The neurobiology of simple choice

Antonio Rangel

Caltech

Goals of neuroeconomics

- Characterize the computational processes used by the brain to make different types of choices

- Understand how does the neurobiology implements and constraints those computations

- Characterize the computational and neurobiological differences underlying decision maker heterogeneity
  Ex:
  > addicts vs non-addicts
  > healthy eaters vs. Big Mac lovers

Simple economic choice

?

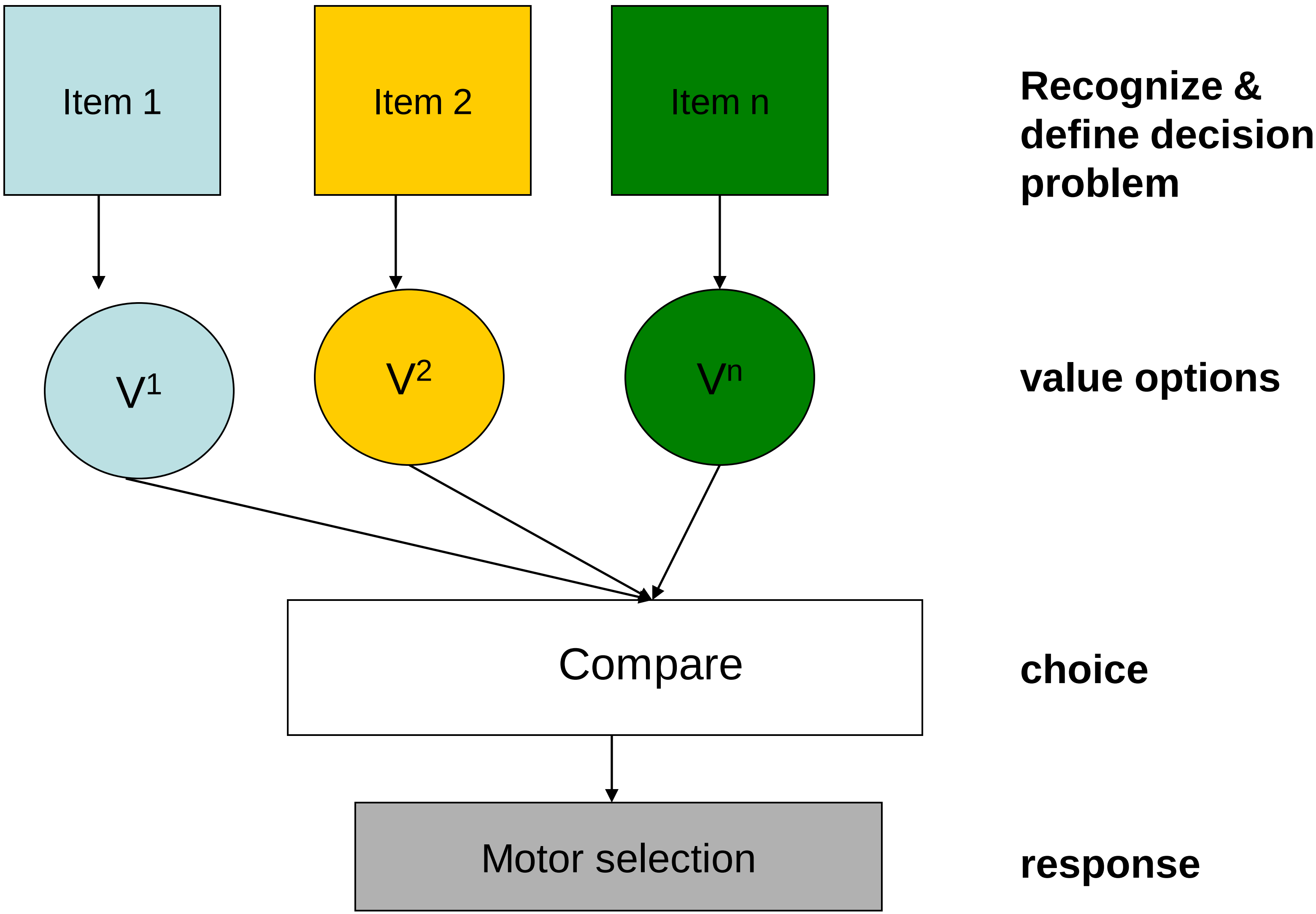
Why study simple choice?

- Simplest setting to study the neurobiology of human DM
- Foundation for more complex choice situations
- Insights about limitations and unexpected features of DM circuitry already be present here


SERVICE & PRICE CHECK
Scoop Away
Scoop Away
Fresh Step
Fresh Step
TIDY CATS

I
A simple but useful framework

Useful conceptual framework



II
Valuation

Experiment 1

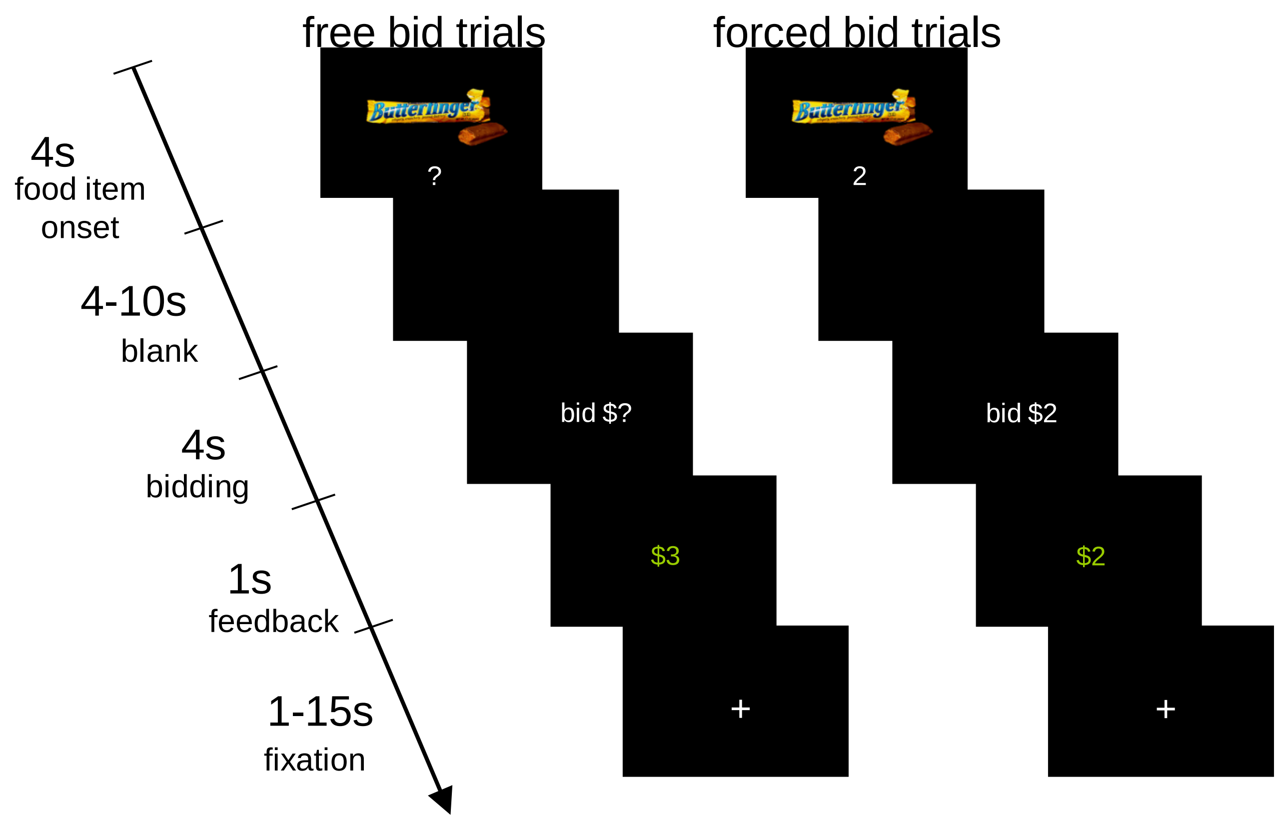
JNeuro 2007, Plassmann O'Doherty Rangel

Fast for 4 hrs

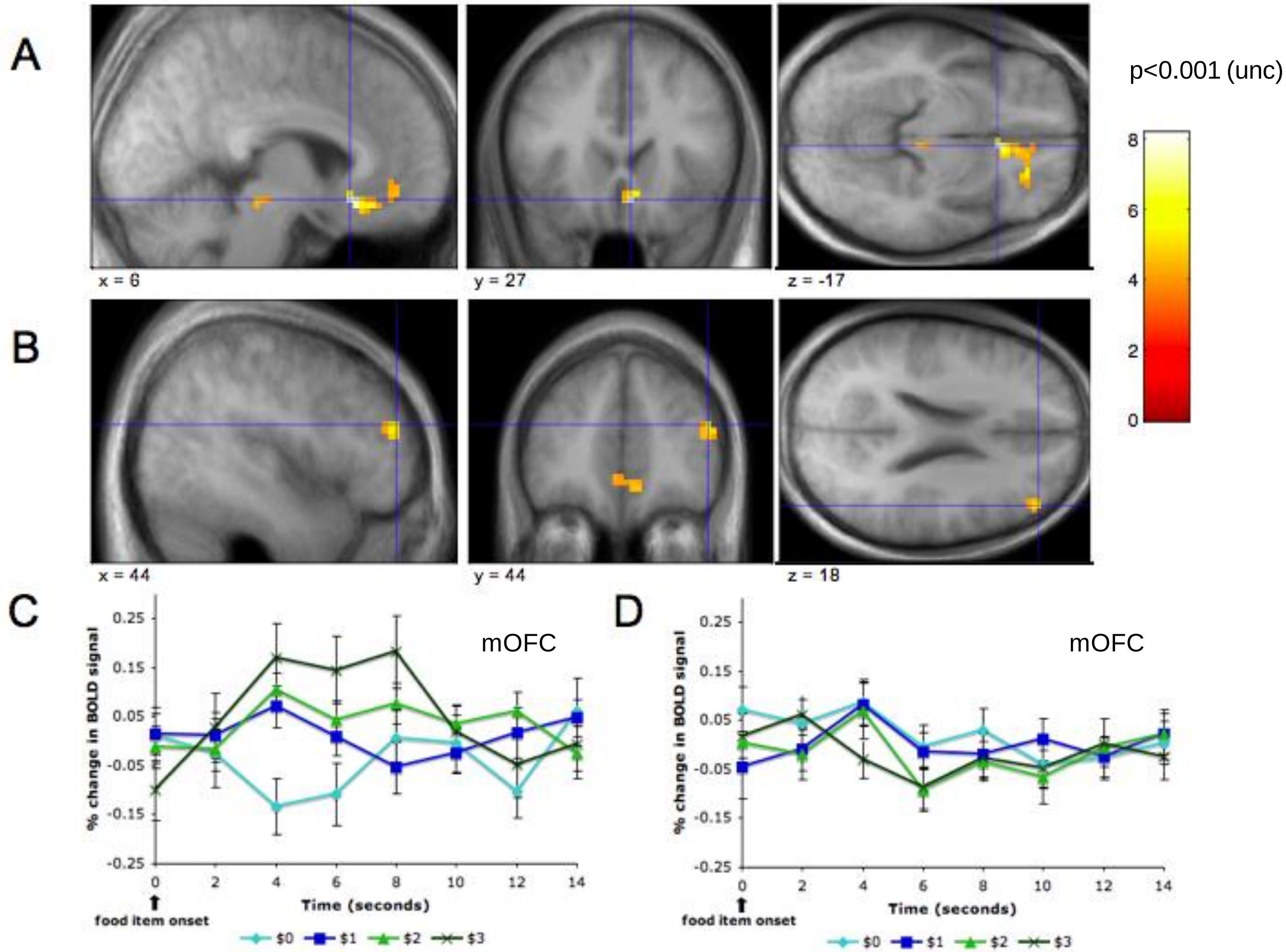
Experiment: Bid in 100 trials & 50 items
- 50 free trials
- 50 forced trials

Select random trial implement BDM auction

Stay in lab for 30 min eat prize (if applicable)



MAIN RESULT: mOFC and DLPFC encode for WTP in free trials, but not in forced trials

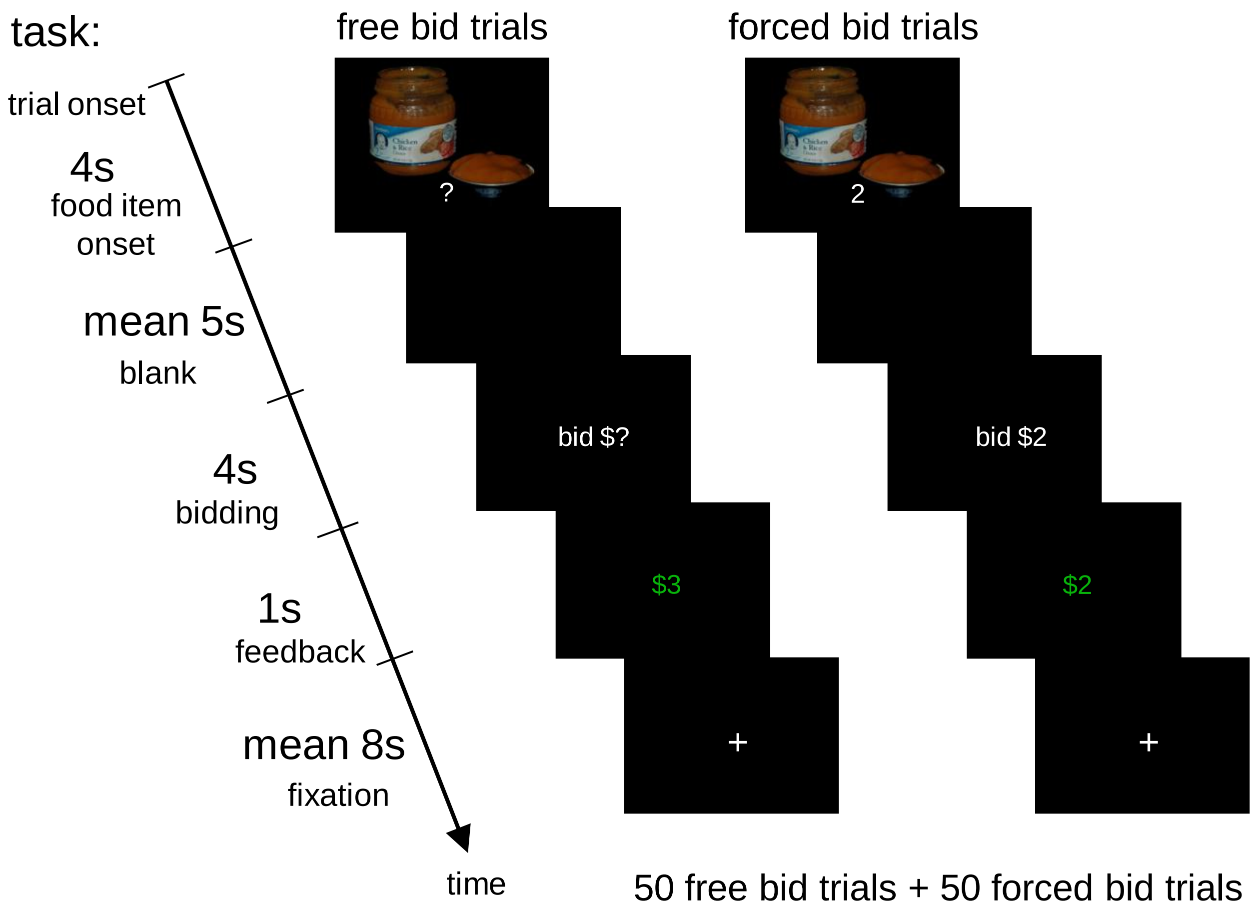


Experiment 2

JNeuro 2010, Plassmann O'Doherty Rangel

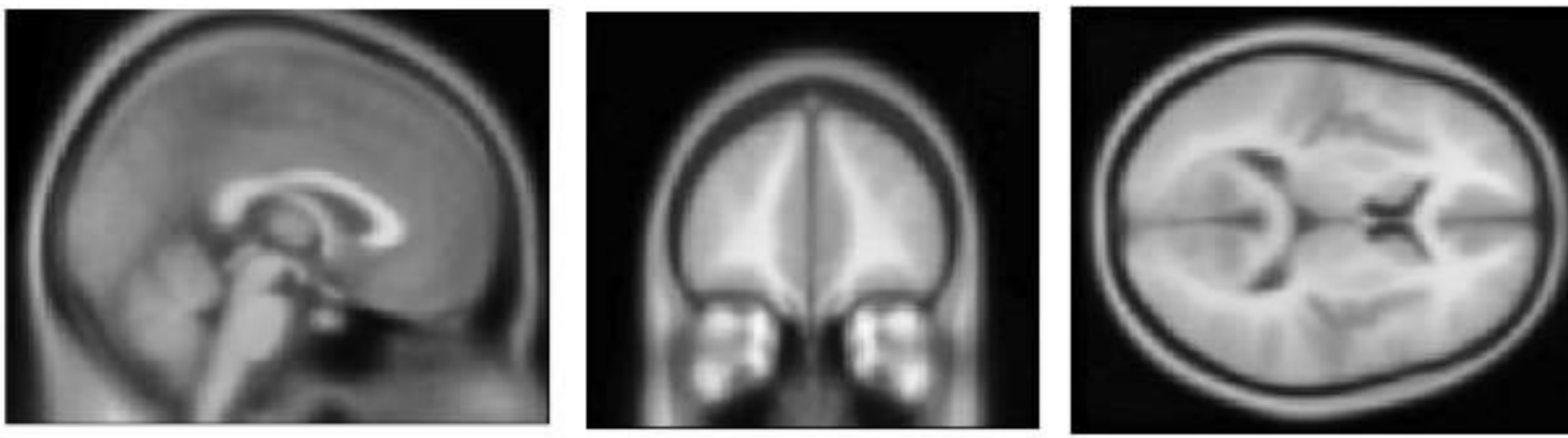
Subjects ate 2 hours prior to the experiment → Bidding task in fMRI scanner → Select random trial & implement auction → Stay in lab for 30 min eat item (if applicable)

Bidding task:



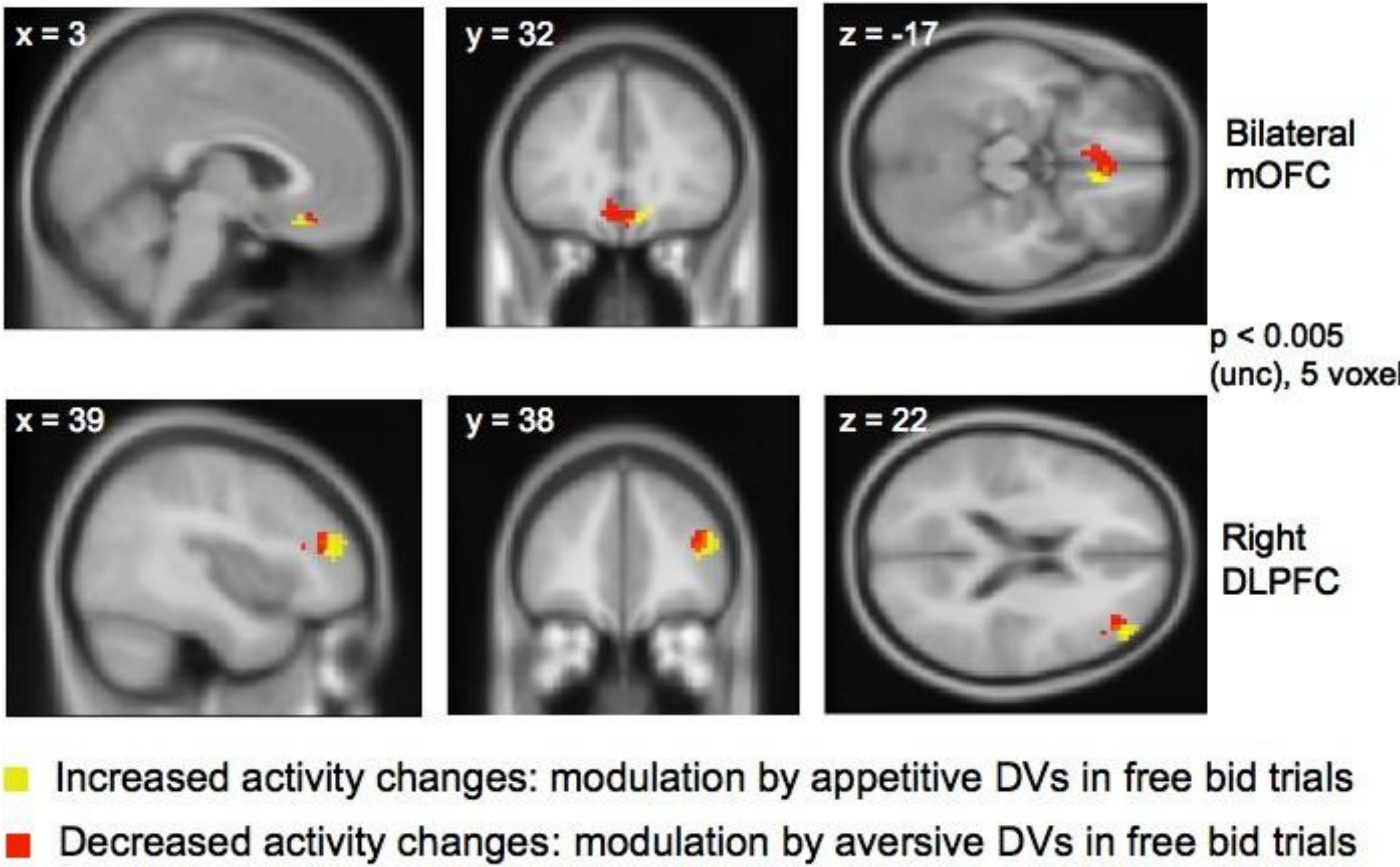
50 free bid trials + 50 forced bid trials = 100 trials

Areas with increased activity with bid (i.e., with aversive value)



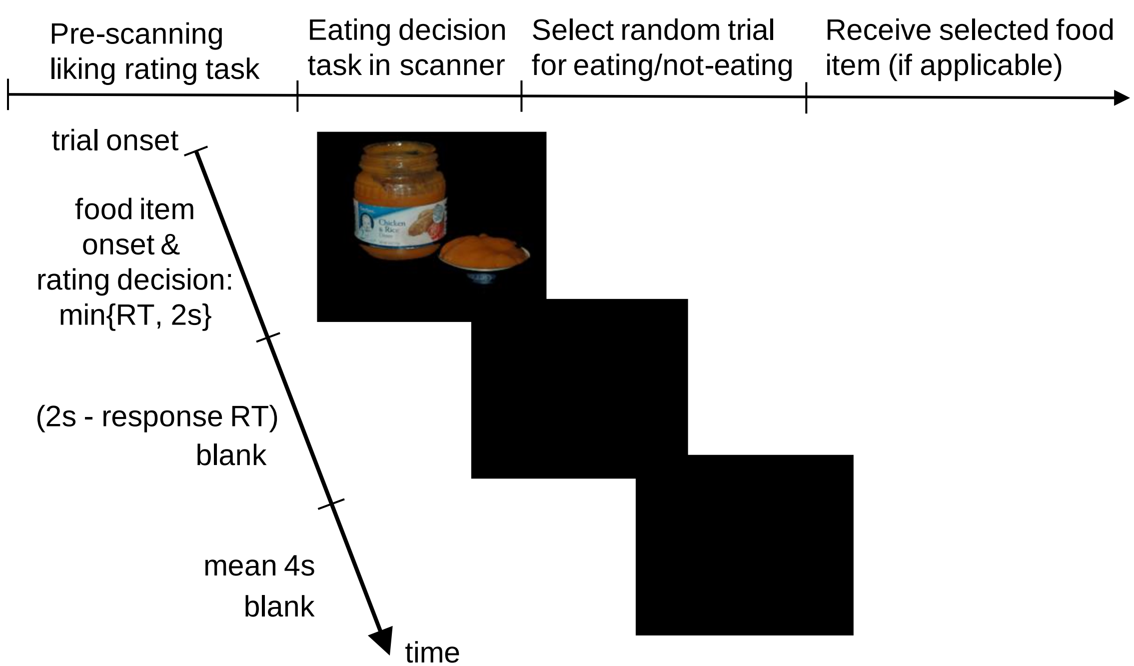
p < 0.01 (uncor), 5 voxel

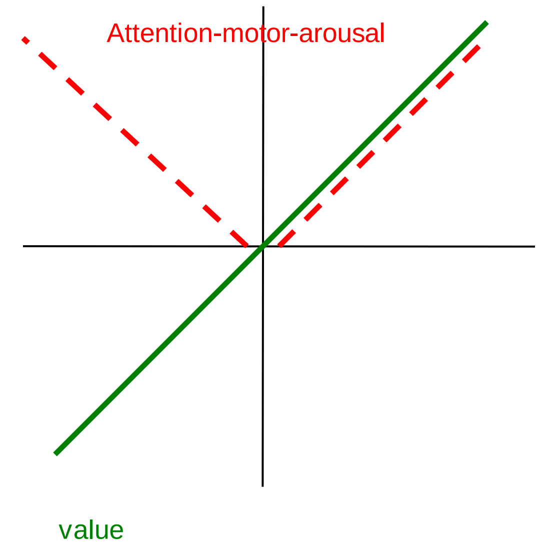
Conjunction of appetitive vs aversive goal value signals



Experiment 3

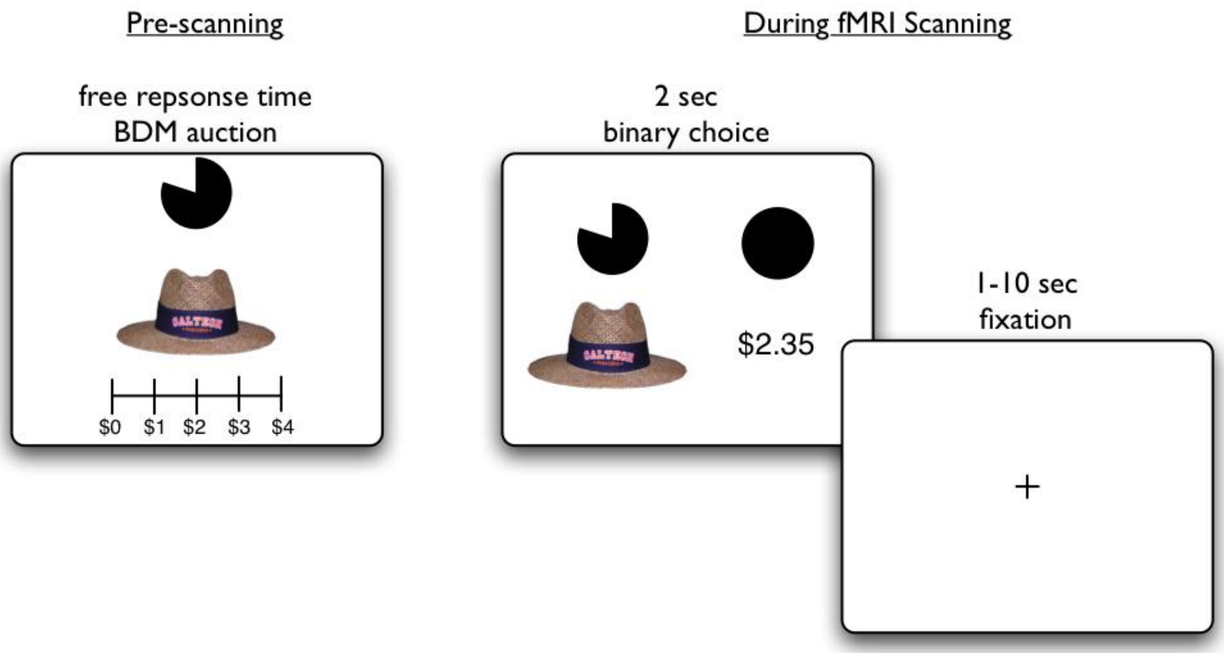
Cerebral Cortex 2010, Lit et al



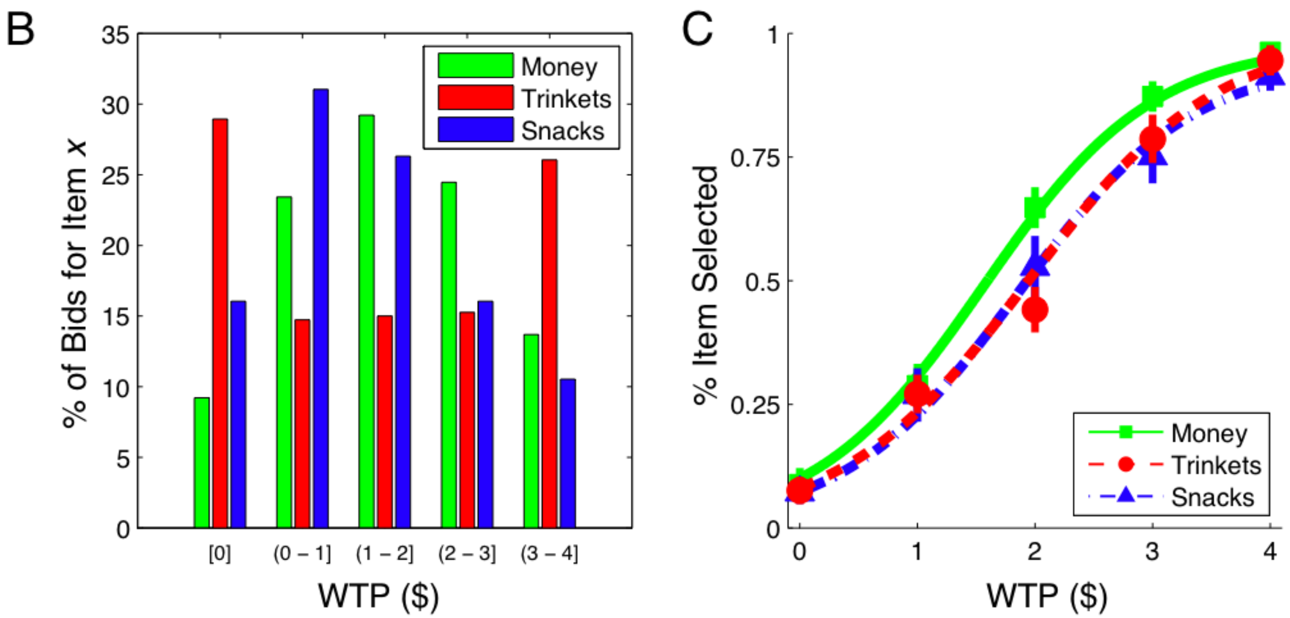


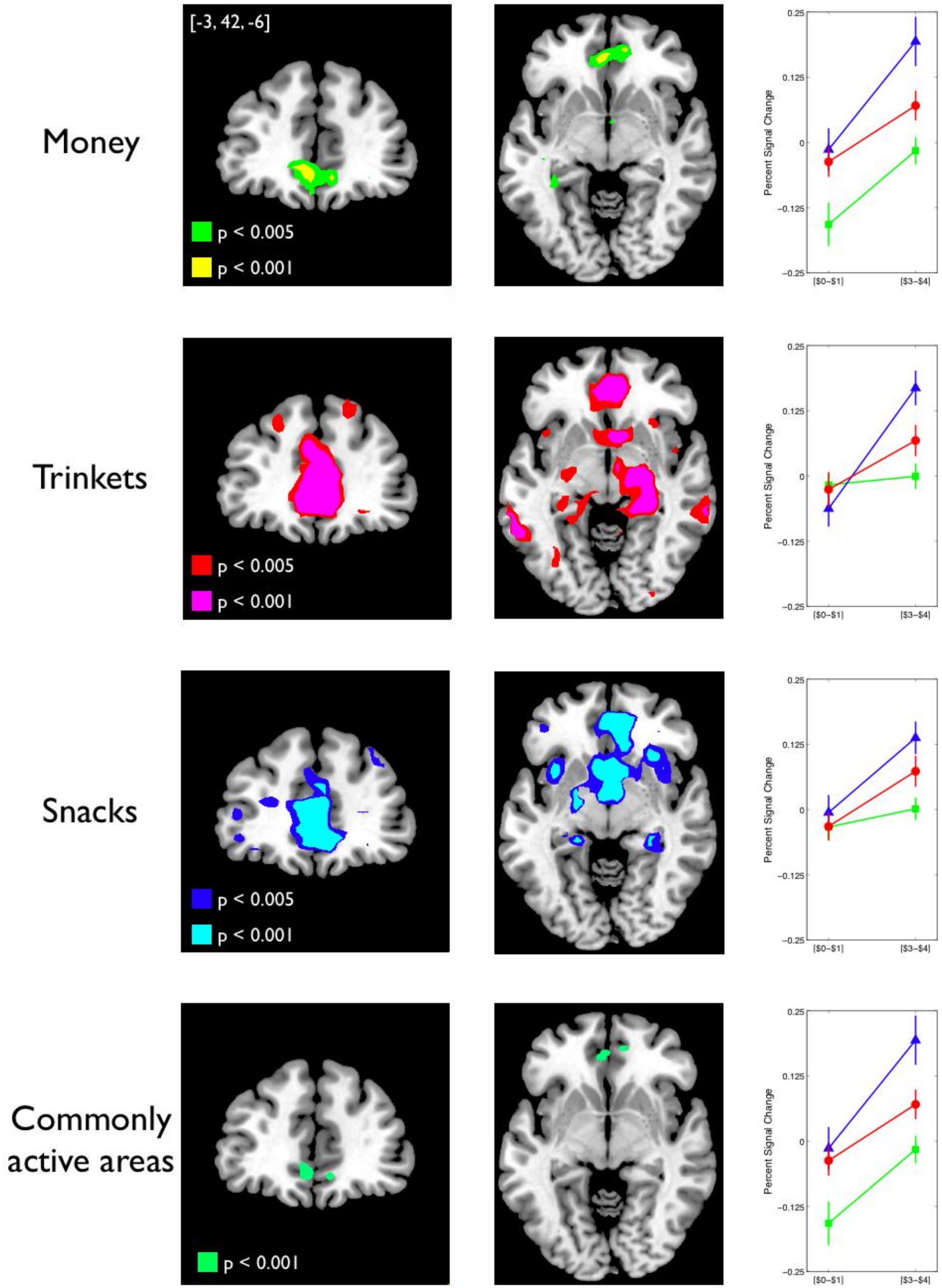
Experiment 3

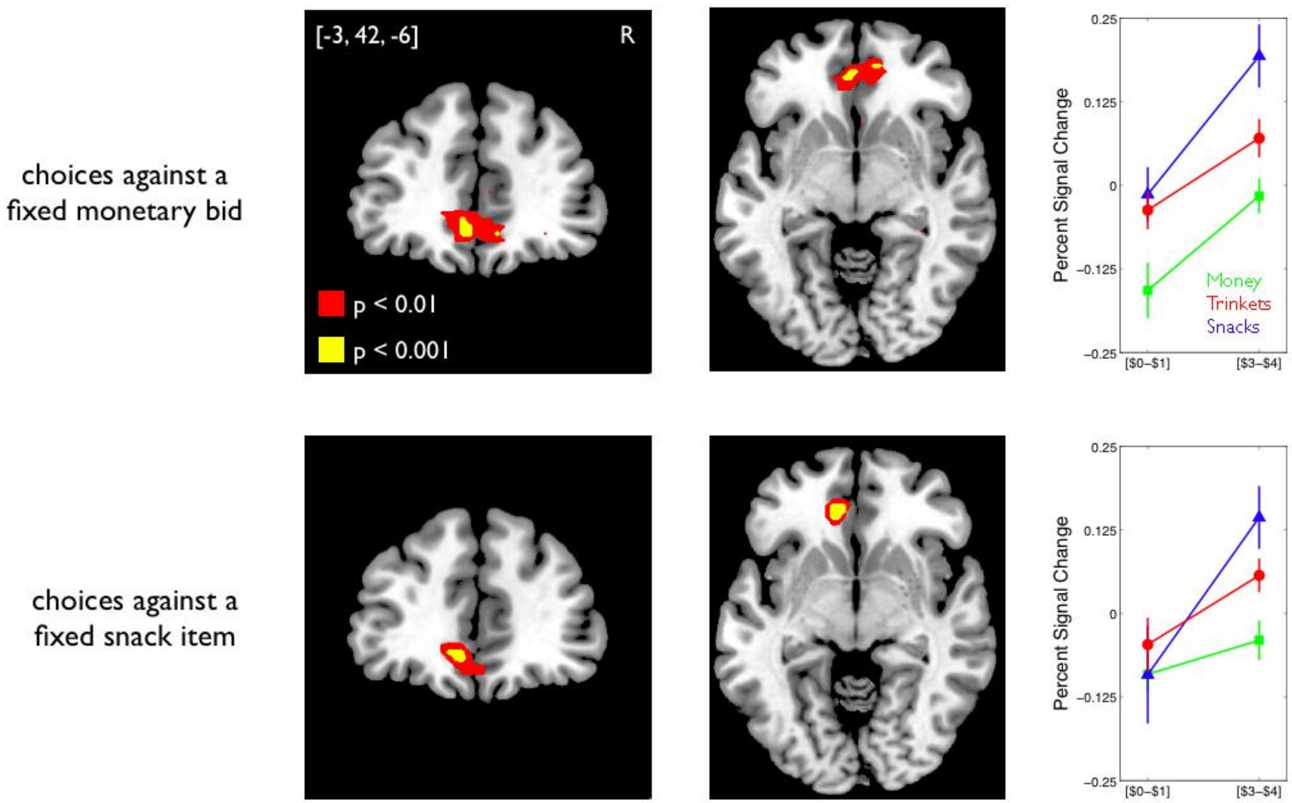
Chib, O'Doherty, Rangel, JNeuro, 2009



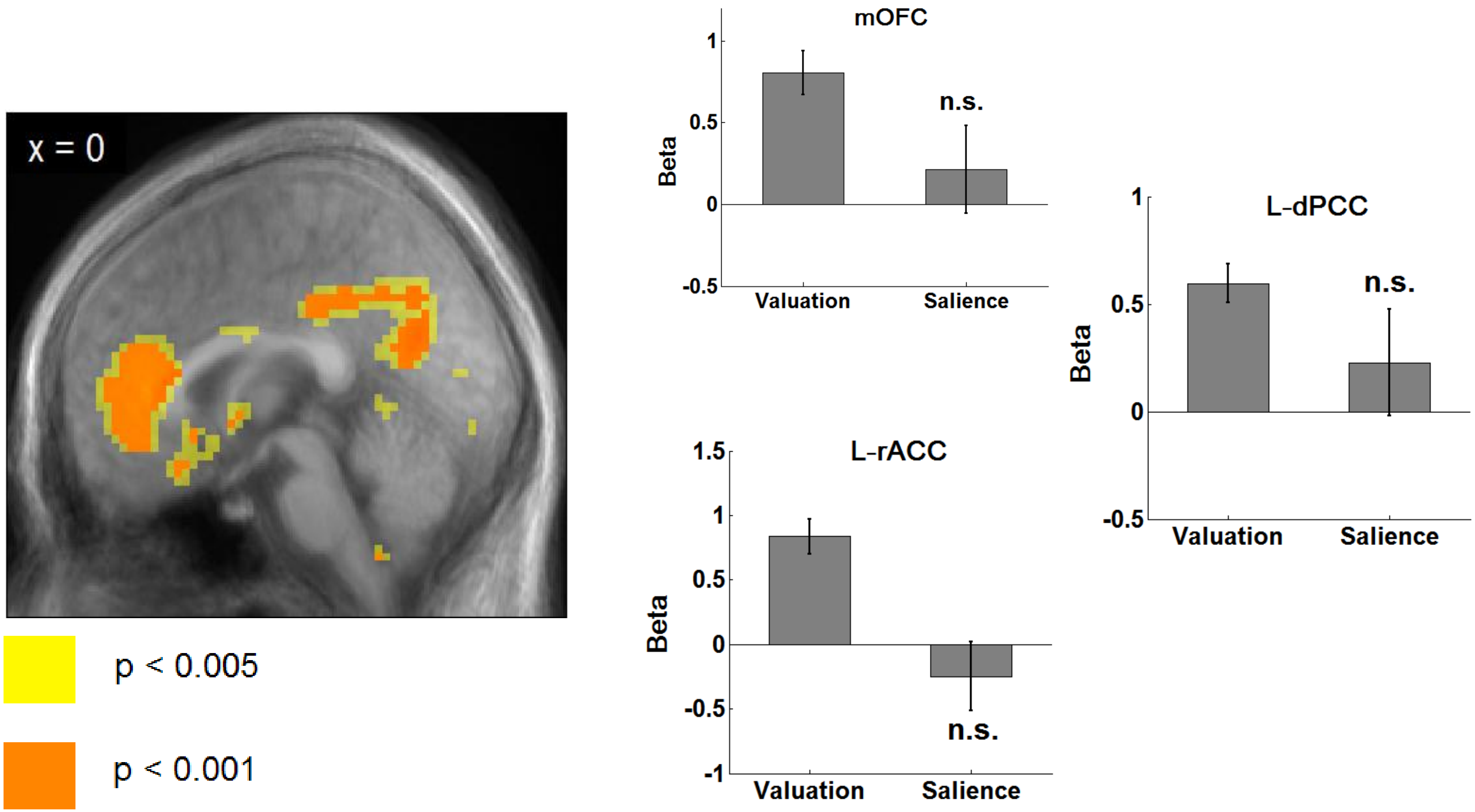
Behavior


B
% of Bids for Item x
Money
Trinkets
Snacks
35
30
25
20
15
10
5
0
[0]
(0 – 1]
(1 – 2]
(2 – 3]
(3 – 4]
WTP ($)
C
% Item Selected
1
0.75
0.5
0.25
0
0
1
2
3
4
WTP ($)
Money
Trinkets
Snacks

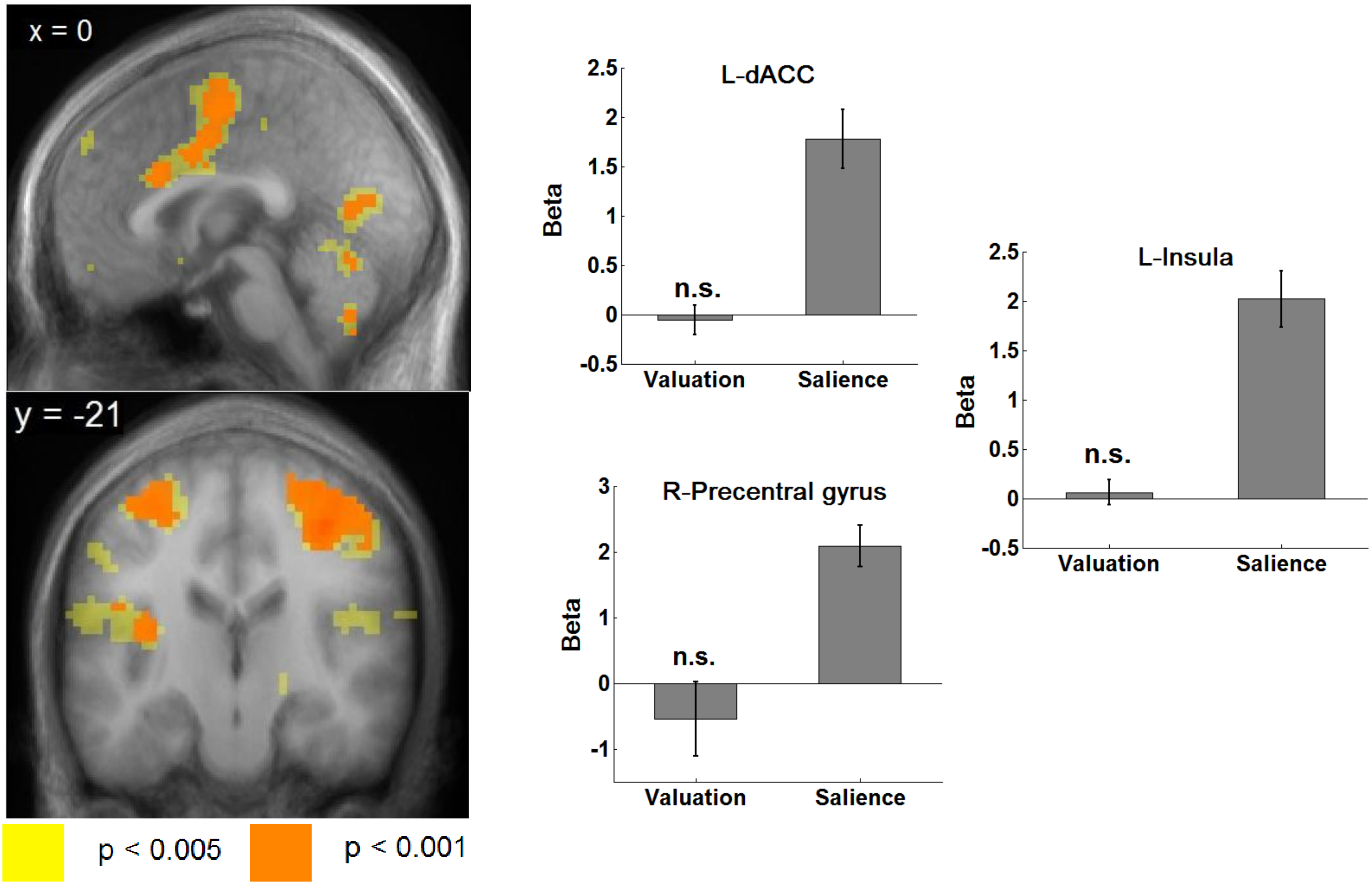

[-3, 42, -6]
Money
p < 0.005
p < 0.001
Trinkets
p < 0.005
p < 0.001
Snacks
p < 0.005
p < 0.001
Commonly active areas
p < 0.001
Percent Signal Change
0.25
0.125
0
-0.125
-0.25
[$0–$1]
[$3–$4]


choices against a fixed monetary bid
[-3, 42, -6]
R
p < 0.01
p < 0.001
Percent Signal Change
0.25
0.125
0
-0.125
-0.25
[$0–$1]
[$3–$4]
Money
Trinkets
Snacks
choices against a fixed snack item

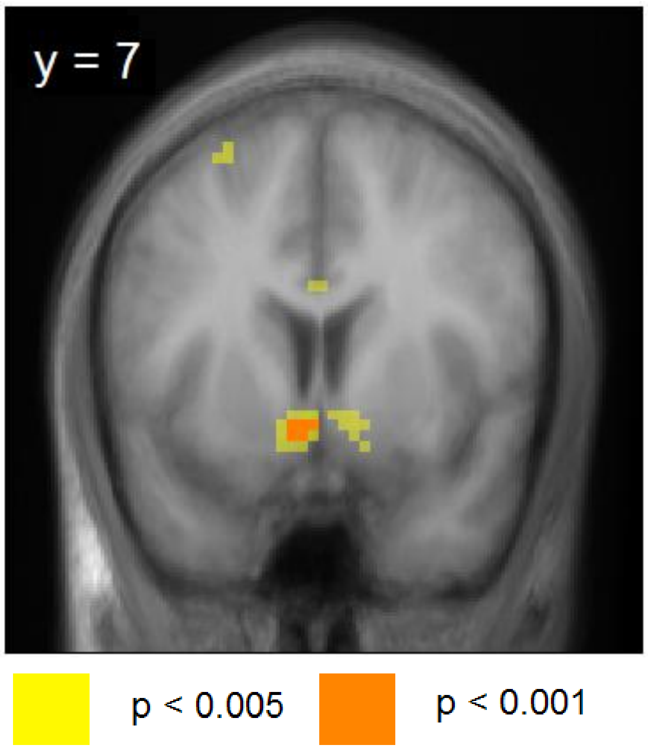
Value only activity

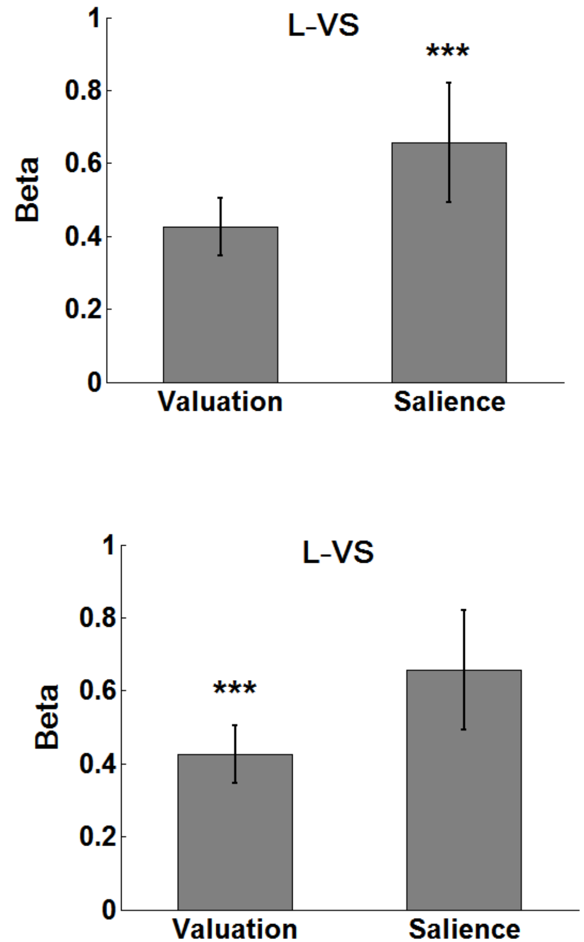


Saliency only activity



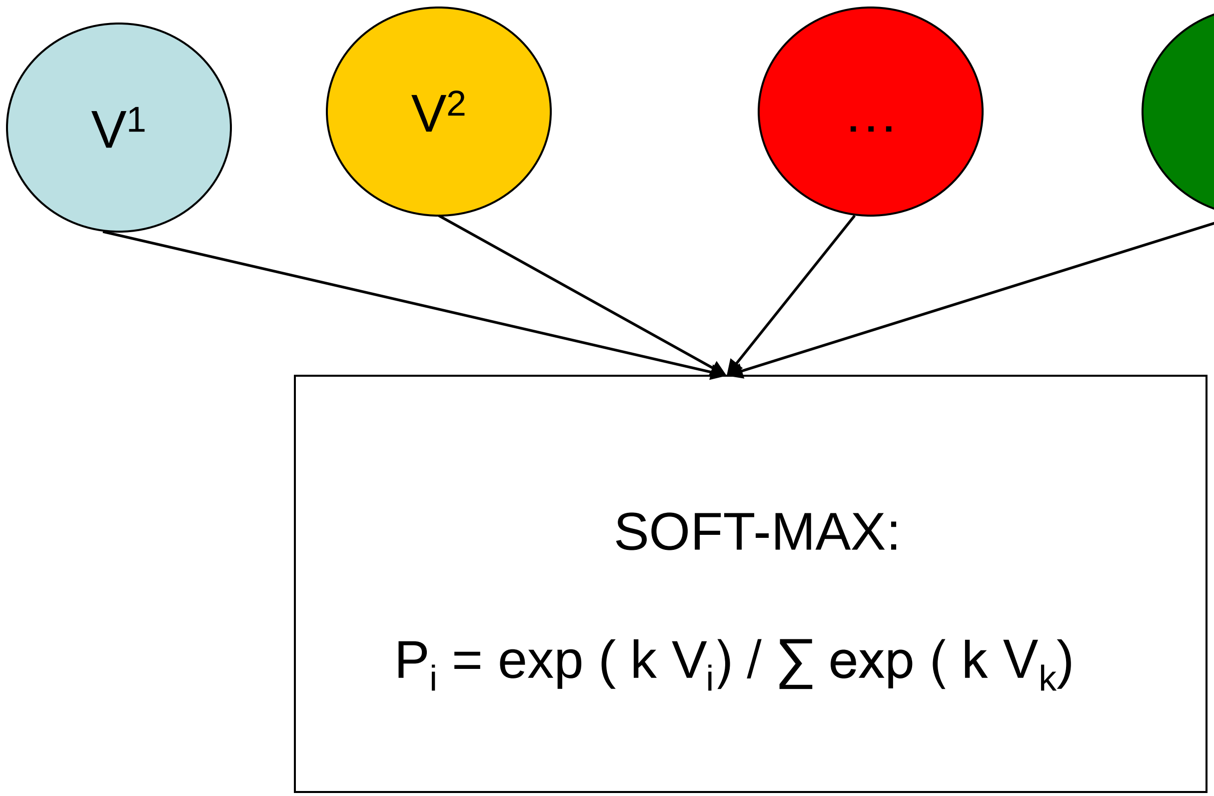
Value & saliency related activity



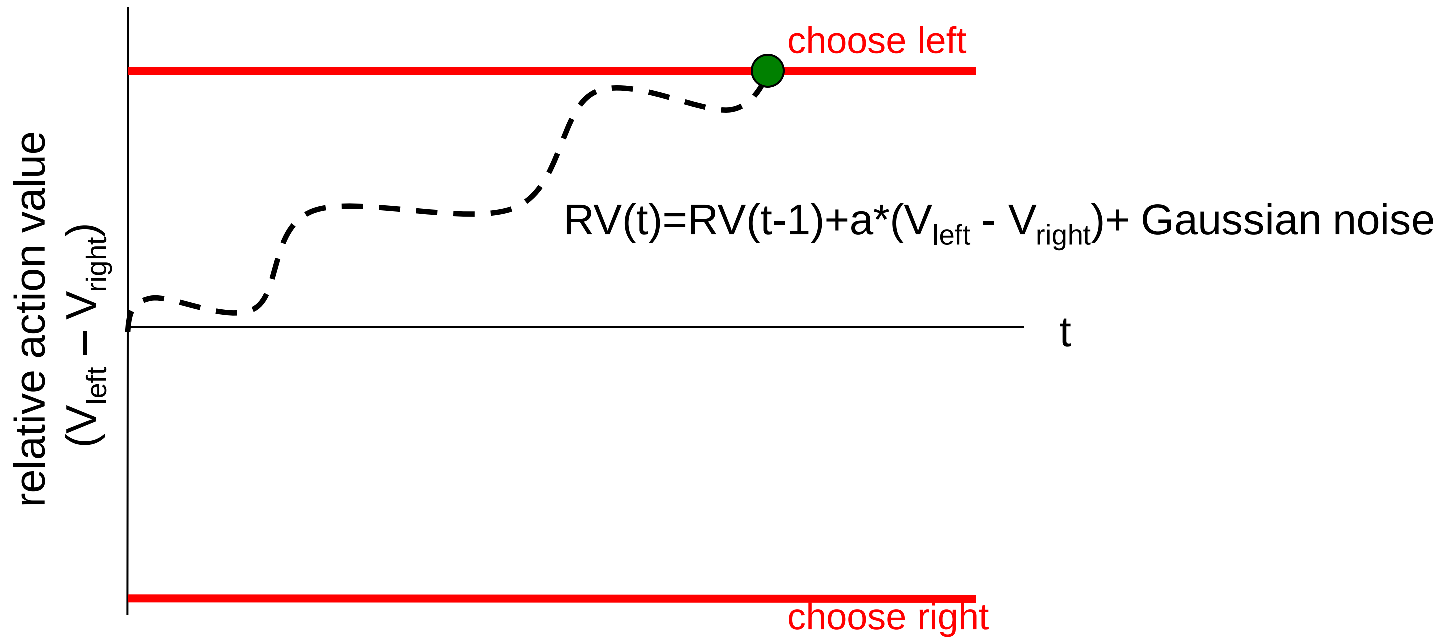


III
Comparison

Common reduced from view

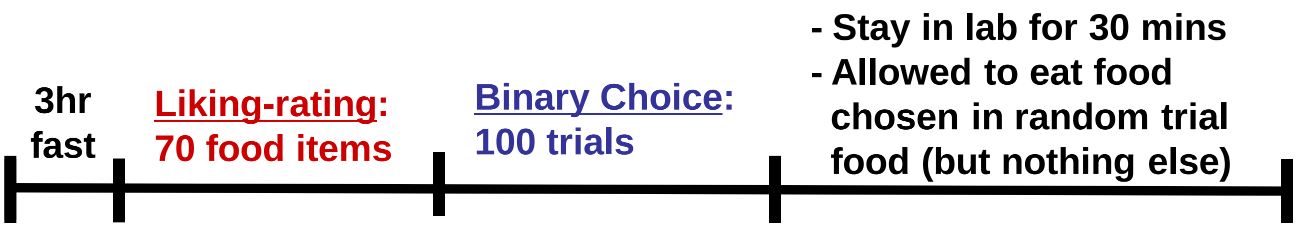


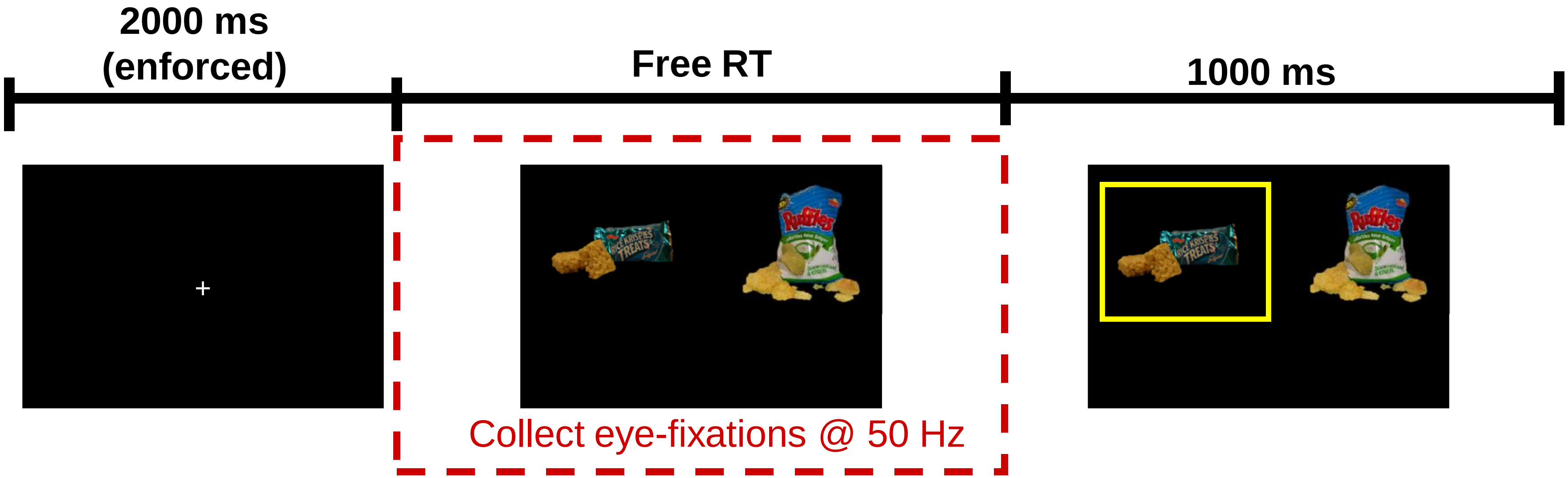
Ratcliff's Drift-Diffusion Model



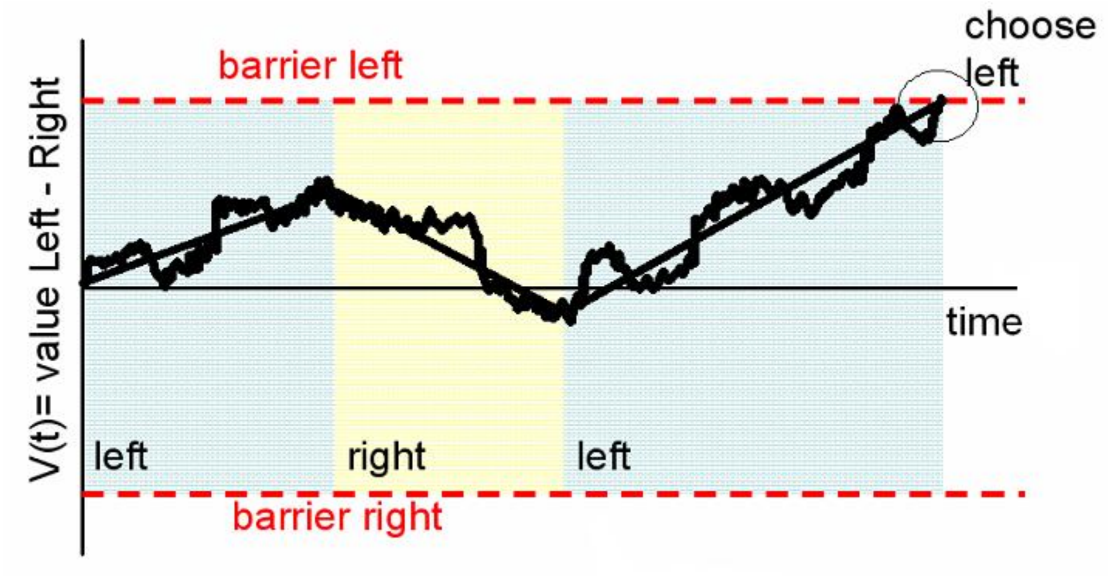
Experimental 4

Nature Neuro 2010, Krajbich Armel Rangel





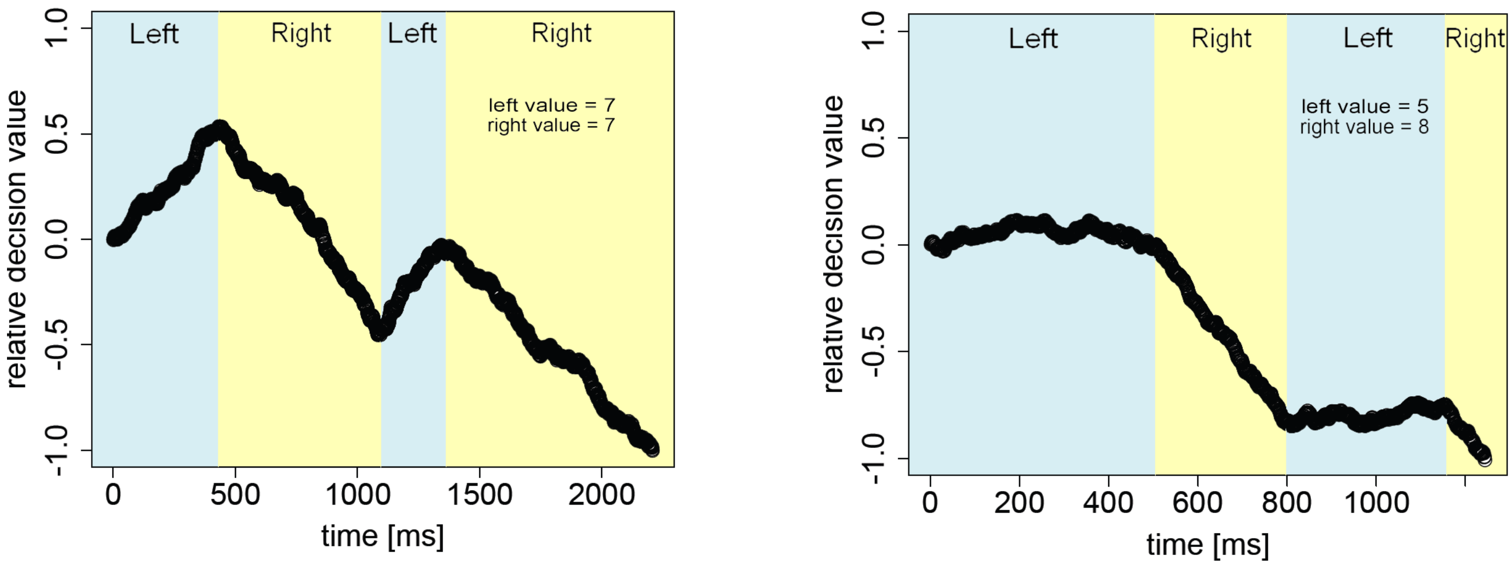
Computational model



$V(t)=V(t-1)+a(v_{target} - \theta v_{non\text{-}target})+u_t$

$u_t \sim N(0,s^2)$

Examples of simulations



Key features:

- Fixation lengths drawn from common distribution
- Integrator follows a random walk with slope $r_{target}-0.3r_{non\text{-}target}$

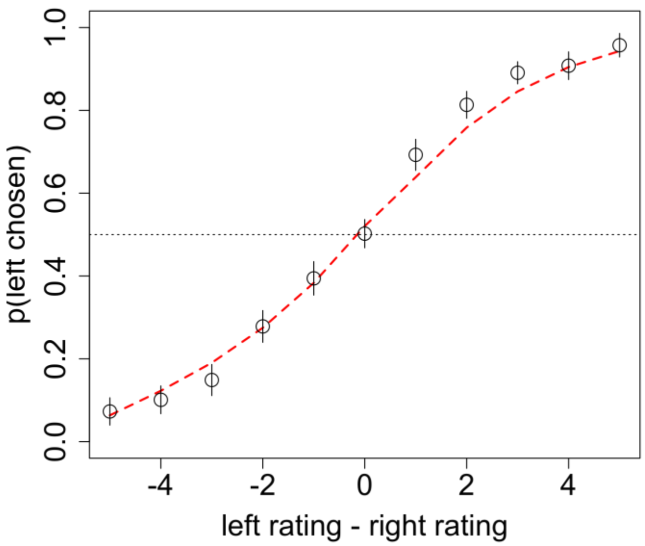
Estimation-prediction exercise

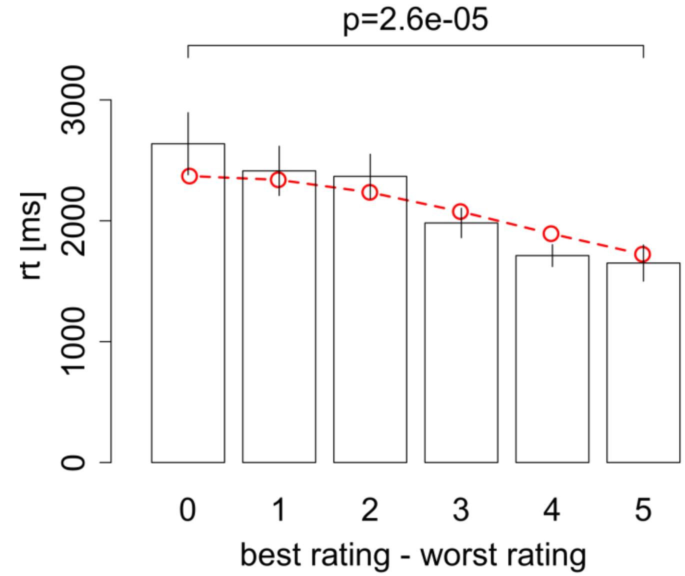
- Free model parameters:
  -- a = slope of integration
  -- s^2= noise variance
  -- θ = attentional bias

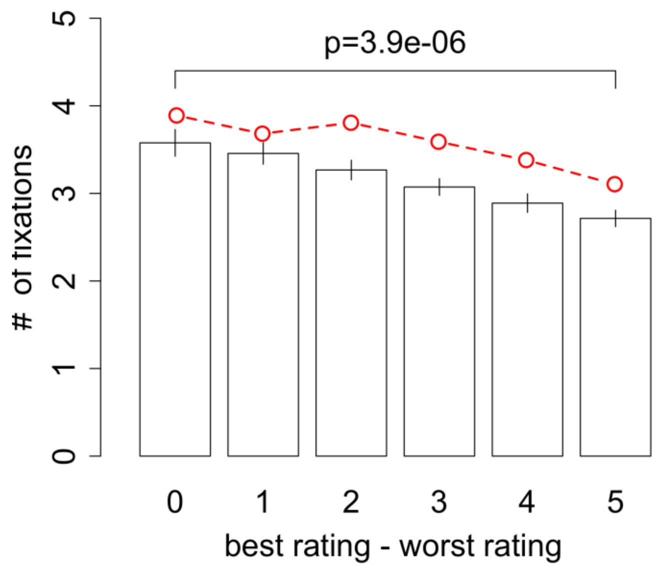
- Estimate parameters in even trials using ML
  Match: choices and reaction times

- Simulate model in odd trials

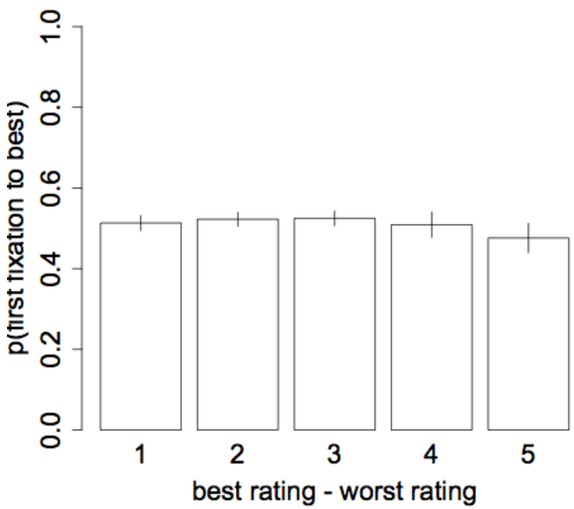
Basic psychometrics

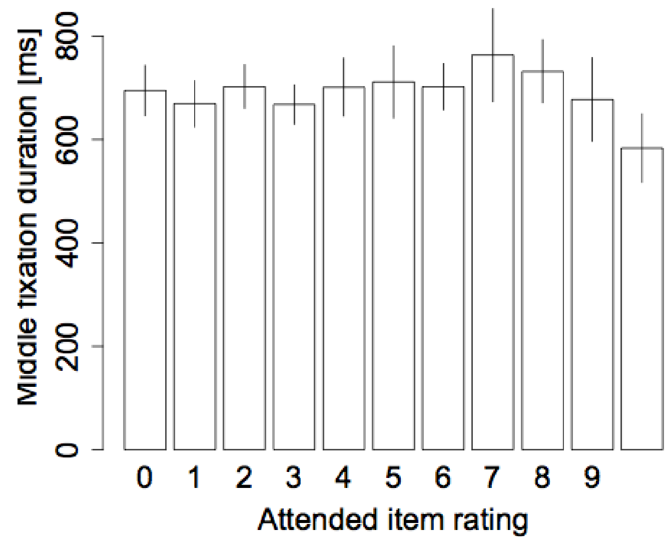


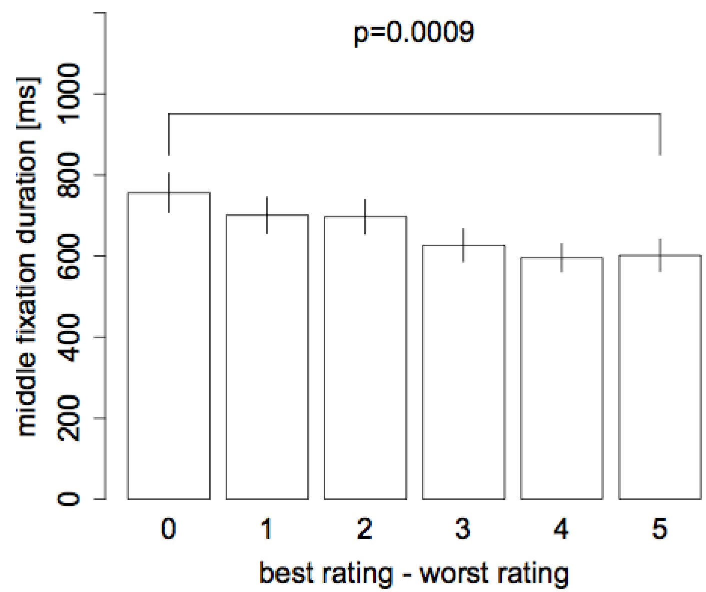




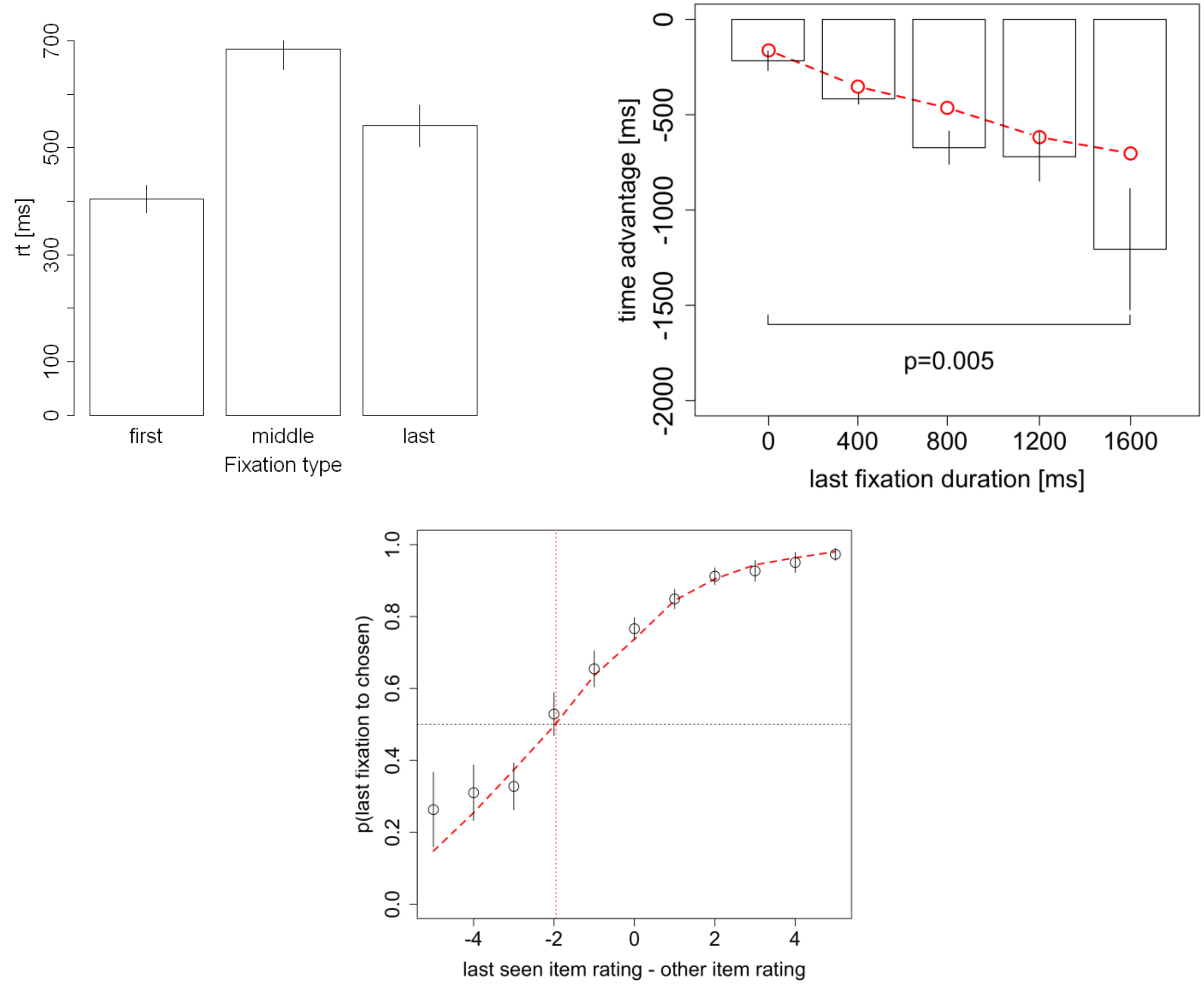
Basic fixation patterns



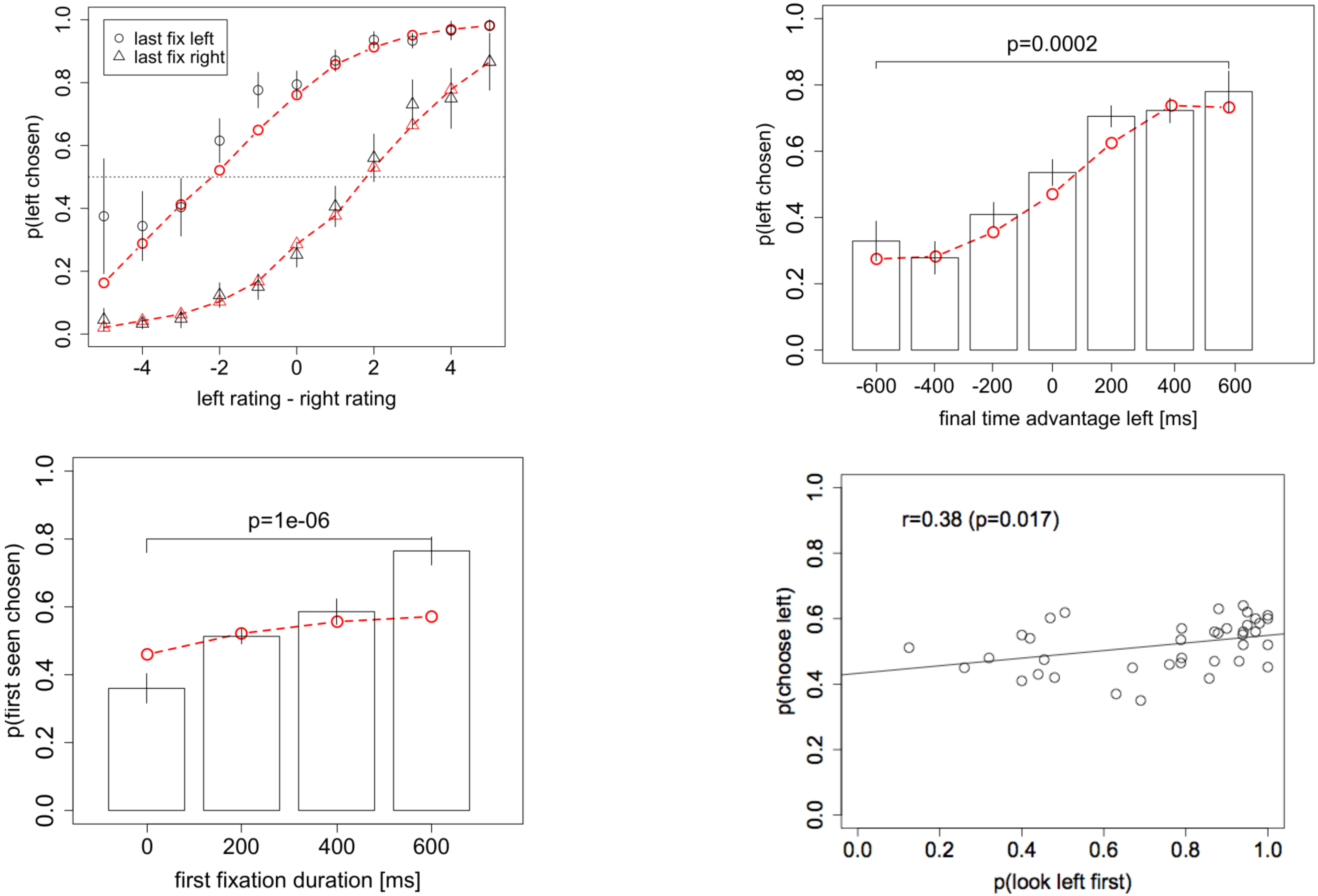




Key tests of the model

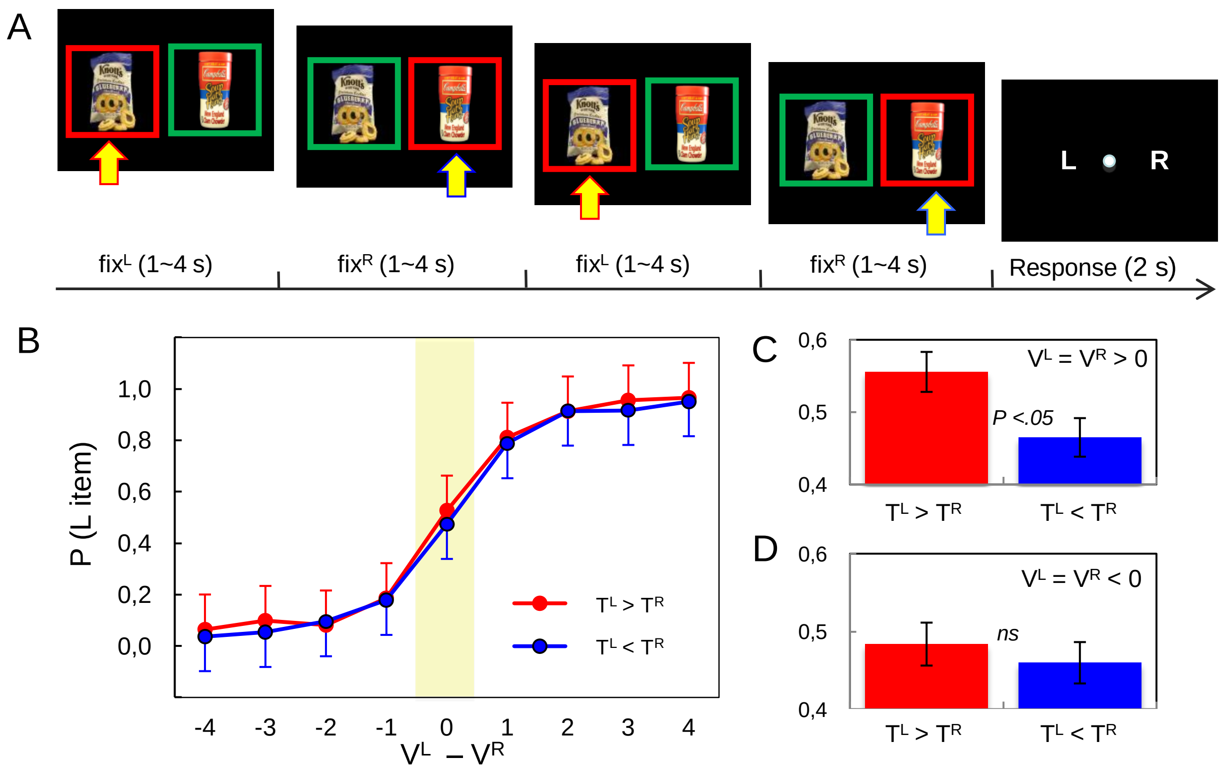


Predicted choice biases

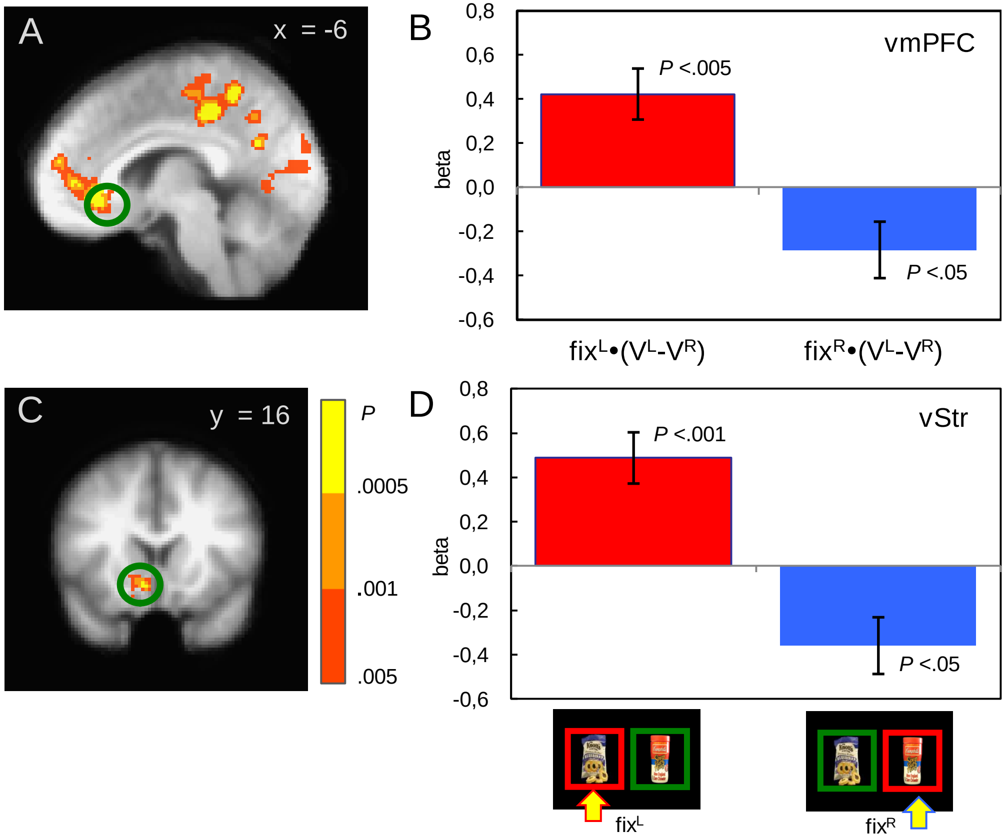


Experiment 5

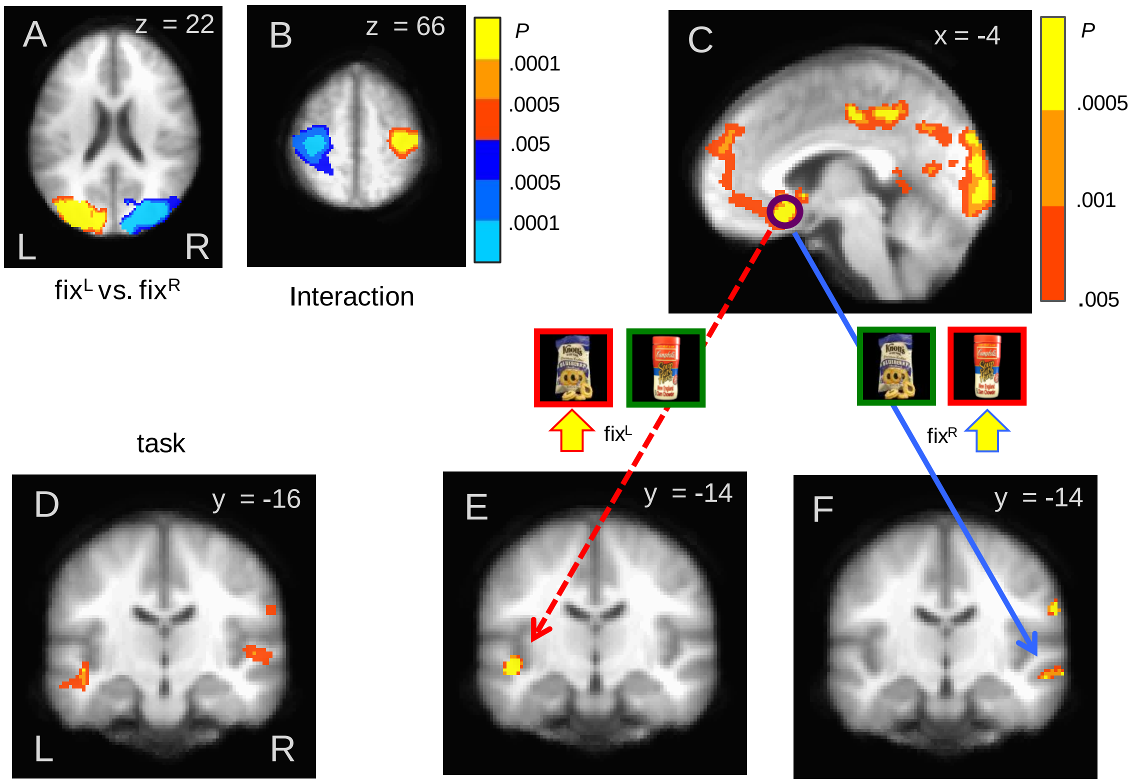
under review, Seung O'Doherty Rangel



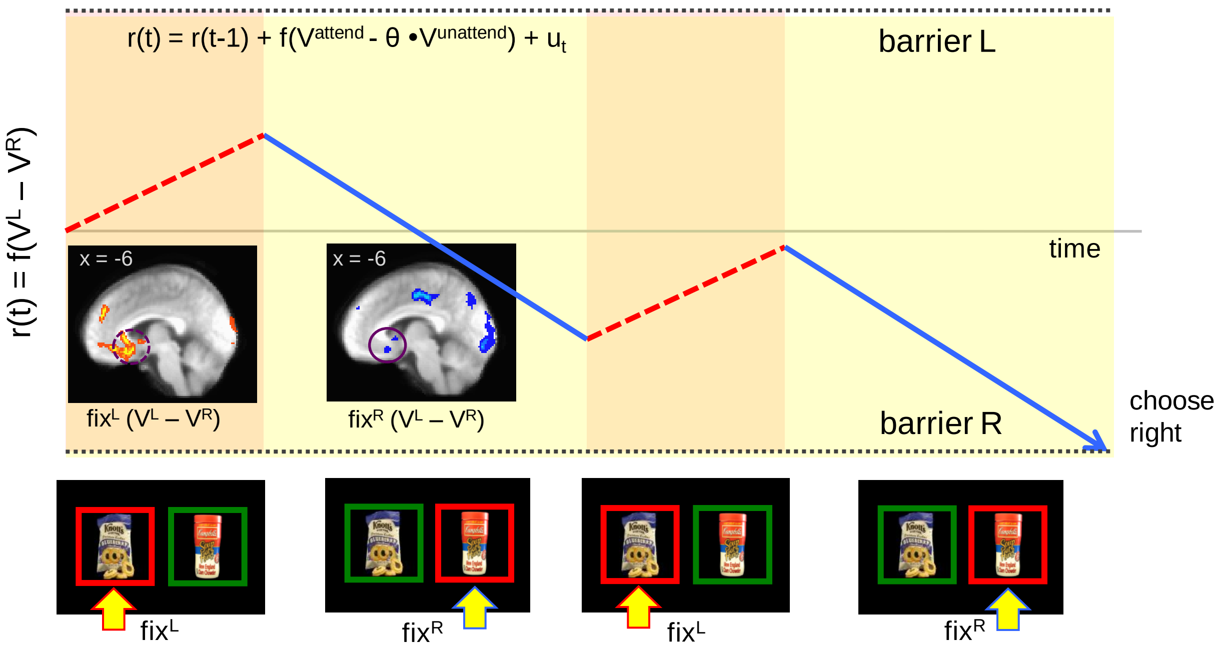
mOFC encodes attention modulated relative value signals



Attentional effect modulated by the STS



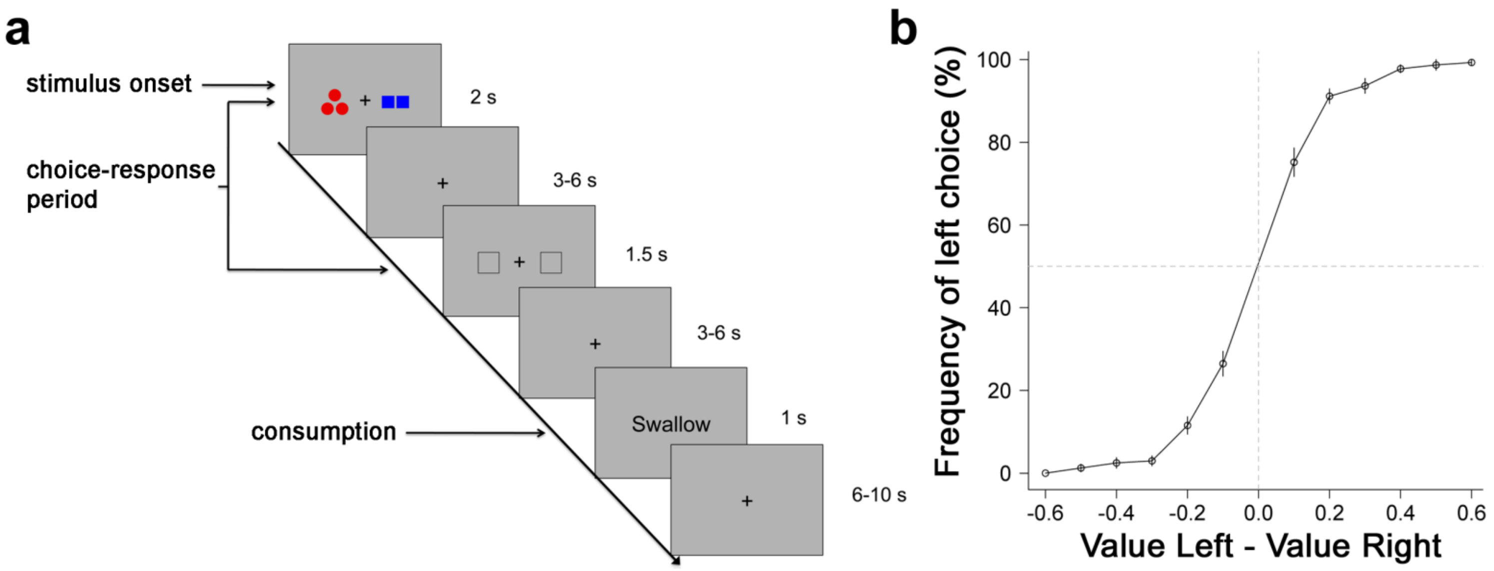
Relationship with computational model



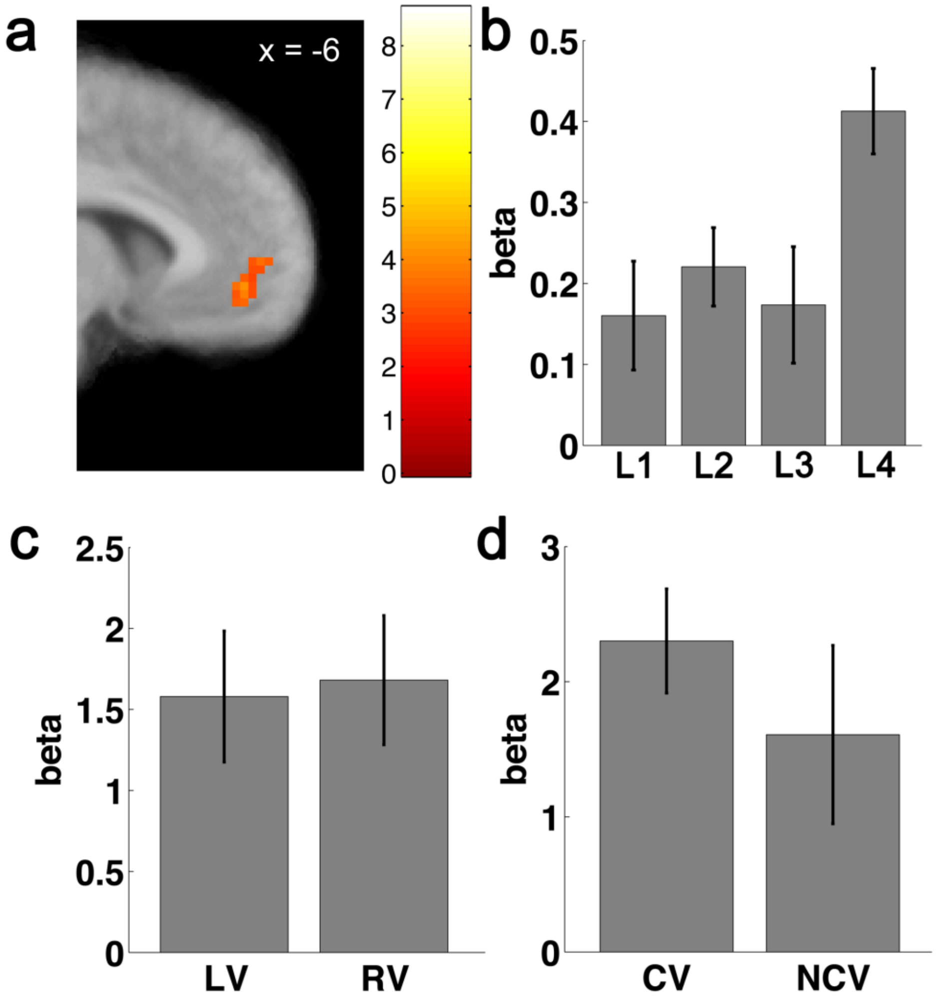
IV
From choices to motor output

Experiment 6

under review, Hare O'Doherty Schulz Rangel



mOFC correlates with stimulus values



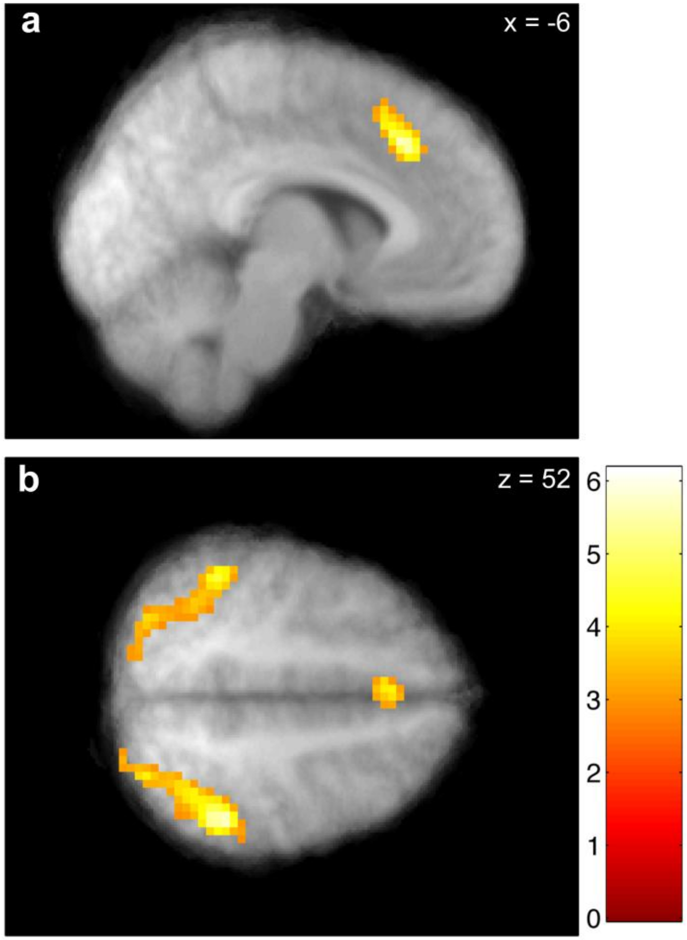
Markers of a region involved in comparison

1. Should exhibit aggregate activation pattern consistent
   with predictions of plausible neural implementations of the DDM

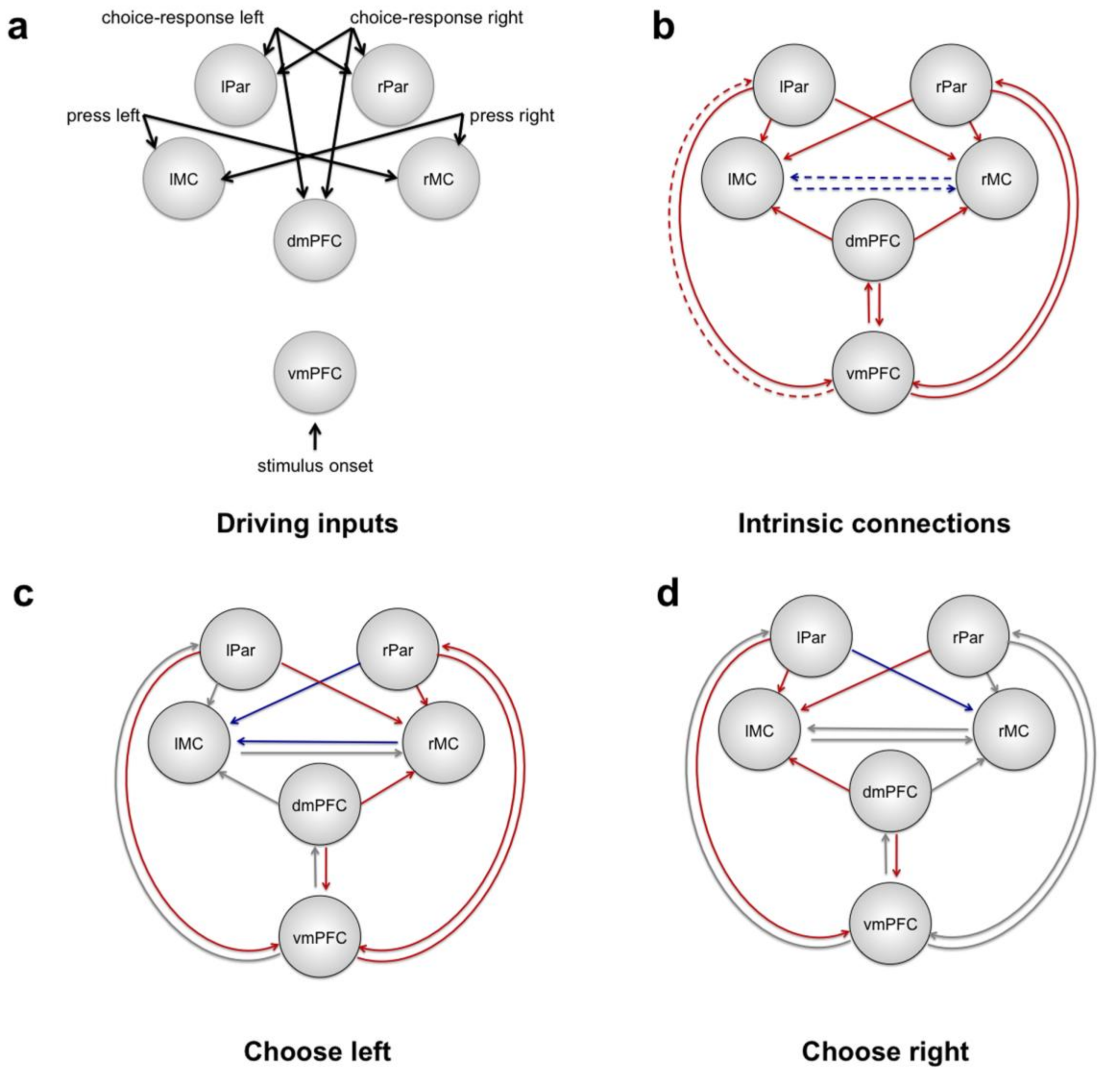
2. Should exhibit connectivity w/ vmPFC valuation areas
   at time of choice

3. Should exhibit choice dependent connectivity with motor cortex output areas

dmPFC activity correlates with predictions of simple neural implementation of best fitting DDM



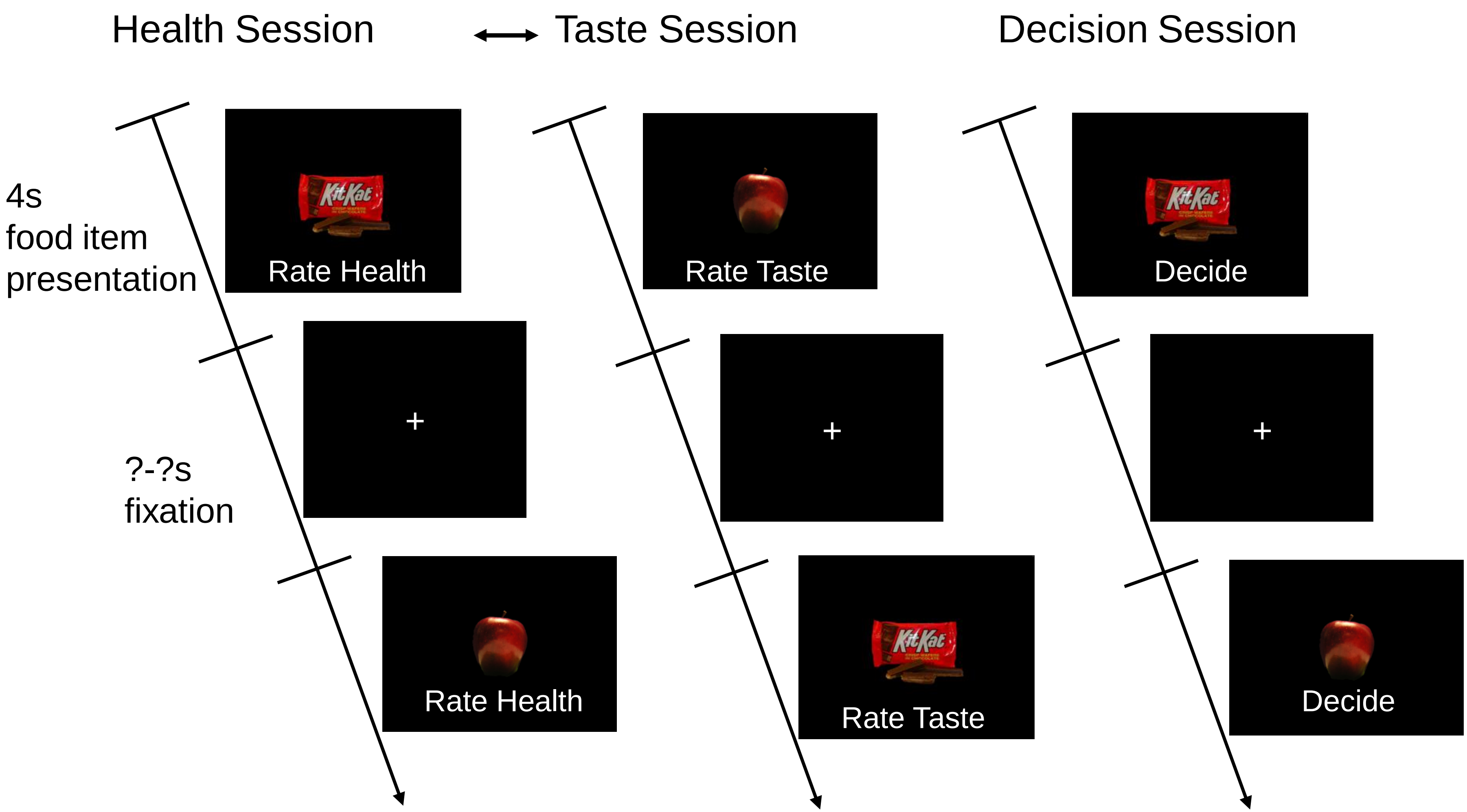
dmPFC modulates transformation of values into motor responses



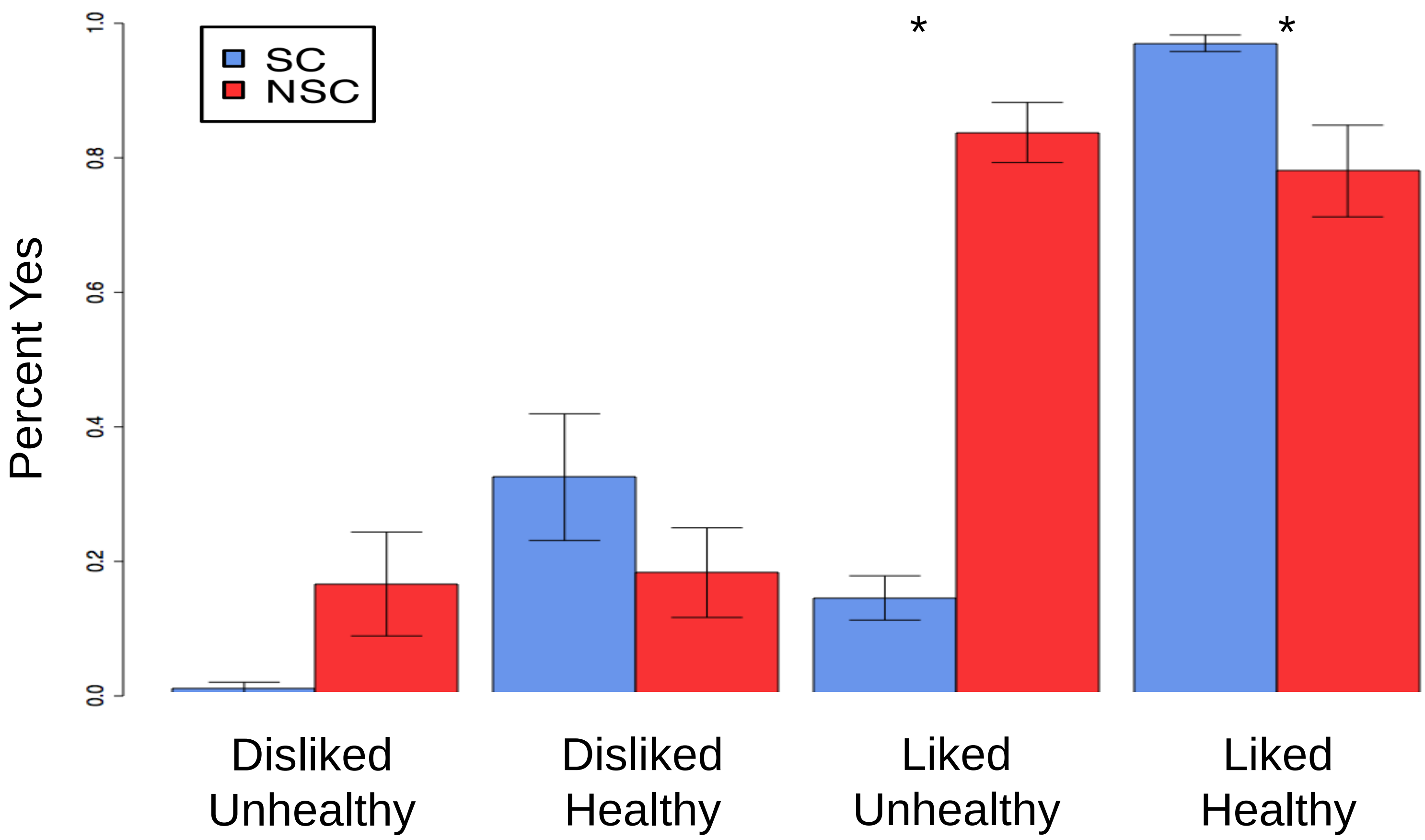
V
Self-control

Neural mechanisms of dietary self-control

Hare, Camerer, Rangel (Science 2009)



Behavioral differences across groups

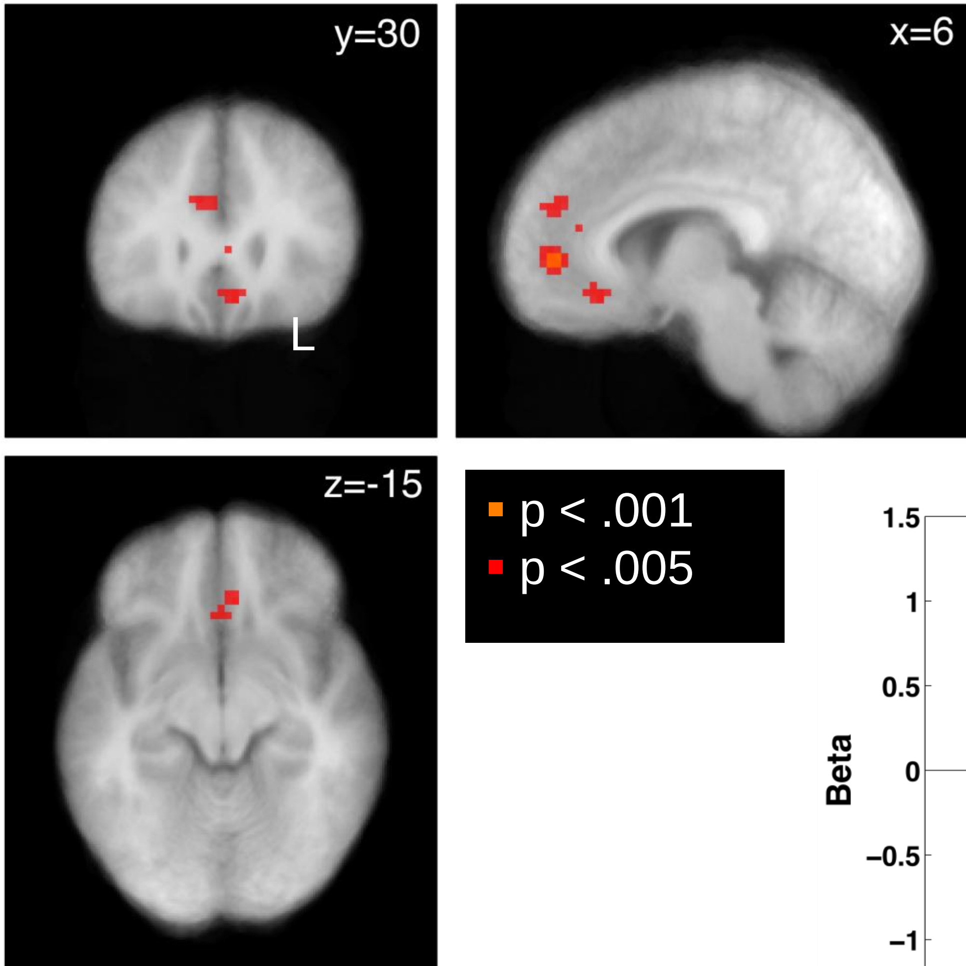


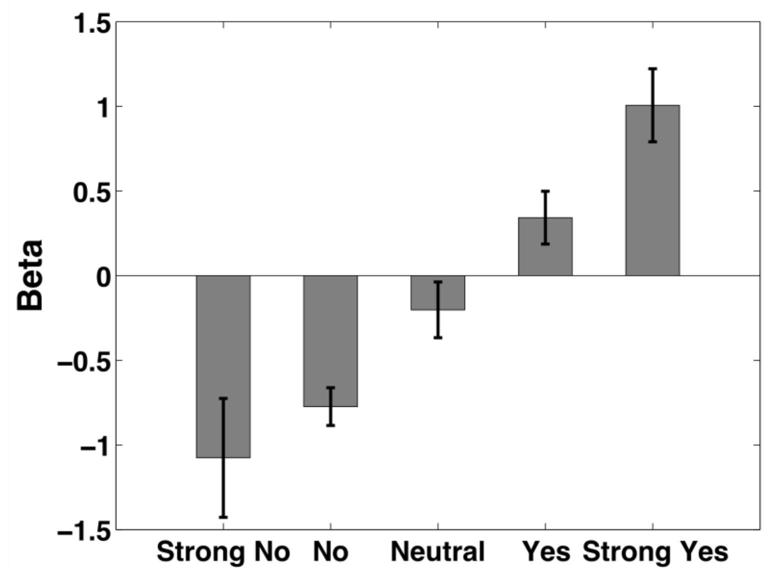
Hypotheses

H1) vmPFC encodes a common decision value signal that has different properties in good and poor self-controllers

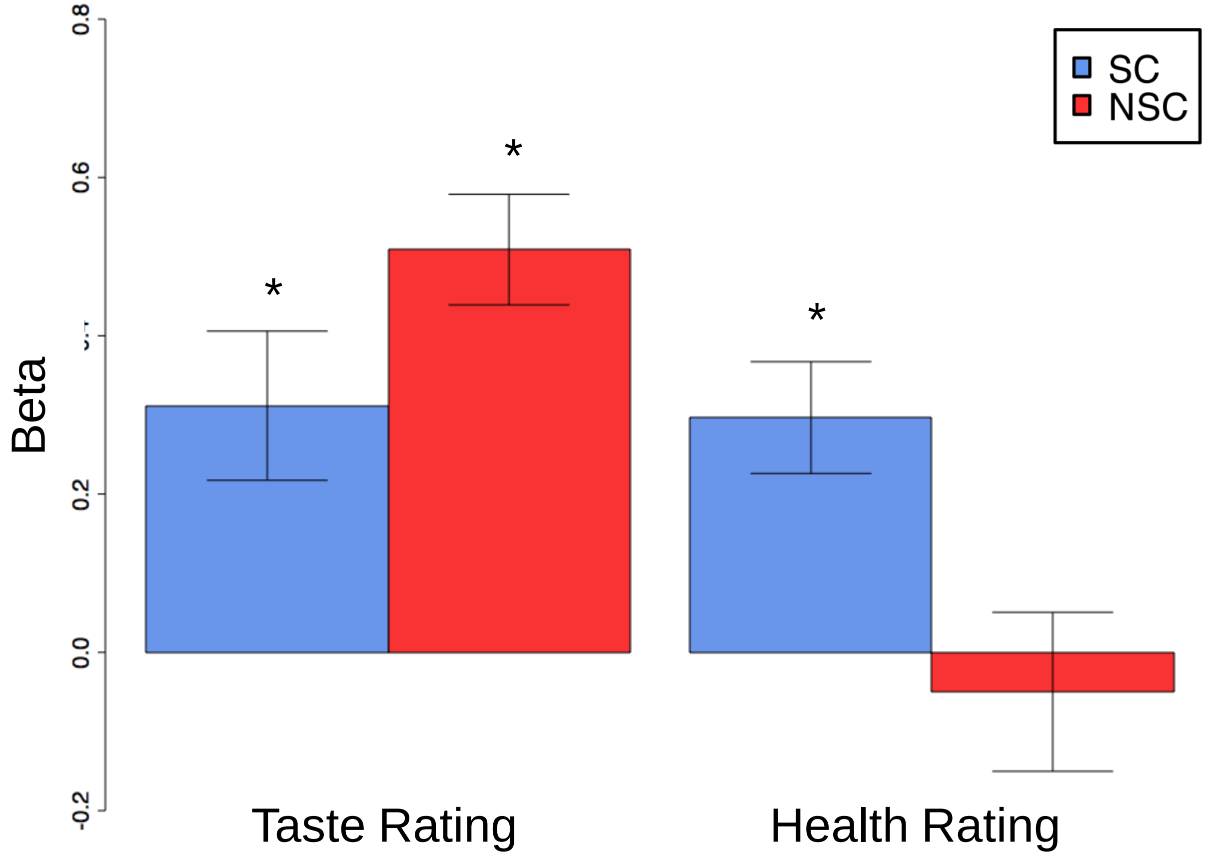
H2) Attentional self-control involves DLFPC modulation of the vmPFC valuation system

Activity in vmPFC is correlated with a behavioral measure of decision value (regardless of SC)

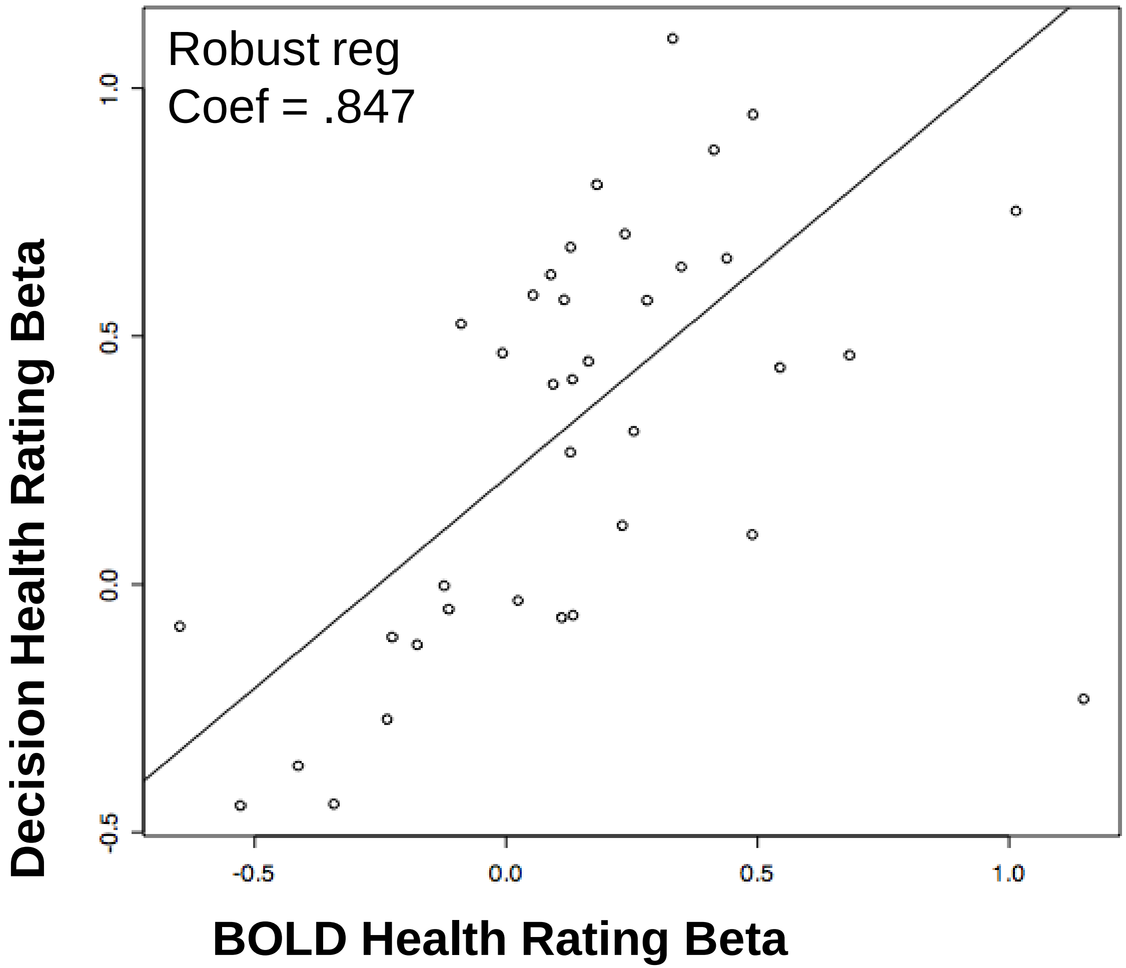




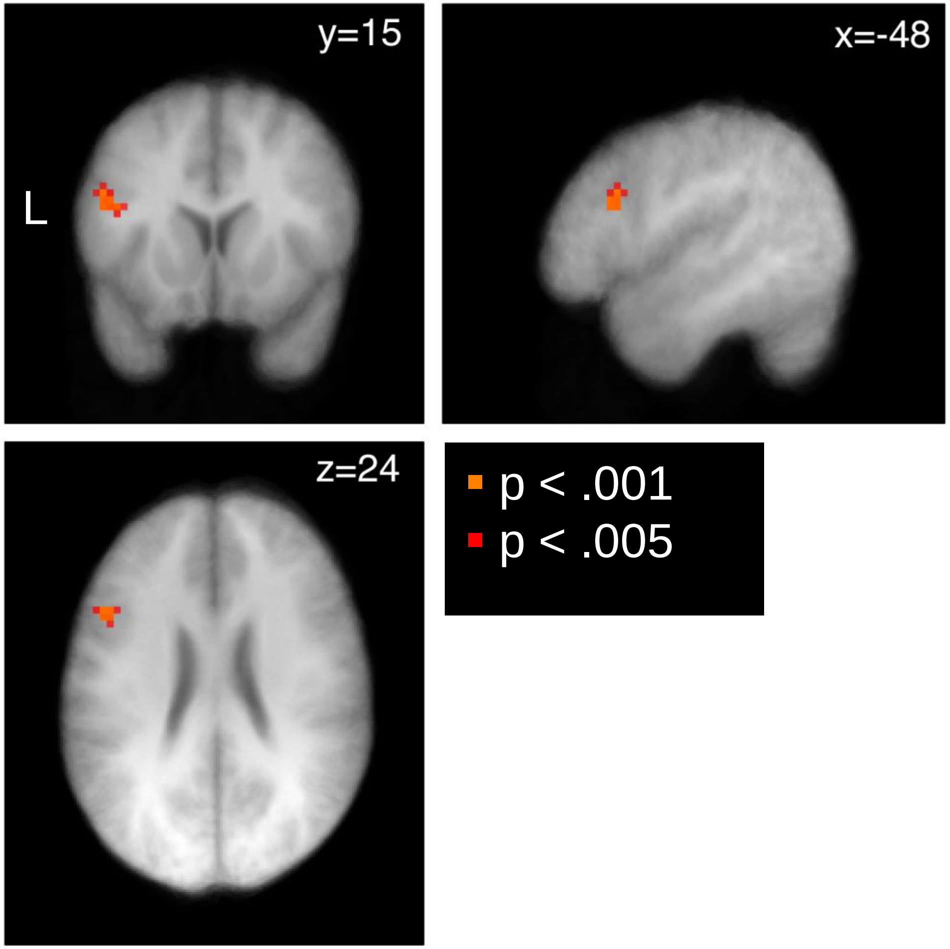
vmPFC BOLD signal reflects both taste and health ratings



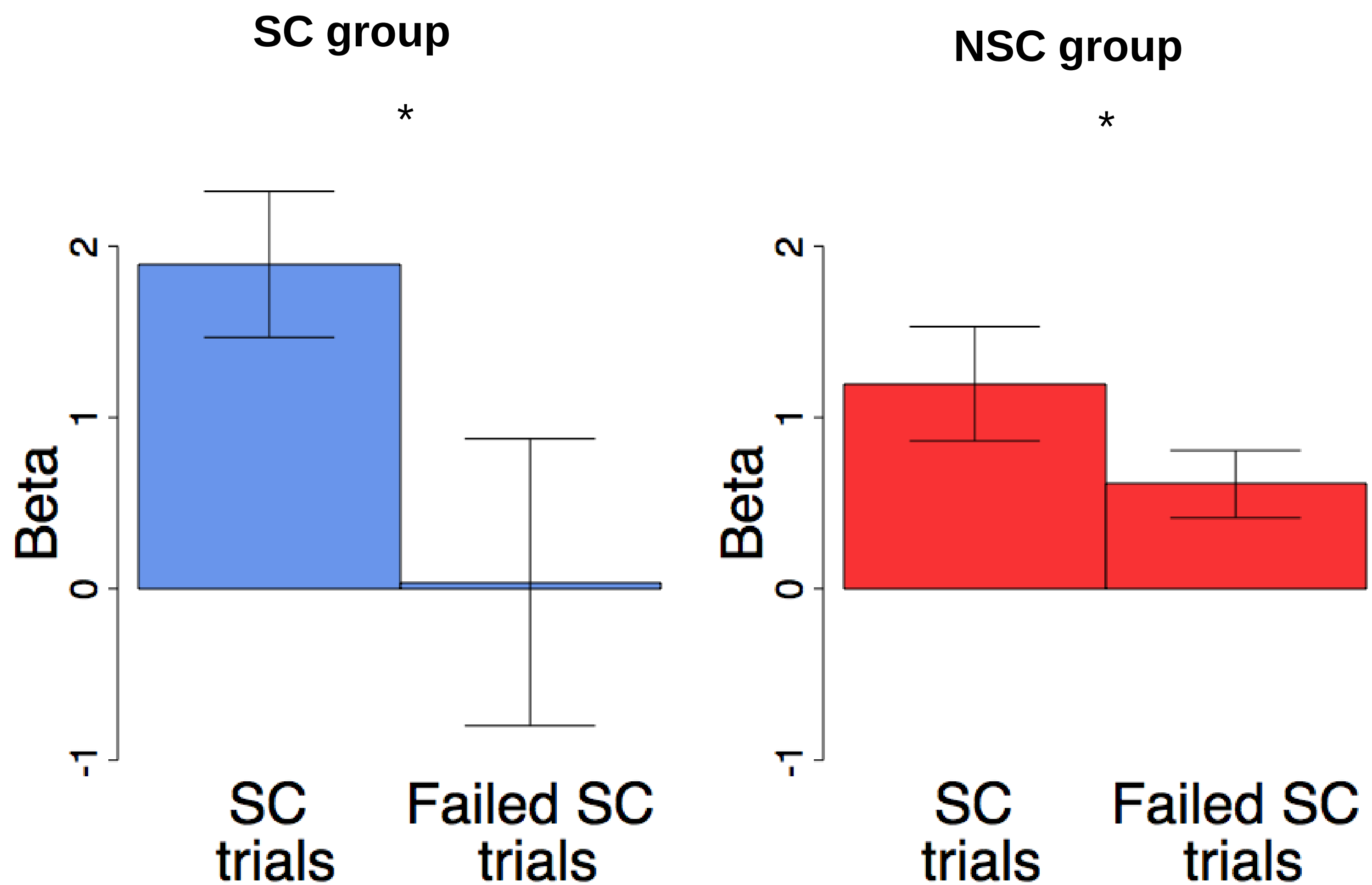
The effect of HR in the vmPFC is correlated with its effect on behavior



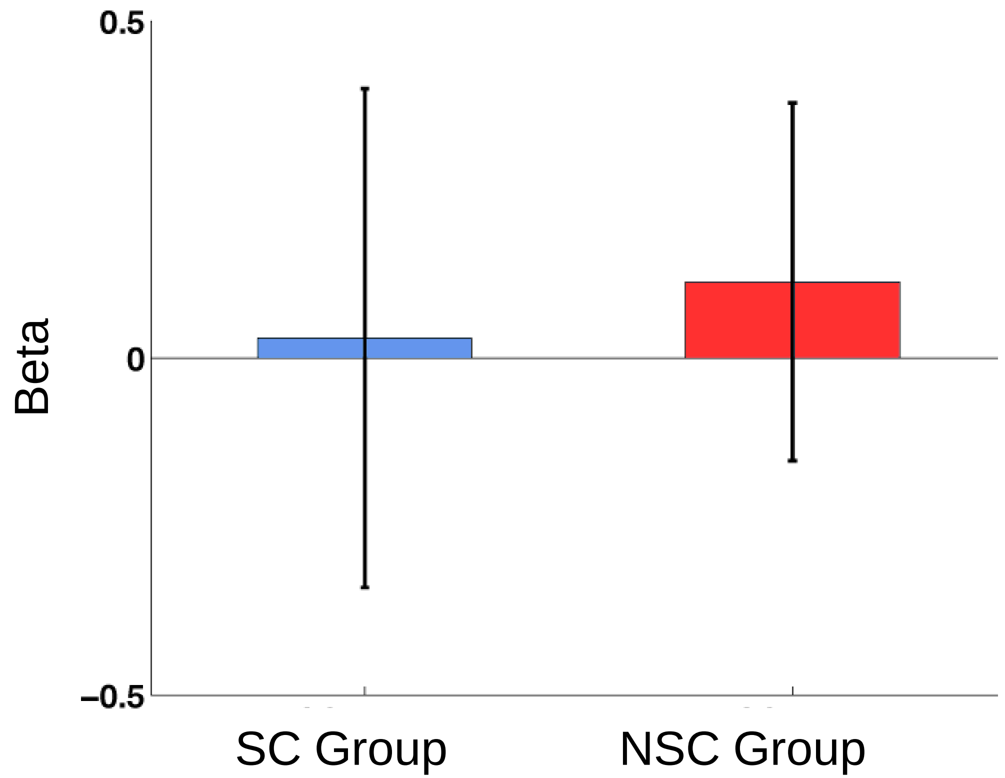
SC group has greater DLPFC than NSC when implementing self-control



More activity in DLPFC in successful SC trials than in failed SC trials



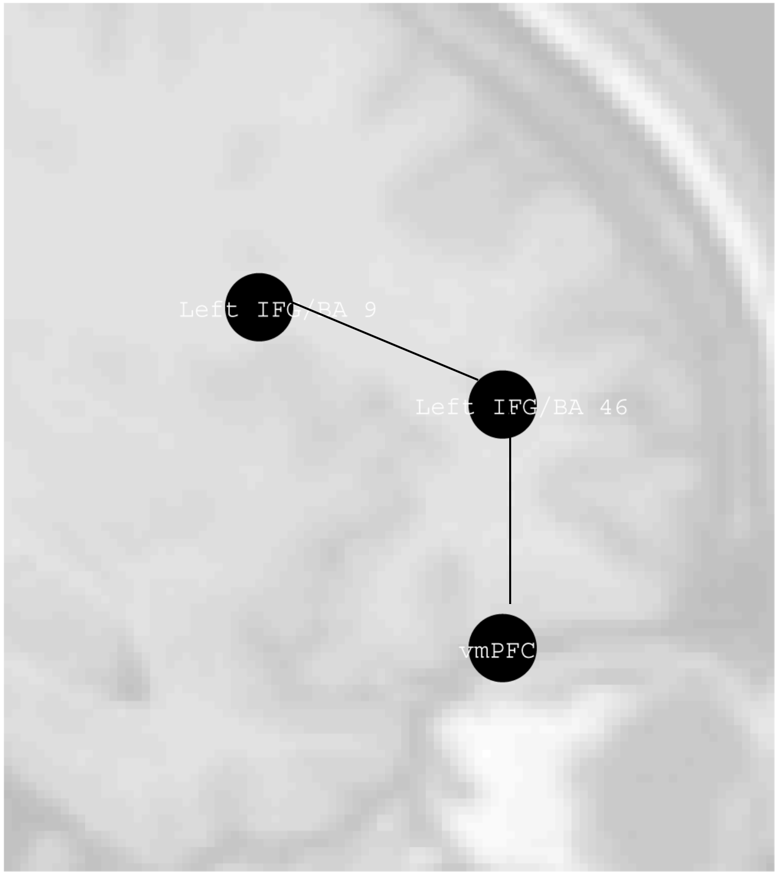
DLPFC activity does not correlate with HR



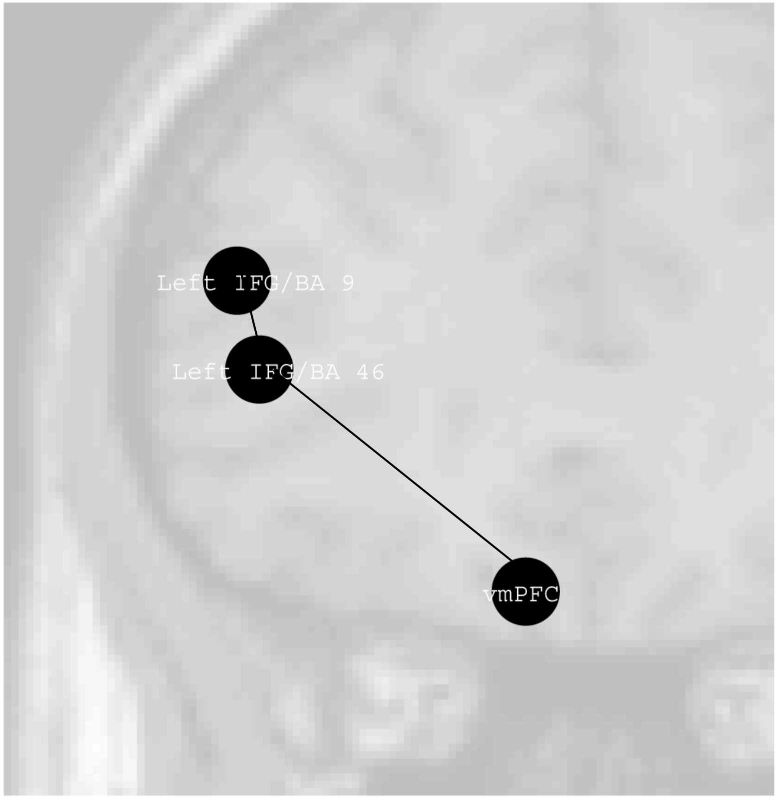
*Error bars = 95% confidence intervals

Attentional self-control network

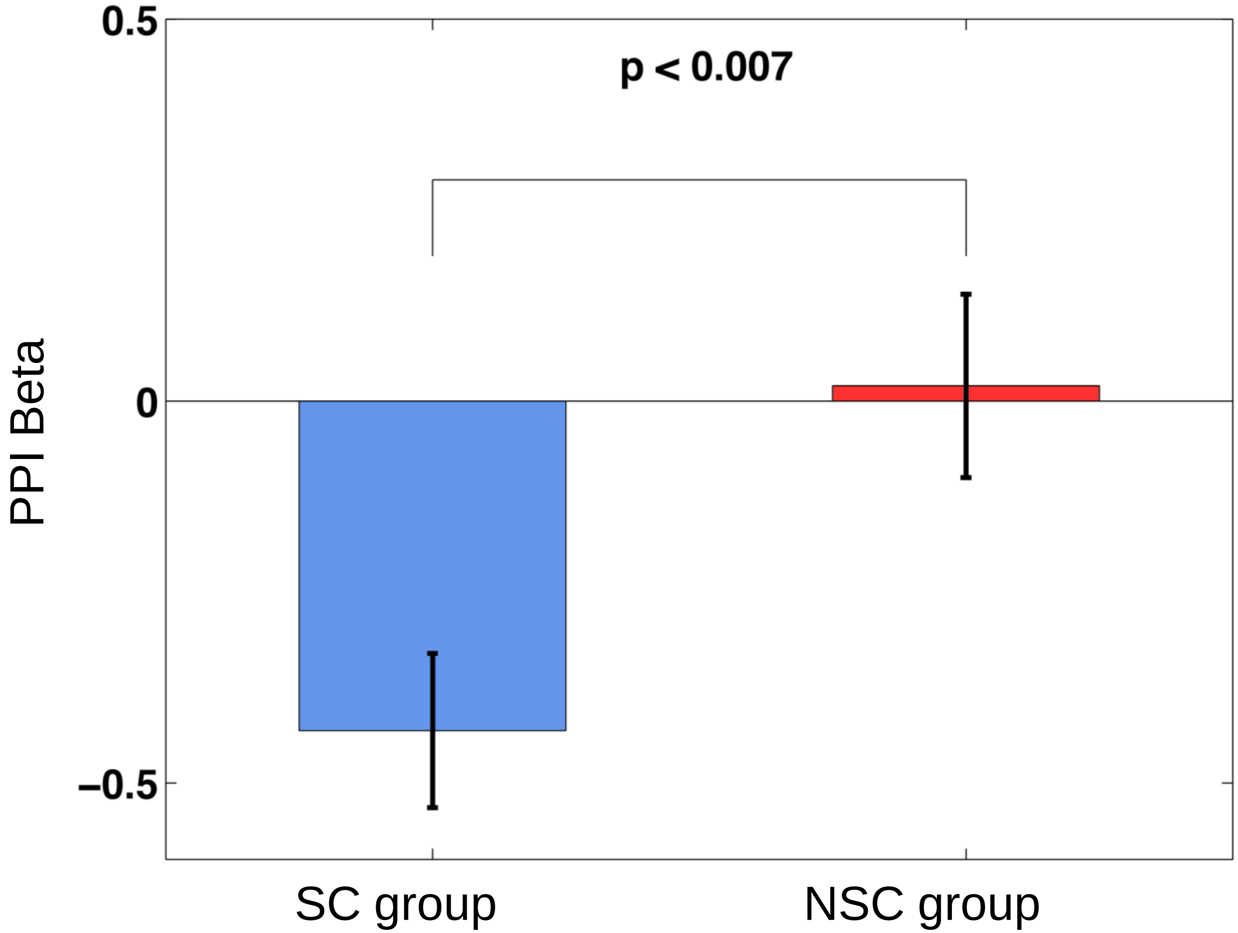
Sagittal



Coronal



Group difference in PPI



Remarks

• Evidence attentional self-control involves modulation of vmPFC value signals by dlPFC so that they incorporate all dimensions of stimuli

• Healthy eaters in sample can do this
Unhealthy eaters cannot do this

• Have replicated results in a monetary discounting task

V
Final Remarks

Key points

- mOFC/vmPFC plays critical role in valuation during decision-making, probably by computing relative values
- A modified DDM provides very high accuracy description of psychometric data
- Both the valuation and comparison process are modulated by visual attention
- Evidence that dmPFC might be part of the comparator process that transforms values into motor responses

Next steps: Examples of critical open questions

Valuation:

> How EXACTLY are the value signals in mOFC computed at time of choice?
> What is the network of inputs that help at work in different decision problems and situations?
> What EXACTLY is the code used in OFC to represent value of a stimulus?
> How are the various components of the valuation learnt?
> How does the brain know when to start and stop valuing a stimuli & which stimuli to evaluate?

-

Next steps: Examples of critical open questions

<u>Comparison</u>:
> More detailed models of comparator process and neurobiological basis

Ex:

-- how are multiple value neurons integrated in comparison

-- how is the DDM mapped to underlying neurobiology

-

Next steps: Examples of critical open questions

Motor:
> How are stimuli and action representations mapped to each other?
> Role of Supplementary Motor Areas
> Role of basal ganglia- thalamic- cortical loops
> Computational role for IPS

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Interested in post-doc
or PhD studies in neuroeconomics?
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