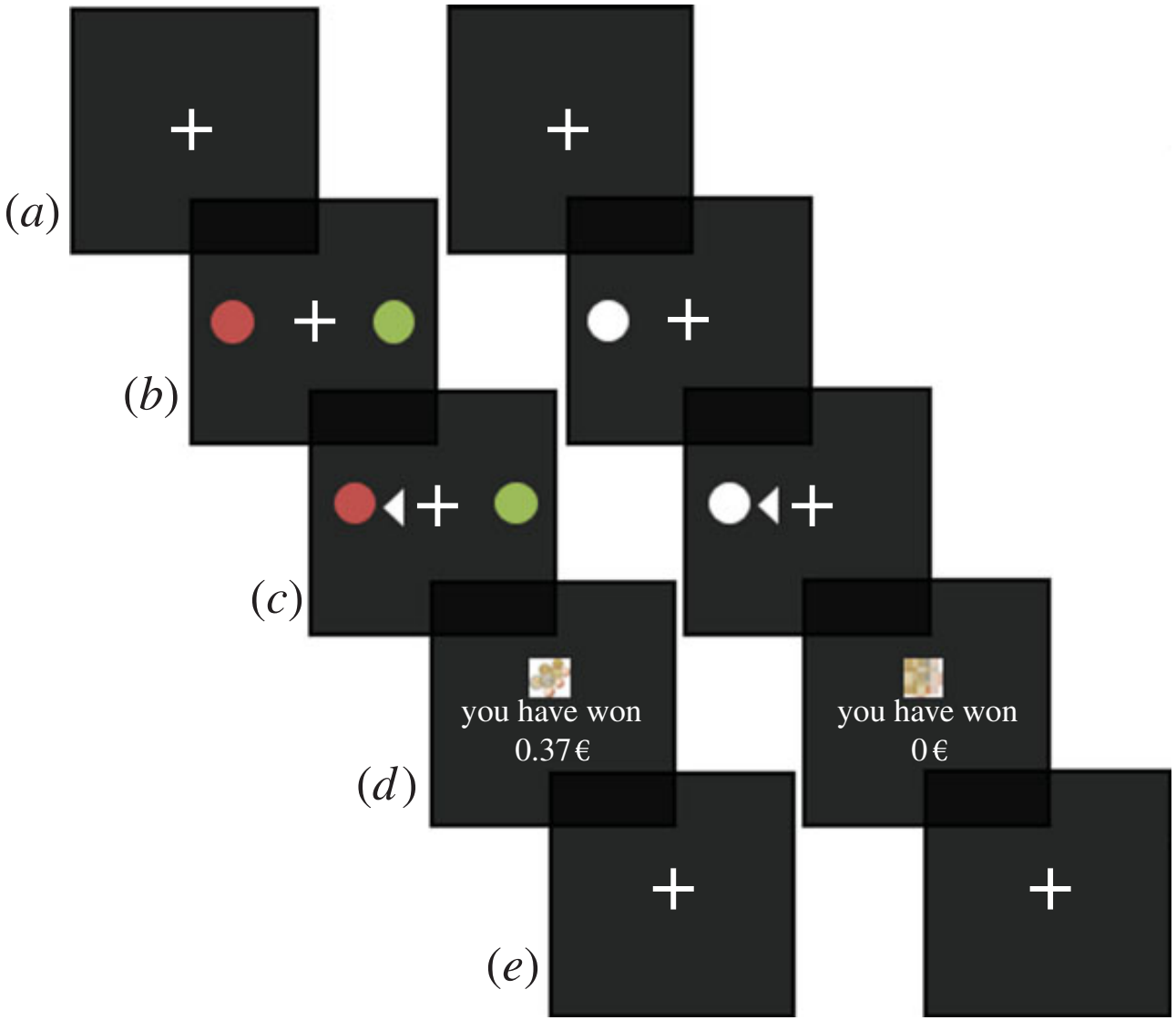


Figure 2. The Major Areas of the Brain

DLPFC: Dorsolateral Prefrontal Cortex - VMPFC: Ventromedial Prefrontal Cortex - OBF: Orbitofrontal Cortex - MPFC: Medial Prefrontal Cortex - ACC/PCC: Anterior/ Posterior Cingulate Cortex - NA: Nucleus Accumbens - A: Amygdala - H: Hippocampus - CN: Caudate Nucleus - IC: Insular Cortex

Uncovering the spatio-temporal dynamics of value-based decision-making in the human brain: a combined fMRI – EEG study

Tobias Larsen[1,2] and John P. O'Doherty[1,2]


(a)
(b)
(c)
(d)
(e)
you have won
0.37€
you have won
0€

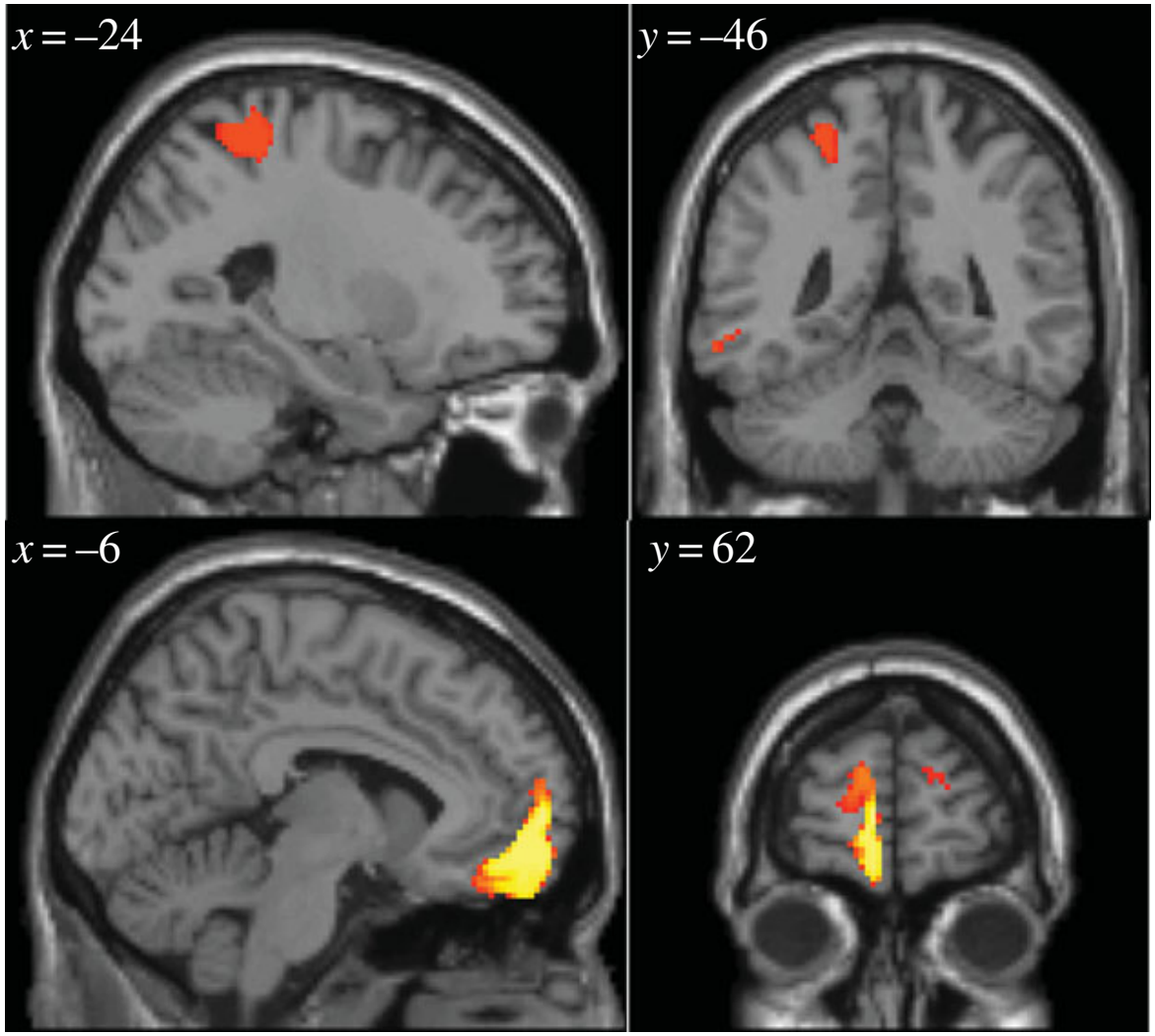
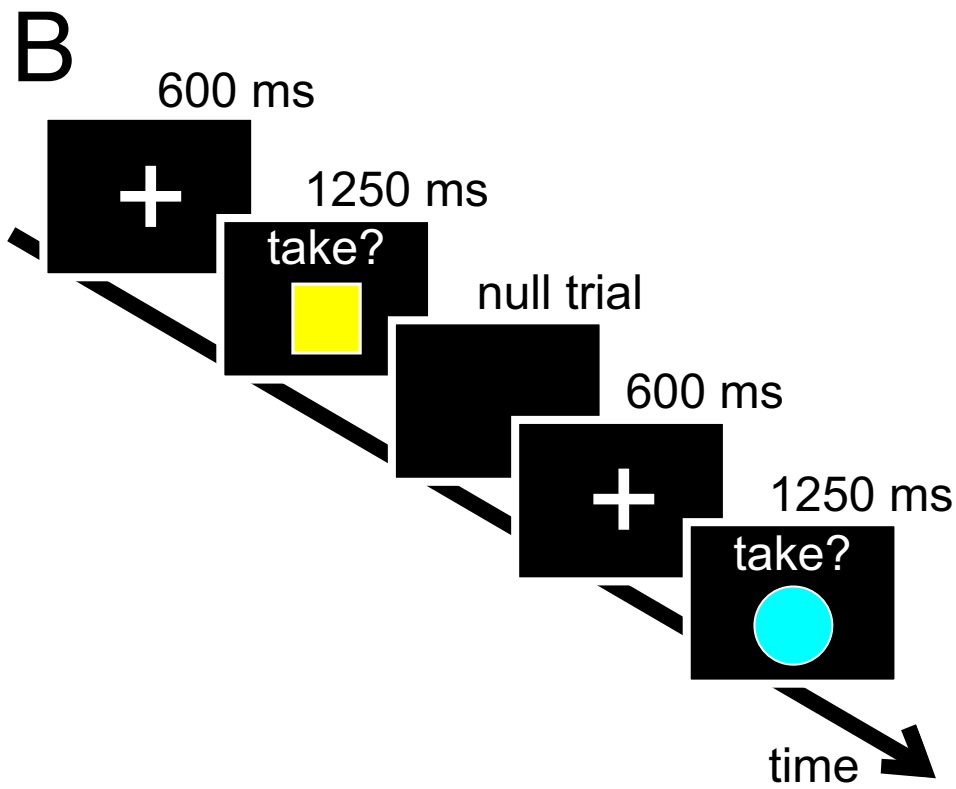


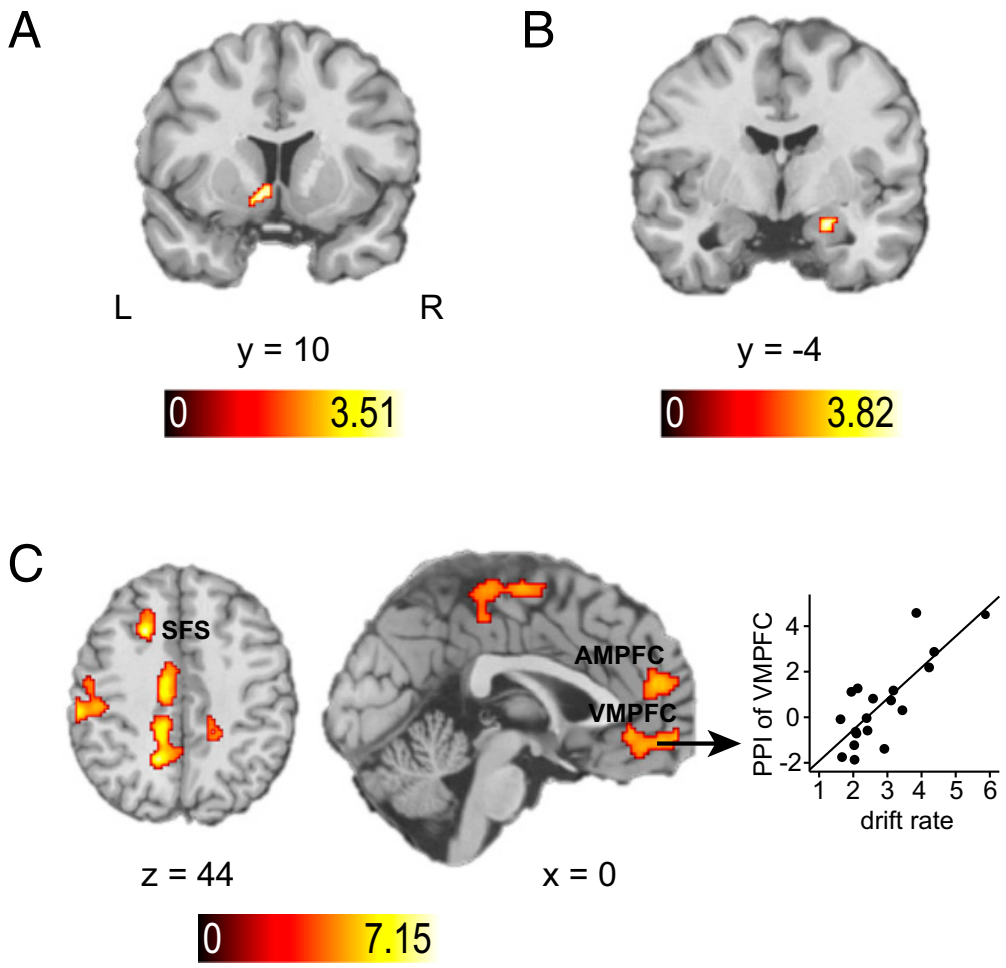
Figure 6. fMRI-informed source localization of chosen value with threshold set at $p < 0.0005$ (unc). (Online version in colour.)

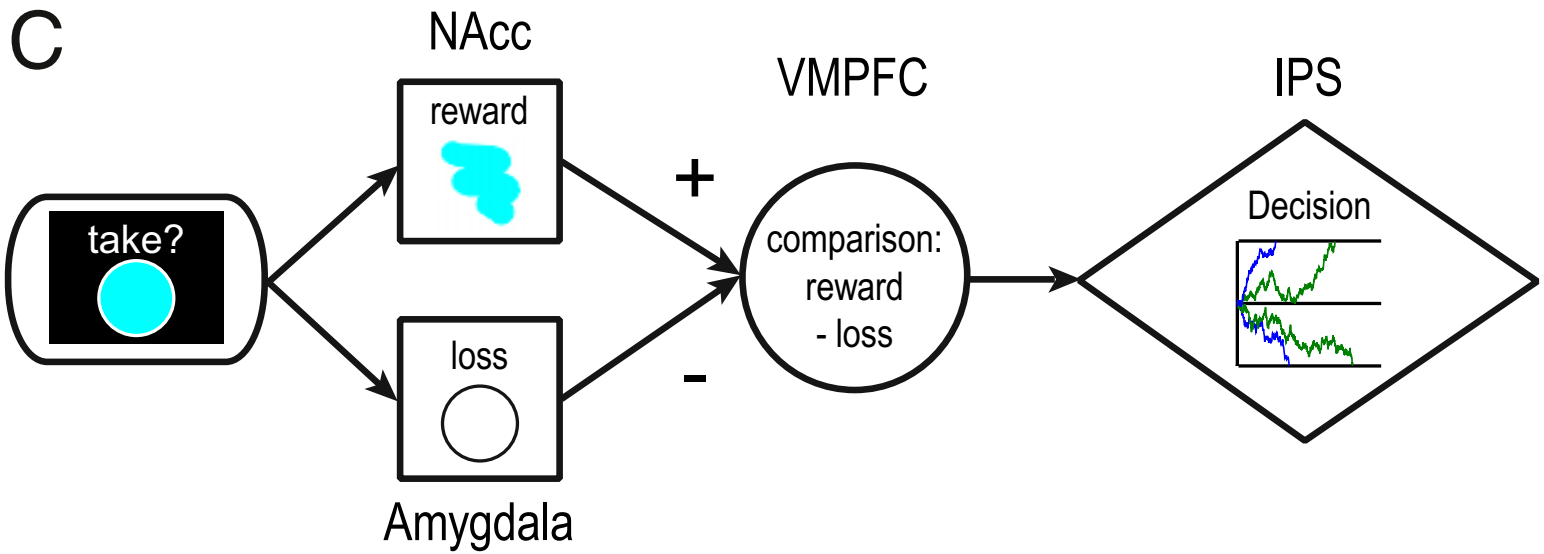
How the brain integrates costs and benefits during decision making

Ulrike Basten[a,1], Guido Biele[b,c,d,1], Hauke R. Heekeren[b,c], and Christian J. Fiebach[a,e,f,2]

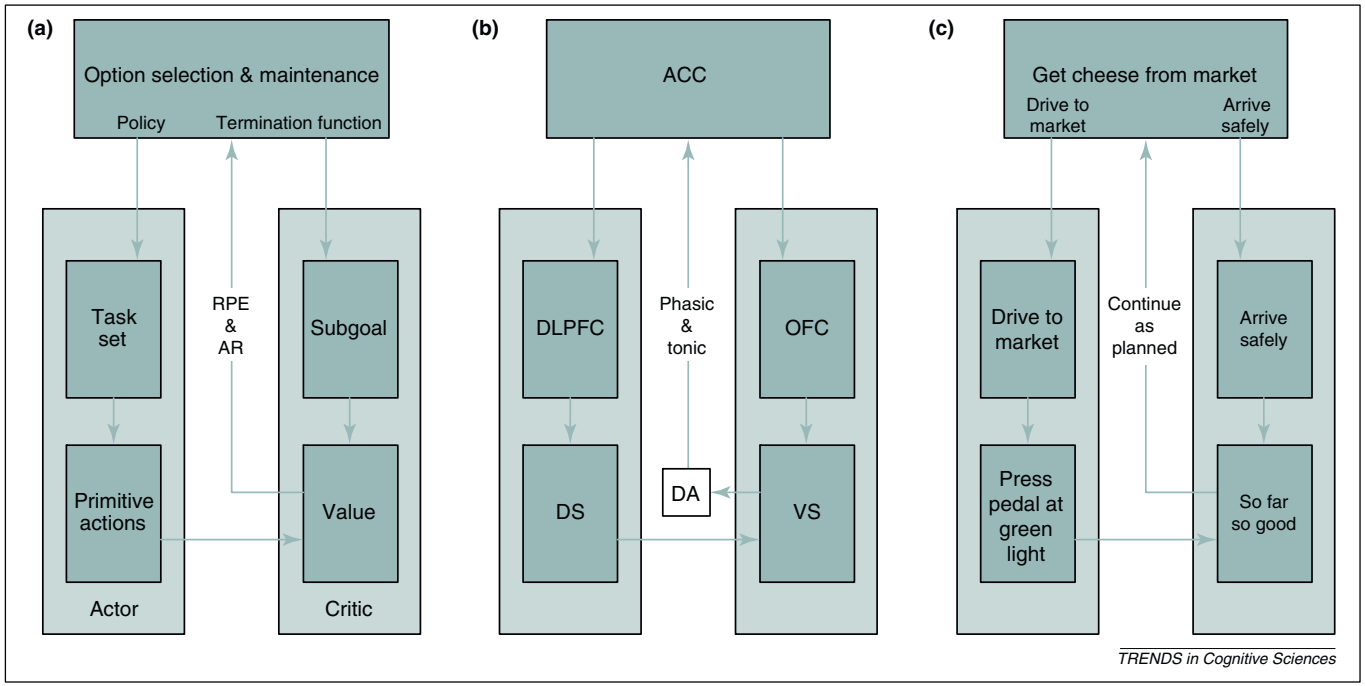
[a]Department of Psychology, Goethe University Frankfurt, D-60325 Frankfurt, Germany; [b]Max Planck Institute for Human Development, D-14195 Berlin, Germany; [c]Department of Education and Psychology, Cluster of Excellence "Languages of Emotion", and Dahlem Institute for Neuroimaging of Emotion (D.I.N.E.), Freie Universität, Berlin, D-14195 Berlin, Germany; [d]Center for the Study of Human Cognition, University of Oslo, N-0136 Oslo, Norway; [e]Bernstein Center for Computational Neurosciences, Heidelberg/Mannheim, D-69120 Heidelberg, Germany; and [f]Donders Institute for Brain, Cognition, and Behavior, Radboud University Nijmegen, 6525 HR, Nijmegen, The Netherlands


B
600 ms
1250 ms
take?
null trial
600 ms
1250 ms
take?
time


A
L
R
y = 10
0
3.51
B
y = -4
0
3.82
C
SFS
AMPFC
VMPFC
z = 44
x = 0
0
7.15
PPI of VMPFC
4
2
0
-2
1
2
3
4
5
6
drift rate


C
NAcc
reward
loss
Amygdala
take?
+
-
VMPFC
comparison:
reward
- loss
IPS
Decision

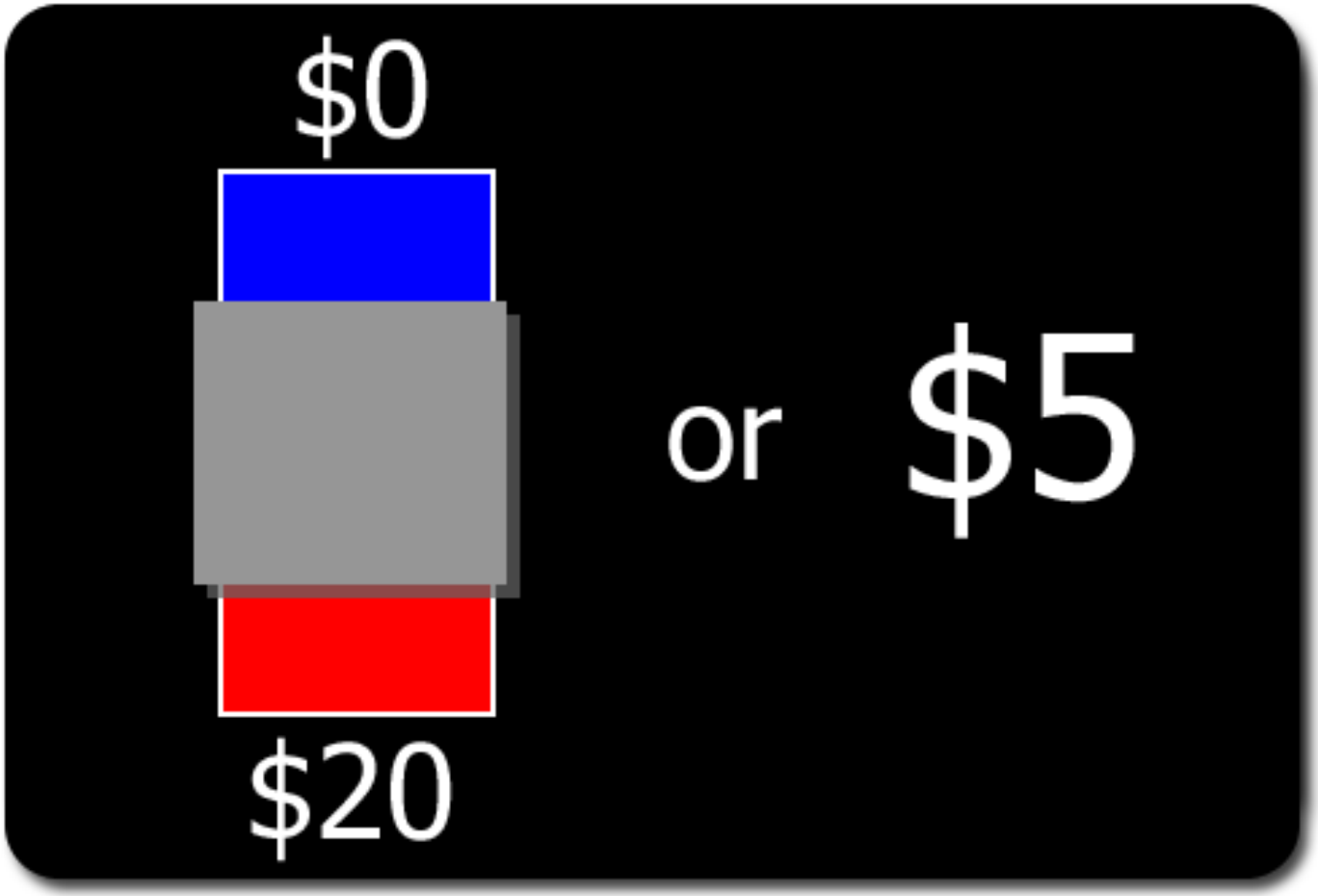
But…


(a)
Option selection & maintenance
Policy
Termination function
Task set
Primitive actions
Actor
RPE & AR
Subgoal
Value
Critic
(b)
ACC
DLPFC
DS
Phasic & tonic
DA
OFC
VS
(c)
Get cheese from market
Drive to market
Arrive safely
Drive to market
Press pedal at green light
Continue as planned
Arrive safely
So far so good
TRENDS in Cognitive Sciences

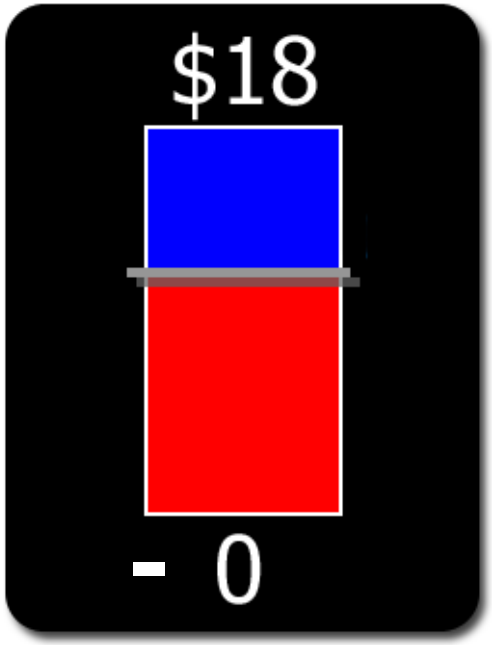
Summary of three study all agree on the role of
Prefrontal Cortex in Decision-Making

Risk and Ambiguity

Experimental design



Experimental design



Amount

Probability

Ambiguity level

Winning color

OR:

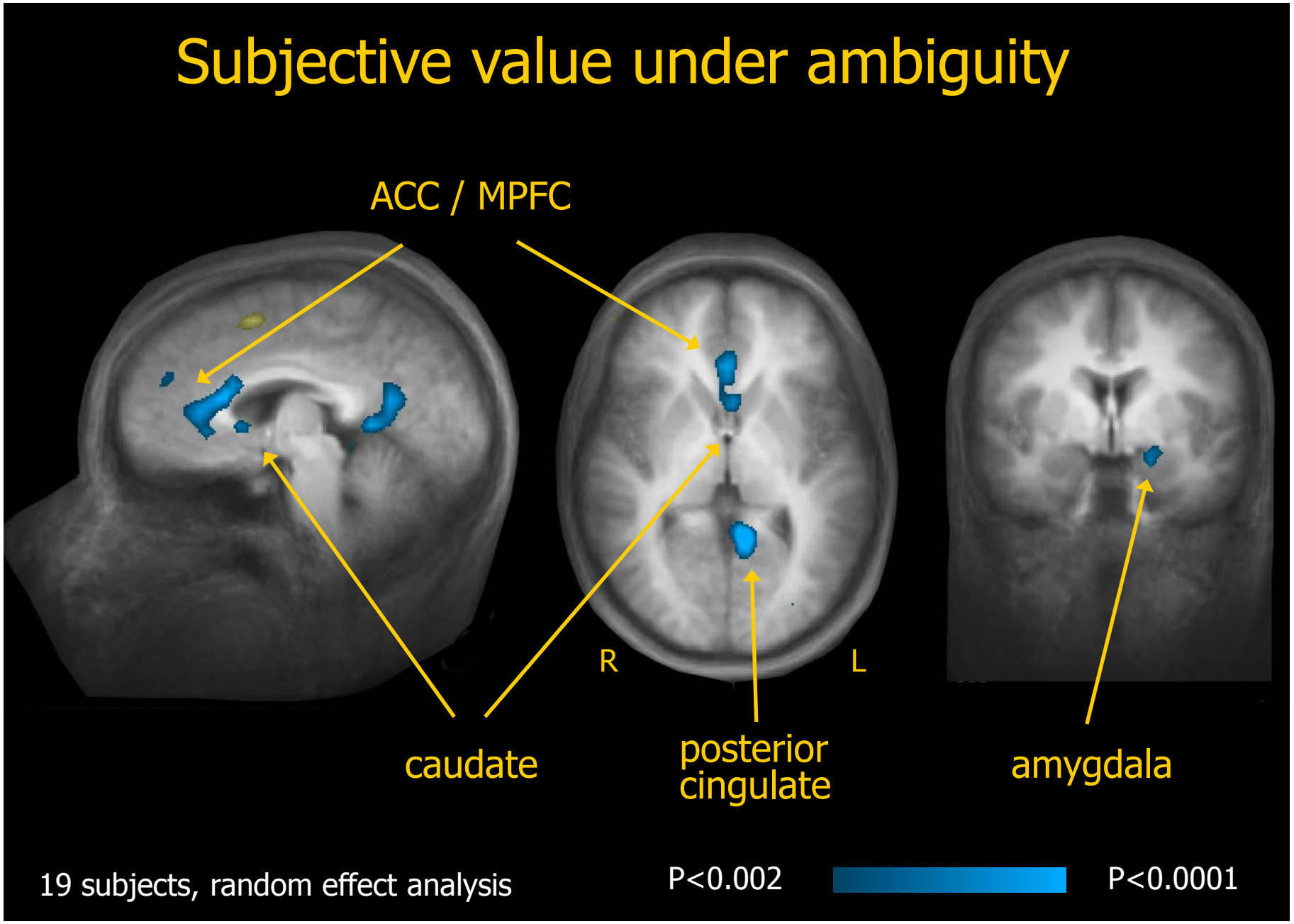
- $5

Parametric design

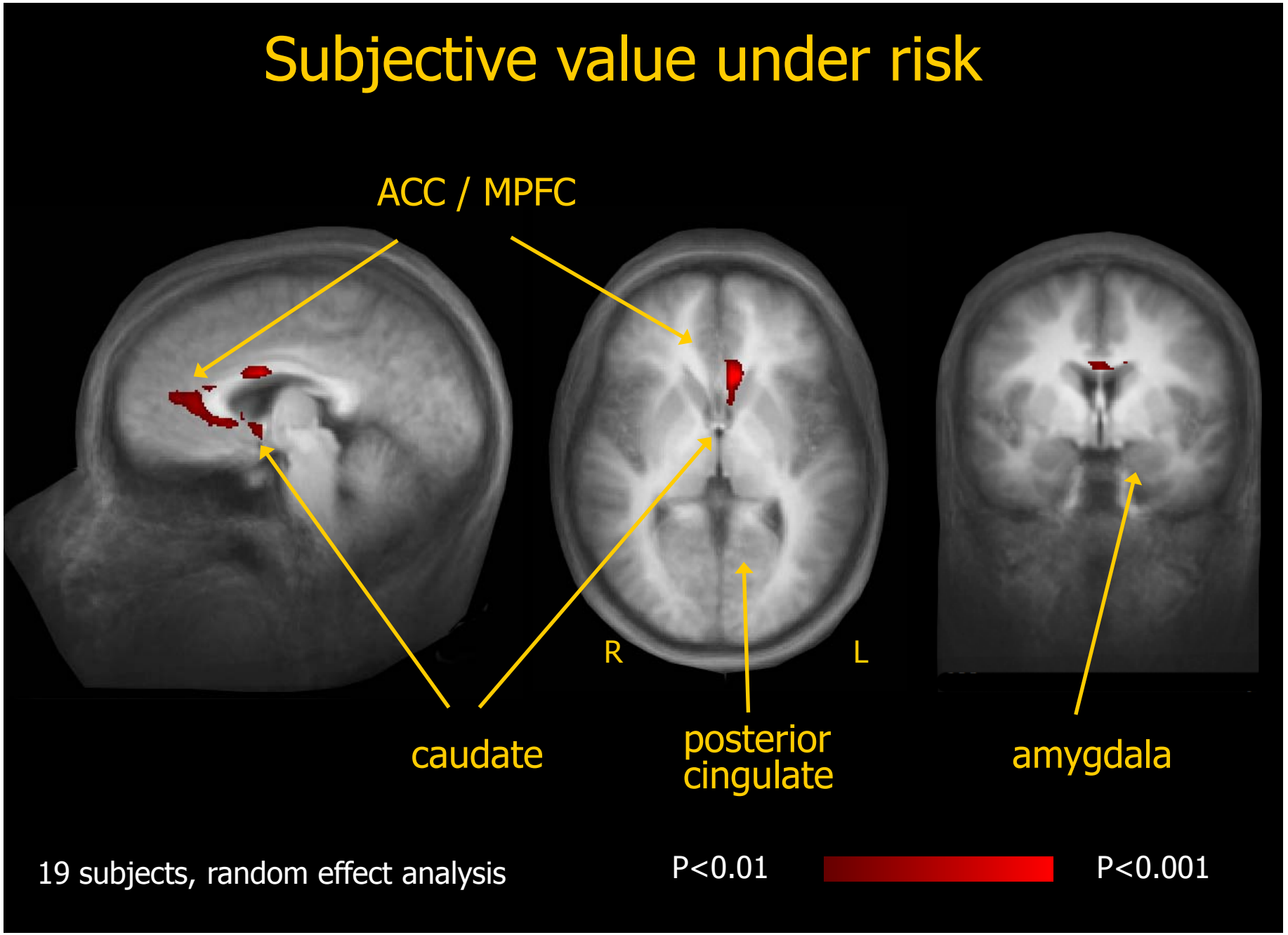
Real bags

One trial played for real money

Subjective value under ambiguity



Subjective value under risk



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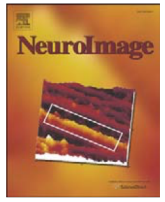
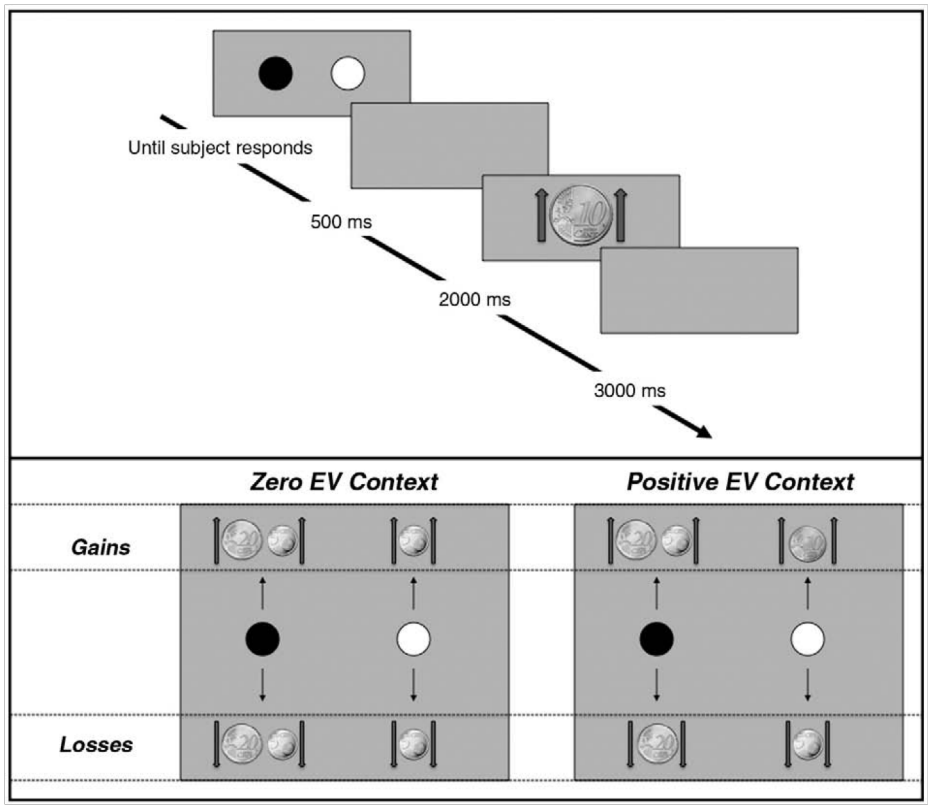


Brain correlates of risky decision-making

David Polezzi [a,b,*], Giuseppe Sartori [b], Rino Rumiati [c], Giulio Vidotto [b], Irene Daum [a]

[a] Institute of Cognitive Neuroscience, Department of Neuropsychology, Ruhr-University of Bochum, Universitätsstraβe 150, D-44780 Bochum, Germany
[b] Department of General Psychology, University of Padova, via Venezia 8, 35131 Padova, Italy
[c] Department of Developmental Psychology and Socialization, University of Padova, via Venezia 8, 35131 Padova, Italy


Until subject responds
500 ms
2000 ms
3000 ms
Zero EV Context
Positive EV Context
Gains
Losses

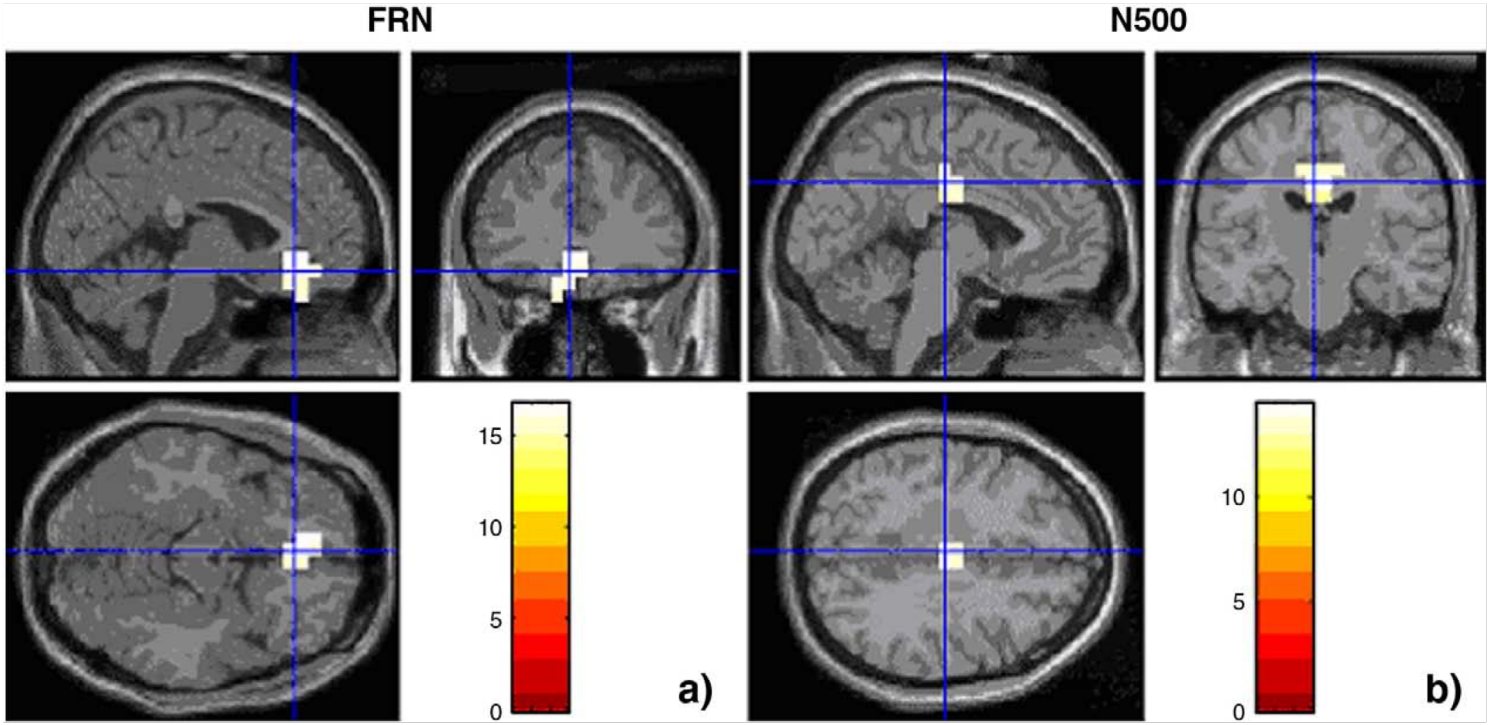


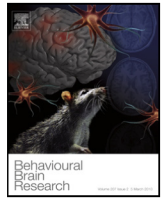
Fig. 4. FRN is generated by Anterior Cingulate Cortex (a), while N500 is generated by Posterior Cingulate Cortex (b).

More activity for risky decision

Contents lists available at ScienceDirect

Behavioural Brain Research

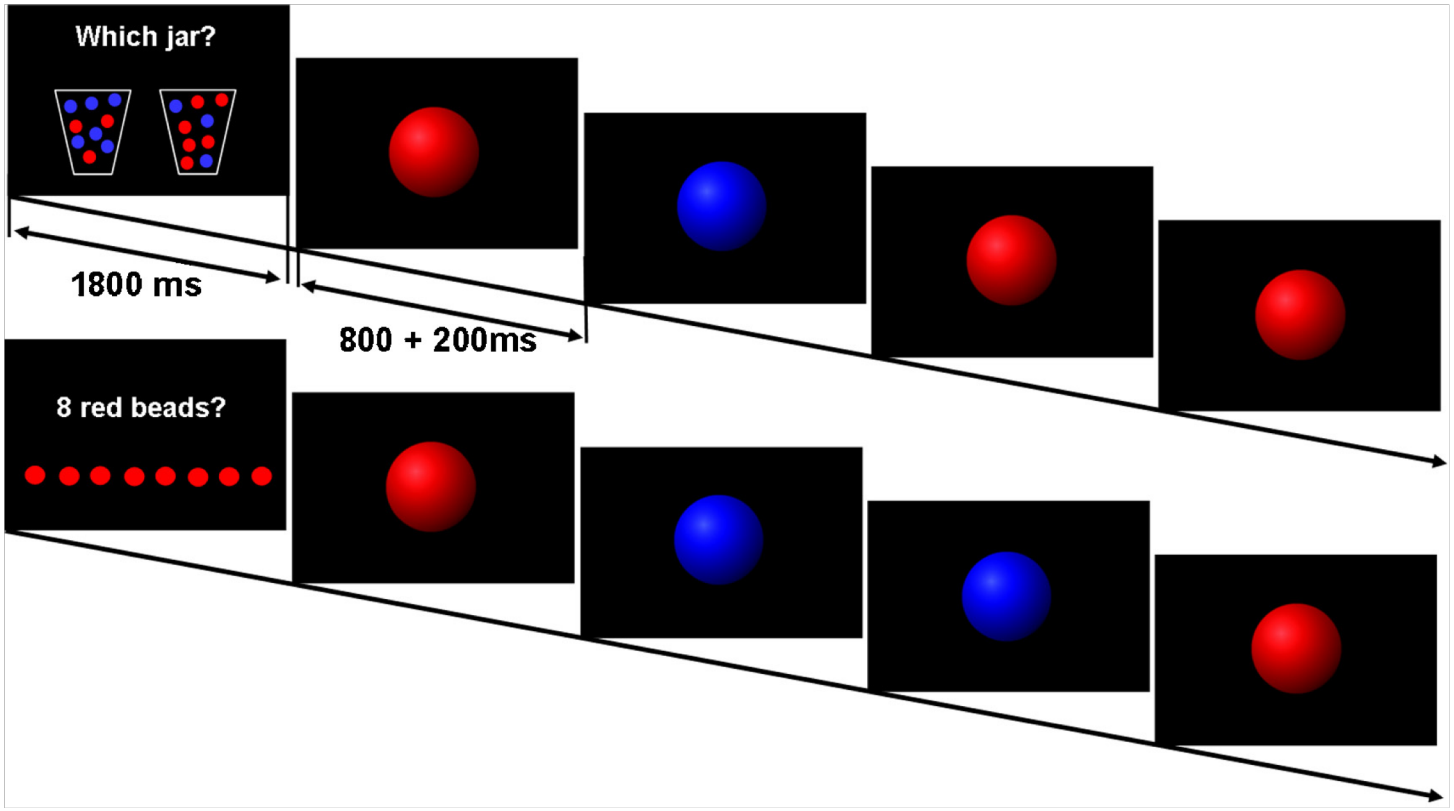
journal homepage: www.elsevier.com/locate/bbr

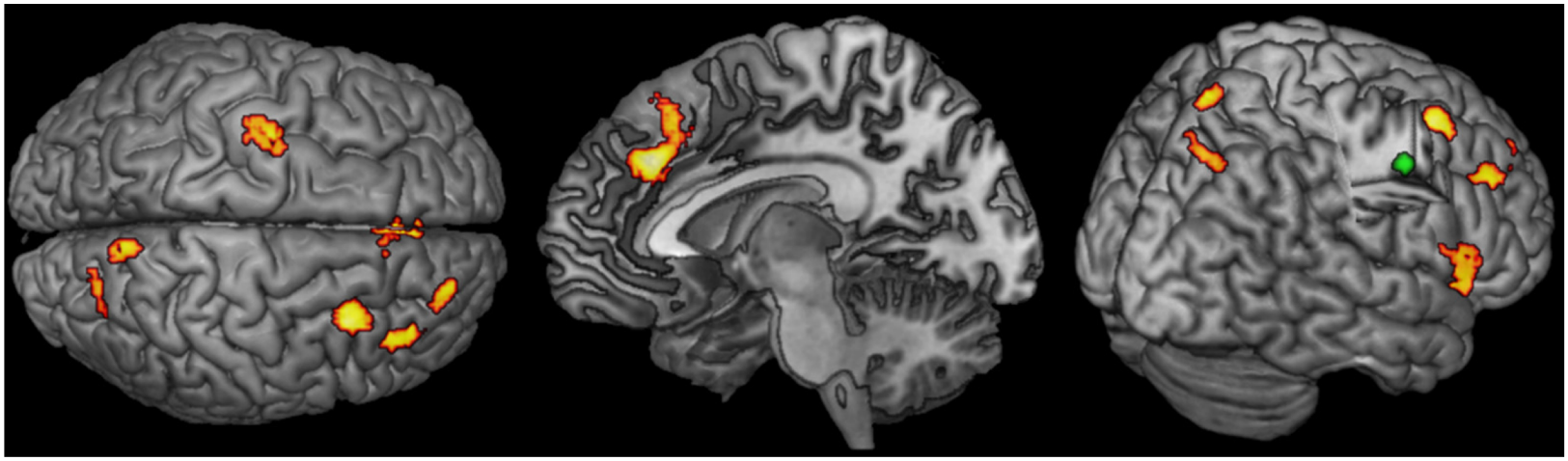


Research report

Investigation of decision-making under uncertainty in healthy subjects: A multi-centric fMRI study

A. Krug[a,*], M. Cabanis[a], M. Pyka[a], K. Pauly[b], H. Walter[c], M. Landsberg[d], N. Jon Shah[e], G. Winterer[f], W. Wölwer[g], F. Musso[g], B.W. Müller[h], G. Wiedemann[i], J. Herrlich[j], K. Schnell[k], K. Vogeley[l,m], L. Schilbach[l], K. Langohr[n], A. Rapp[n], S. Klingberg[n], T. Kircher[a]


Which jar?
1800 ms
800 + 200ms
8 red beads?



More activity for risky decision

Explore or Exploit?

Received 1 May 2012; Final revision received 29 October 2013

UNDERSTANDING THE EXPLORATION–EXPLOITATION DILEMMA: AN fMRI STUDY OF ATTENTION CONTROL AND DECISION-MAKING PERFORMANCE

DANIELLA LAUREIRO-MARTÍNEZ,[1,6] STEFANO BRUSONI,[1]* NICOLA CANESSA,[2,3] and MAURIZIO ZOLLO[4,5]

[1] *Department of Management, Technology and Economics, ETH Zurich, Zürich, Switzerland*

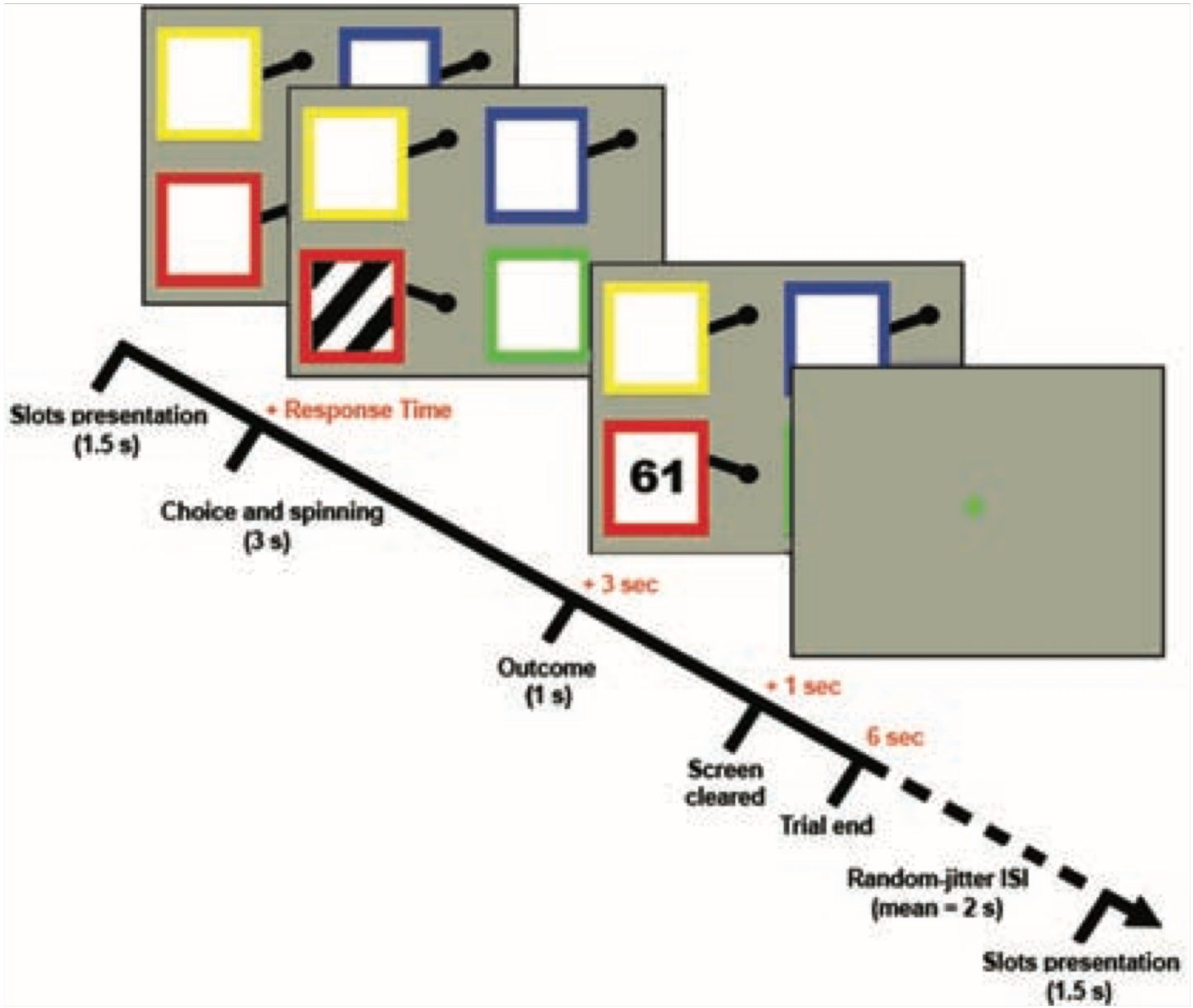
[2] *Center for Cognitive Neuroscience & CERMAC, Vita-Salute San Raffaele University, Milano, Italy*

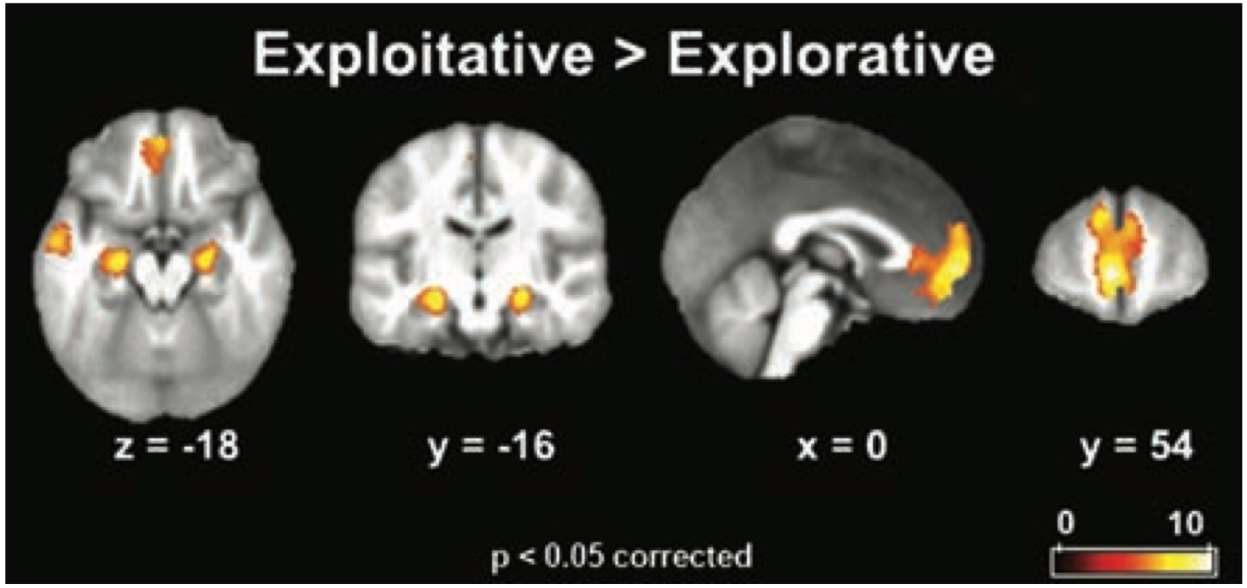
[3] *Division of Neuroscience, San Raffaele Scientific Institute, Milano, Italy*

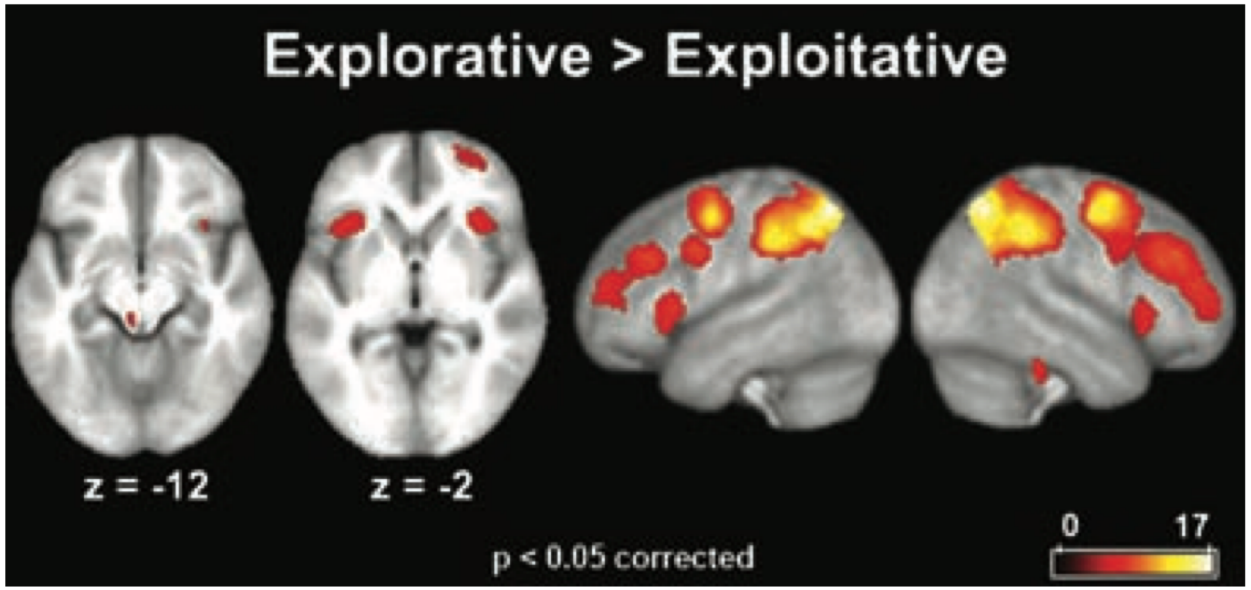
[4] *Department of Management and Technology, Center for Research on Innovation, Organization and Strategy (CRIOS), Bocconi University, Milano, Italy*

[5] *Department of Strategy and Innovation, WU Vienna School of Economics and Business, Vienna, Austria*

[6] *School of Management, Universidad de los Andes, Bogotá, Colombia*


61
Slots presentation
(1.5 s)
+ Response Time
Choice and spinning
(3 s)
+ 3 sec
Outcome
(1 s)
+ 1 sec
Screen
cleared
6 sec
Trial end
Random-jitter ISI
(mean = 2 s)
Slots presentation
(1.5 s)


Exploitative > Explorative
z = -18
y = -16
x = 0
y = 54
0
10
p < 0.05 corrected


Explorative > Exploitative
z = -12
z = -2
0
17
p < 0.05 corrected

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WHAT DO I DO NOW? AN ELECTROENCEPHALOGRAPHIC INVESTIGATION OF THE EXPLORE/EXPLOIT DILEMMA

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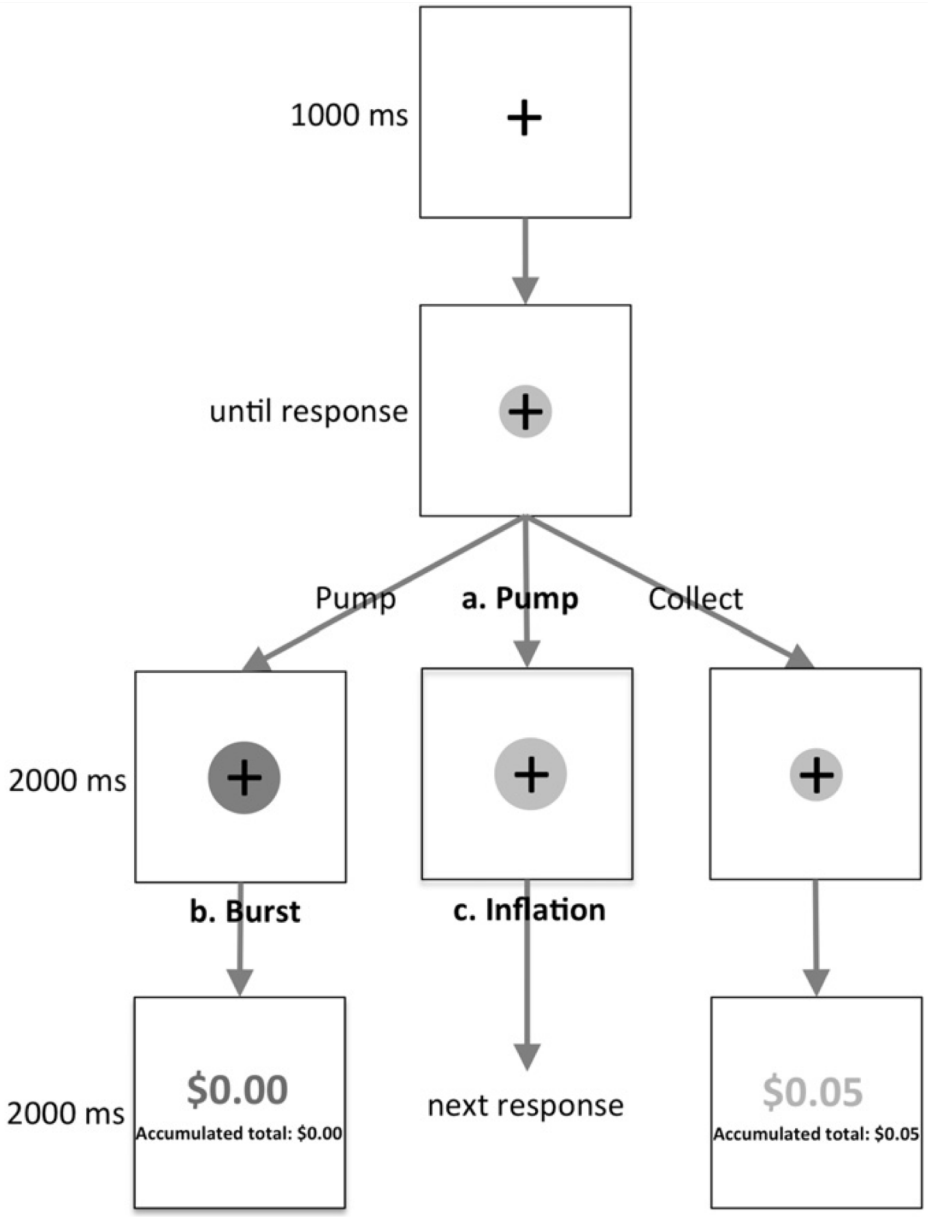
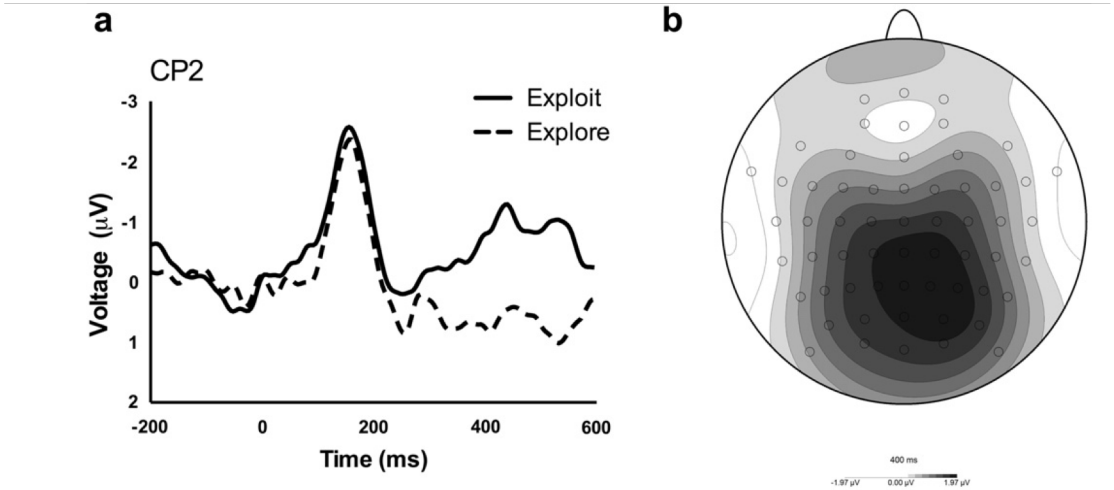
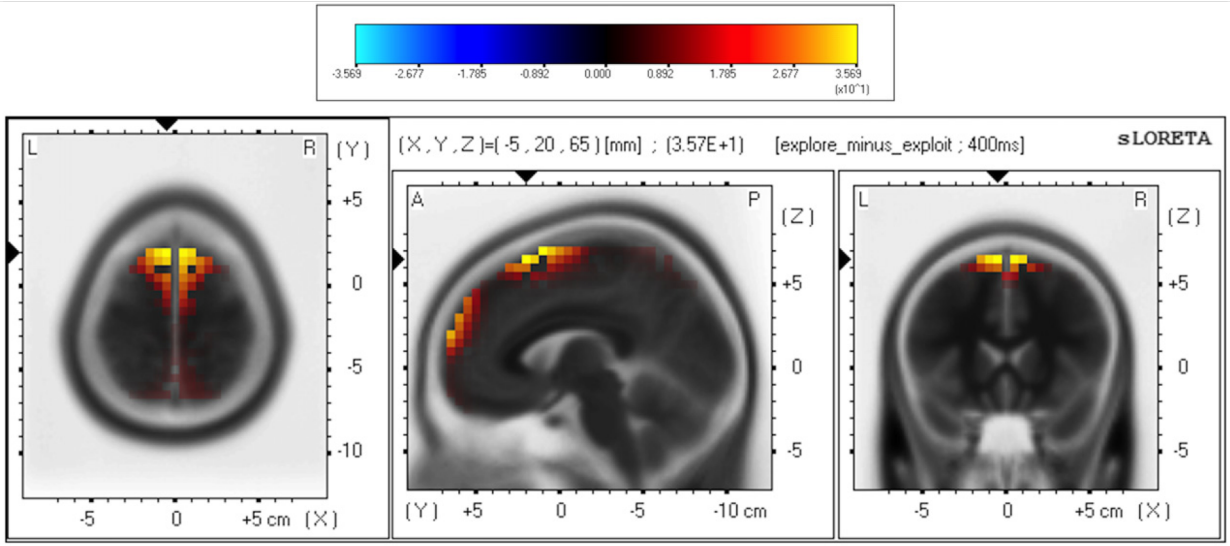

1000 ms
until response
Pump
a. Pump
Collect
2000 ms
b. Burst
c. Inflation
2000 ms
$0.00
Accumulated total: $0.00
next response
$0.05
Accumulated total: $0.05


a
CP2
Exploit
Explore
Voltage (μV)
-3
-2
-1
0
1
2
-200
0
200
400
600
Time (ms)
b
400 ms
-1.97 μV
0.00 μV
1.97 μV


-3.569
-2.677
-1.785
-0.892
0.000
0.892
1.785
2.677
3.569
(x10^1)
L
R
(Y)
+5
0
-5
-10
-5
0
+5 cm (X)
(X,Y,Z)=(-5,20,65) [mm] ; (3.57E+1)
[explore_minus_exploit ; 400ms]
sLORETA
A
P
(Z)
+5
0
-5
(Y) +5
0
-5
-10 cm
L
R
(Z)
+5
0
-5
-5
0
+5 cm (X)

Summary

We know that…

1. Parts of the brain encode expected values
2. Parts of the brain are sensitive to actual decision point
3. Factors that impact decision-making (risk, uncertainty) are encoded as well
4. Parts of the brain mitigate the explore – exploit dilemma