Value-based prioritization of episodic memory

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Outline

- Memory prioritization
- Value-directed remembering (VDR) paradigm
- EEG correlates of VDR
- Diffusion imaging of VTA-hippocampus pathways

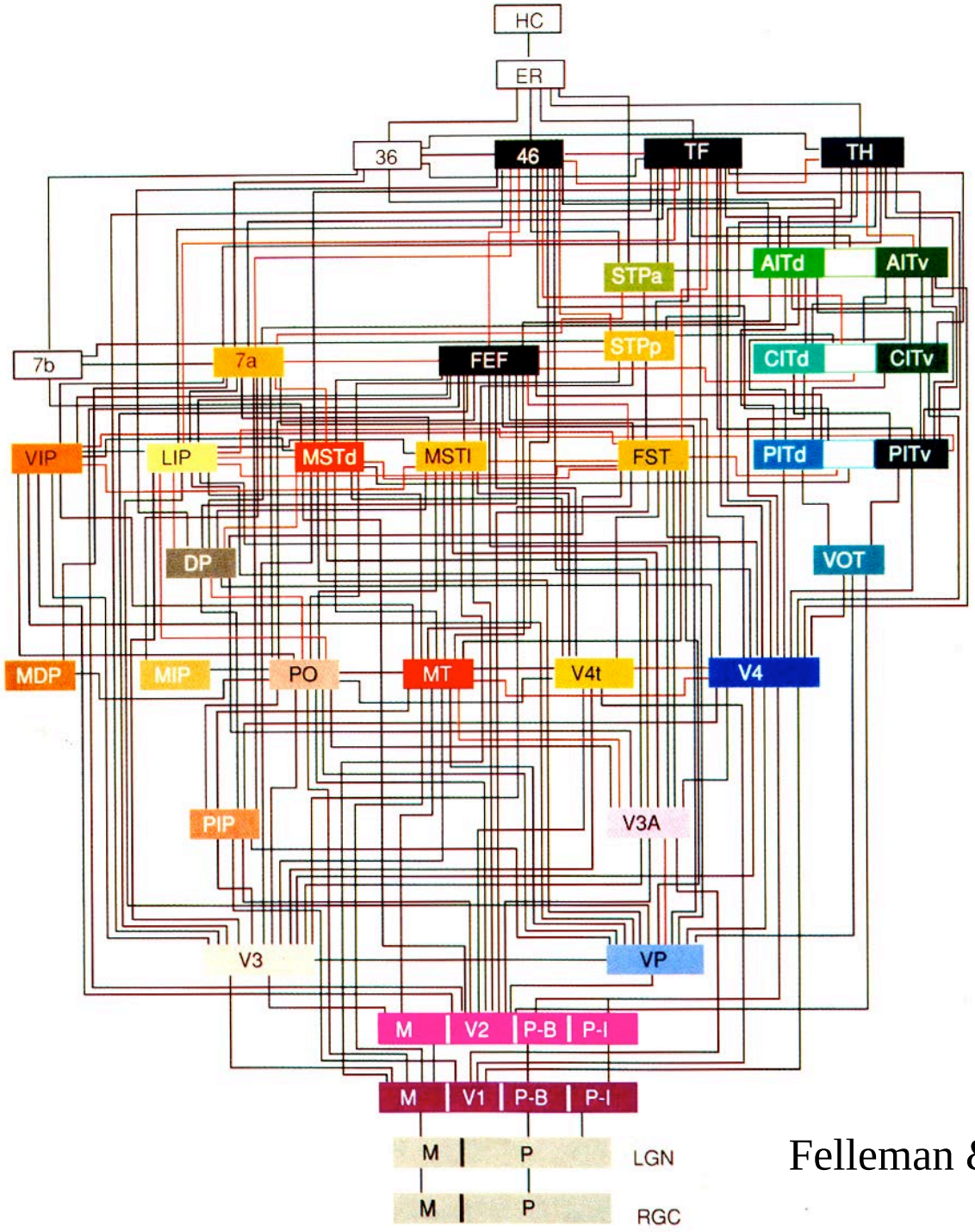
Collaboration

Gene Brewer

Blake Elliott

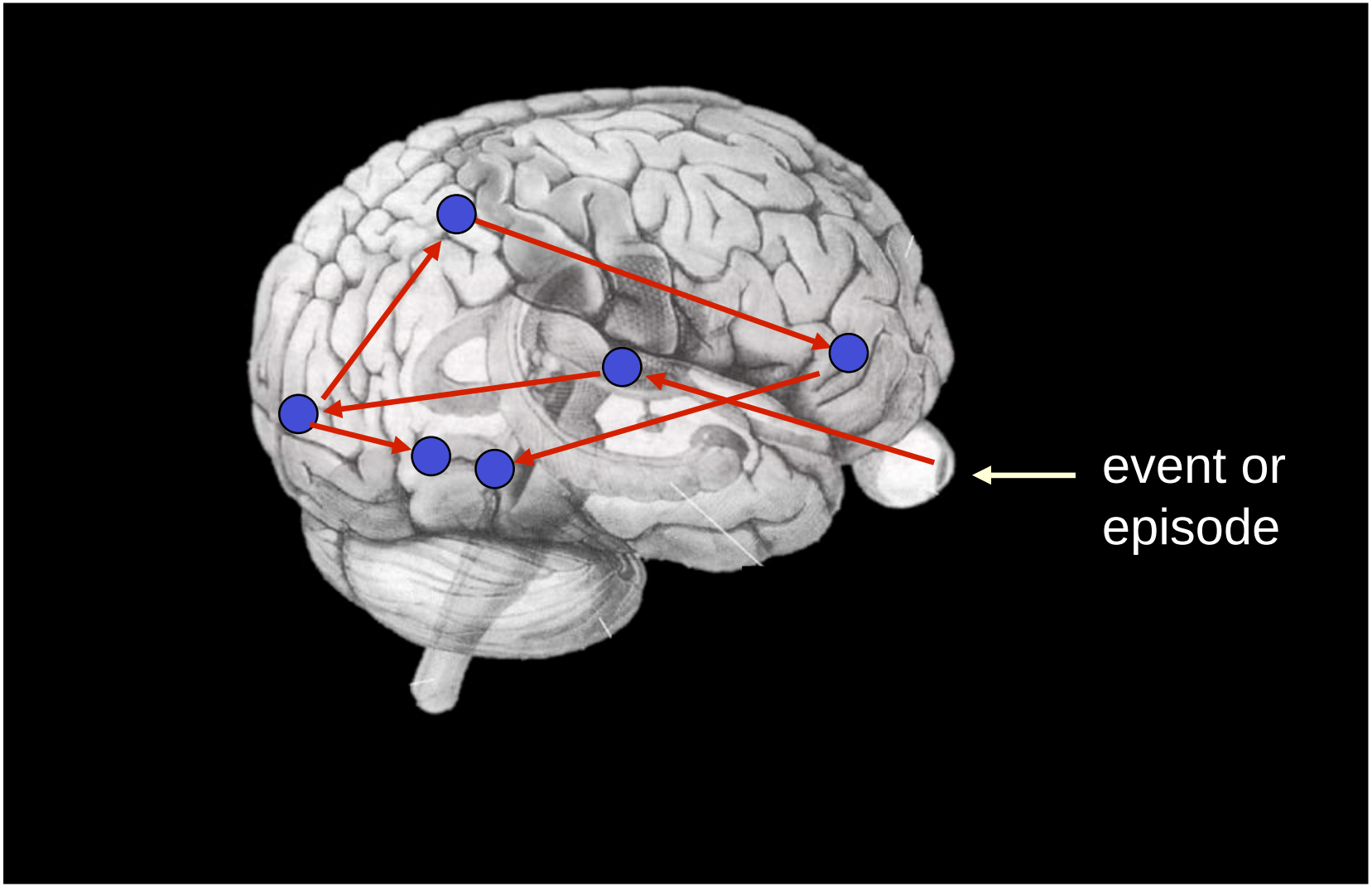
Memory

Memory

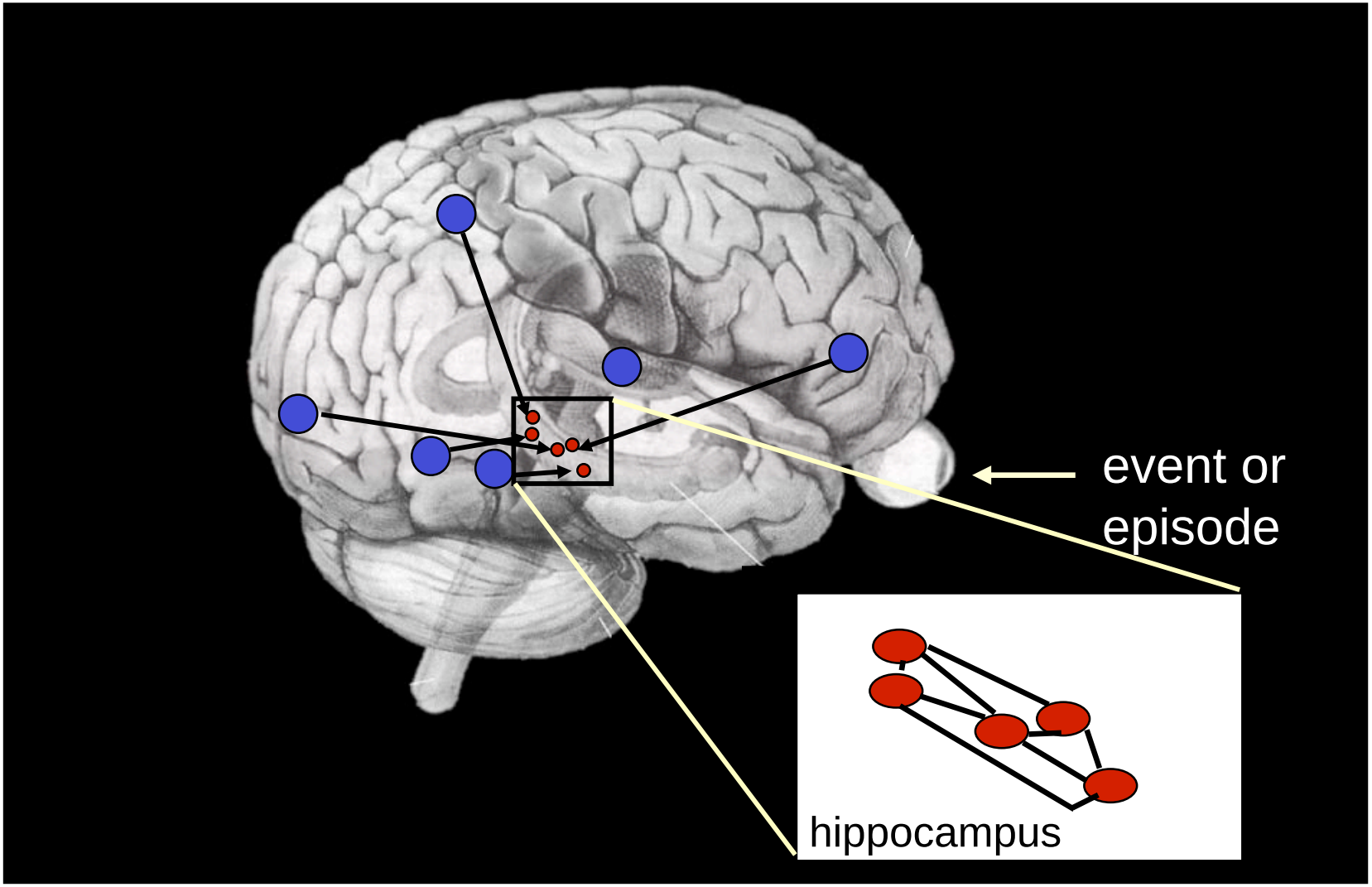


Felleman & Van Essen, ‘93

Memory formation



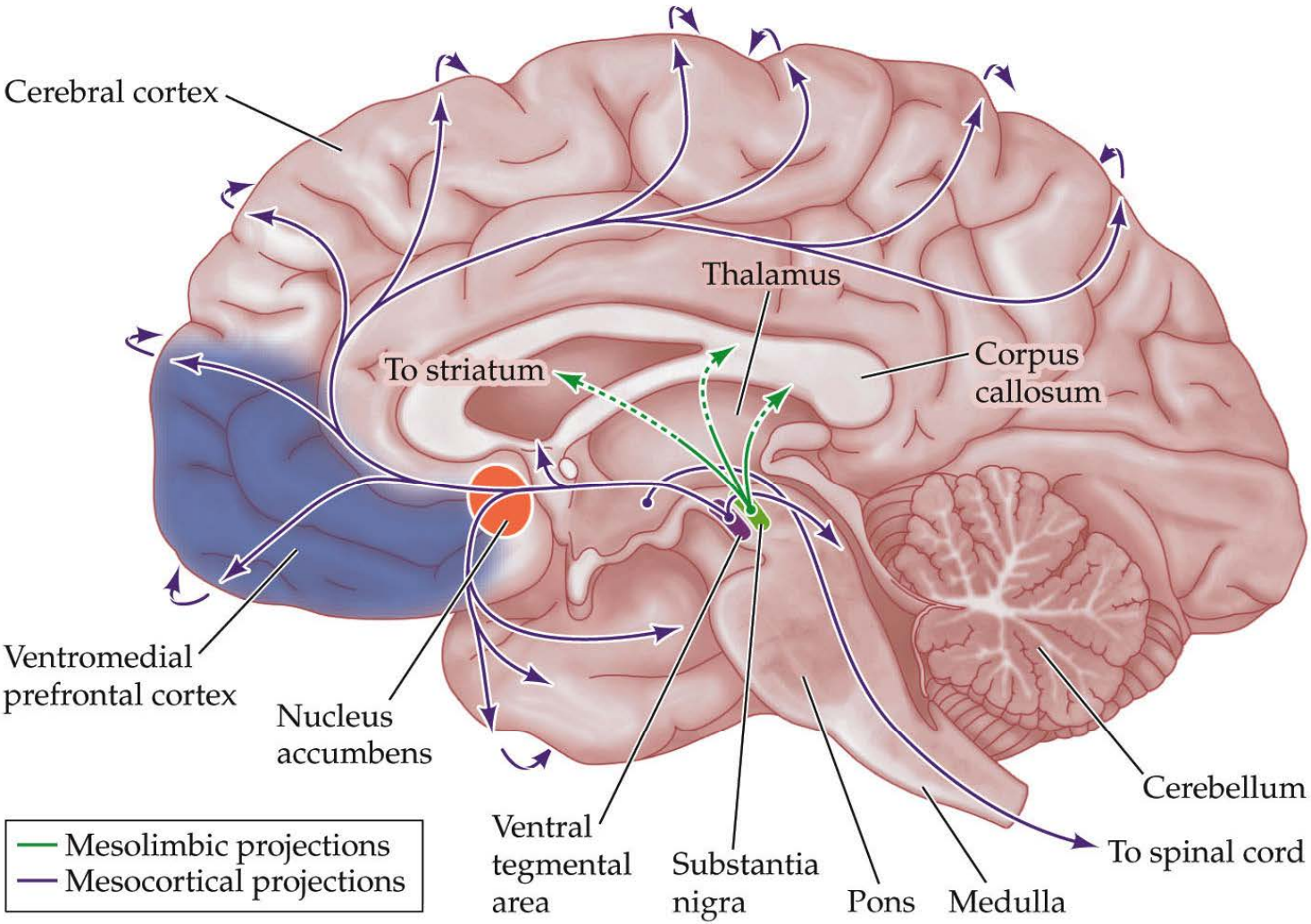
Memory formation



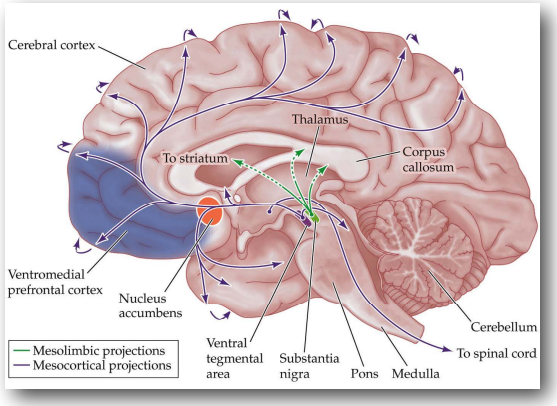
Memory prioritization

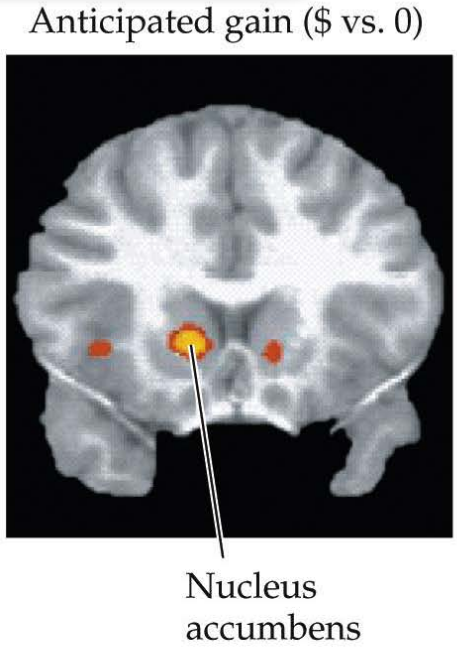
- Preferential encoding of some episodic memories over others
- Due to a number of factors:
  - Saliency
  - Effort
  - Reward

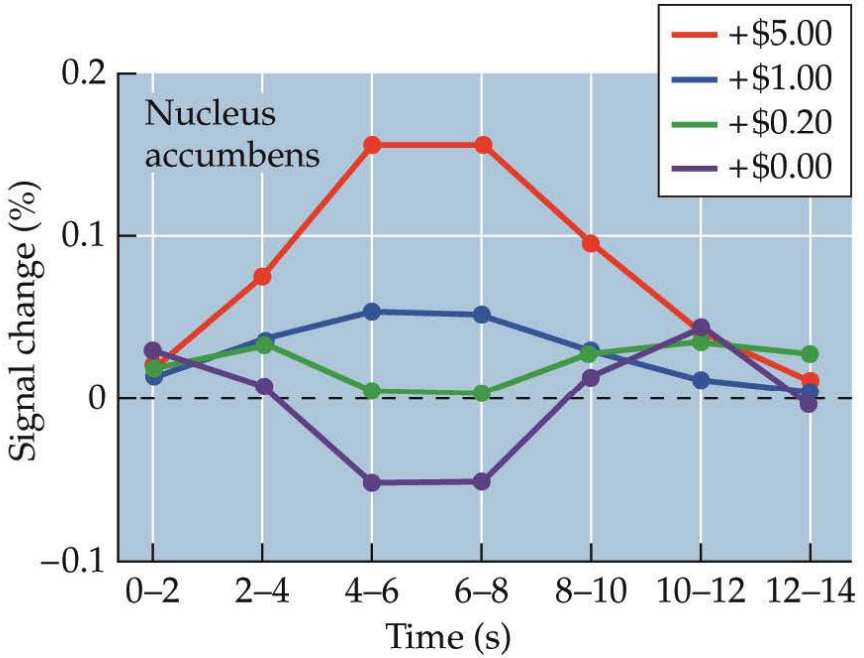
Midbrain dopamine system



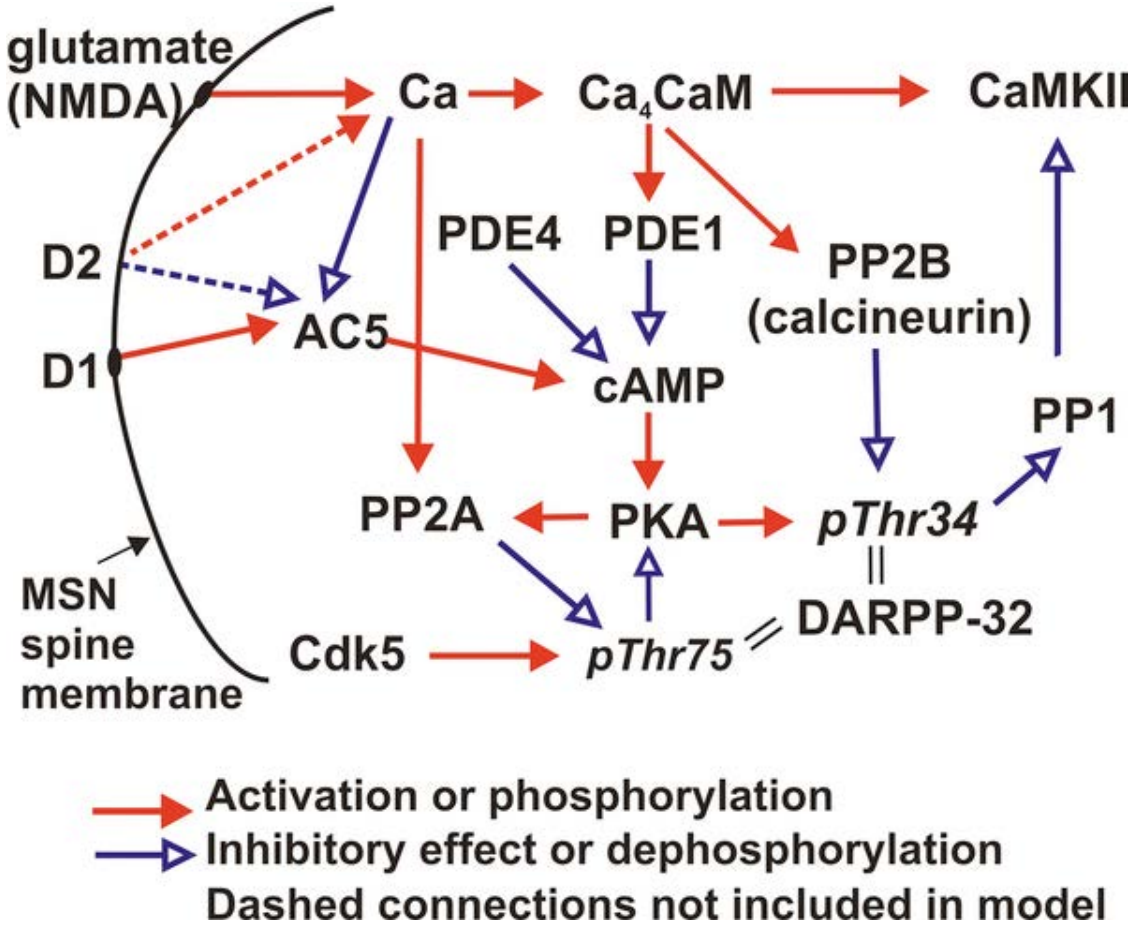
Reward


Cerebral cortex
Thalamus
To striatum
Corpus callosum
Ventromedial prefrontal cortex
Nucleus accumbens
Cerebellum
To spinal cord
Ventral tegmental area
Substantia nigra
Pons
Medulla
Mesolimbic projections
Mesocortical projections


Anticipated gain ($ vs. 0)
Nucleus accumbens

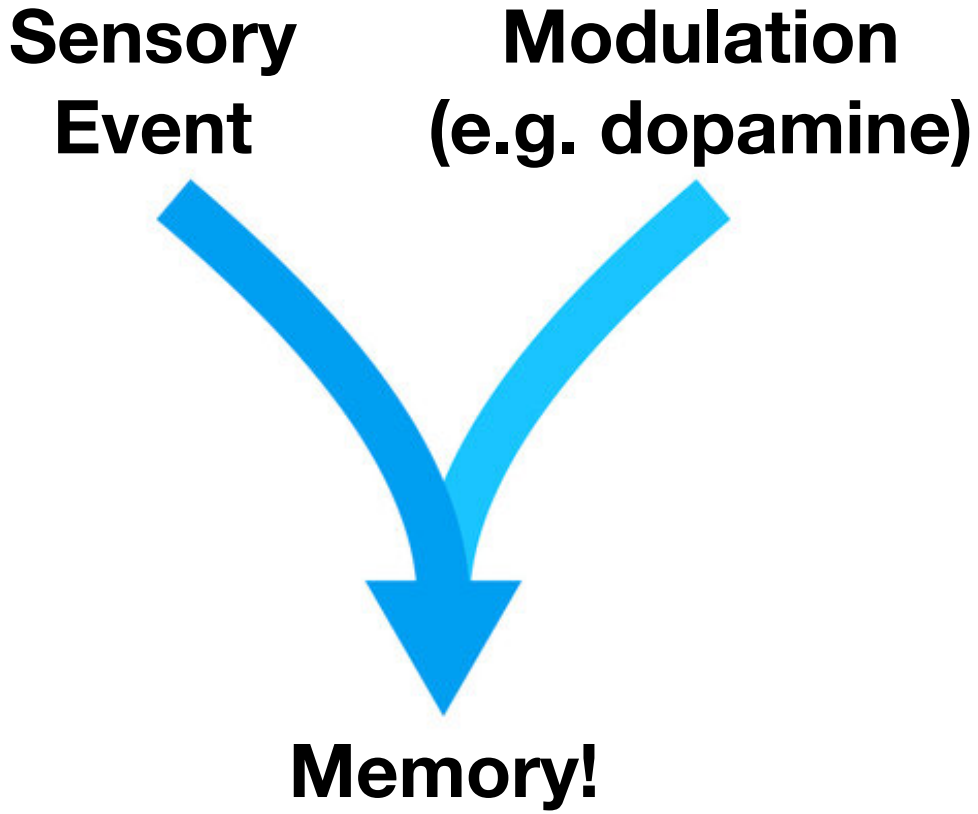

+$5.00
+$1.00
+$0.20
+$0.00
Nucleus accumbens
Signal change (%)
0.2
0.1
0
−0.1
0–2
2–4
4–6
6–8
8–10
10–12
12–14
Time (s)

DA and LTP


glutamate
(NMDA)
Ca
Ca4CaM
CaMKII
D2
D1
AC5
PDE4
PDE1
PP2B
(calcineurin)
cAMP
PP1
PP2A
PKA
pThr34
DARPP-32
MSN
spine
membrane
Cdk5
pThr75
Activation or phosphorylation
Inhibitory effect or dephosphorylation
Dashed connections not included in model

Memory prioritization

(in theory)



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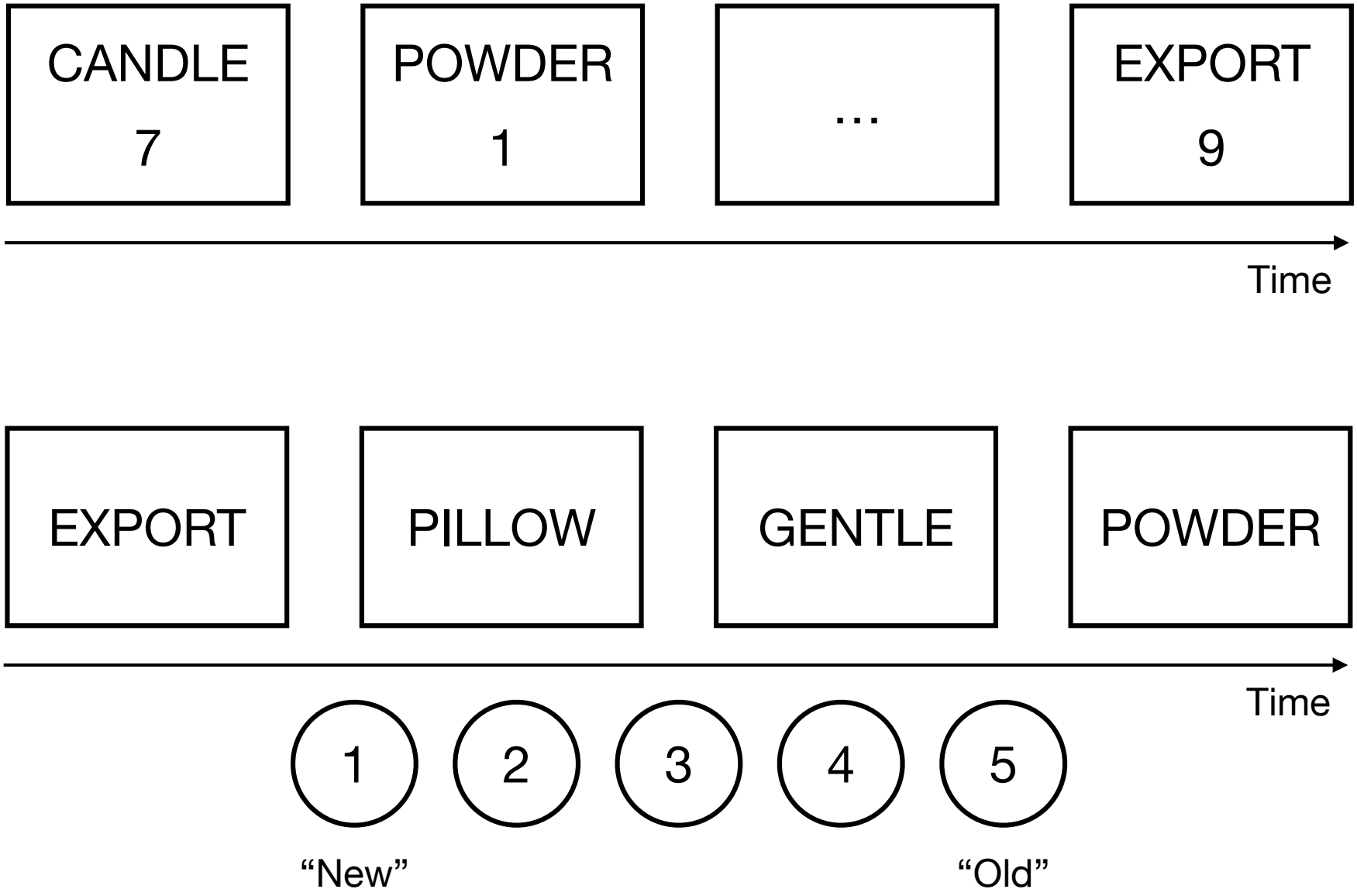
- EEG correlates of VDR
- Diffusion imaging of VTA-hippocampus pathways

Value-Directed Recognition Memory Task

- **Goal:** Earn as many points / as much money as you can
- **Task:** Shown a series of words, each associated with a points value (e.g. 1, 3, 7, 9)
- **Recall:** Make “old” / “new” decisions on words
  - Earn associated points for correctly recalling “old”
  - Lose points for incorrectly reporting “old” for lures or “new” for trained words (-1)

VDR Task


CANDLE
7
POWDER
1
...
EXPORT
9
Time
EXPORT
PILLOW
GENTLE
POWDER
Time
1
2
3
4
5
“New”
“Old”

Remember / Know

- “Remember”
  - Recollection has occurred
  - Can recall details, perhaps including associated point value
- “Know”
  - Recollection has not occurred
  - Judgment based on familiarity

Remember / Know

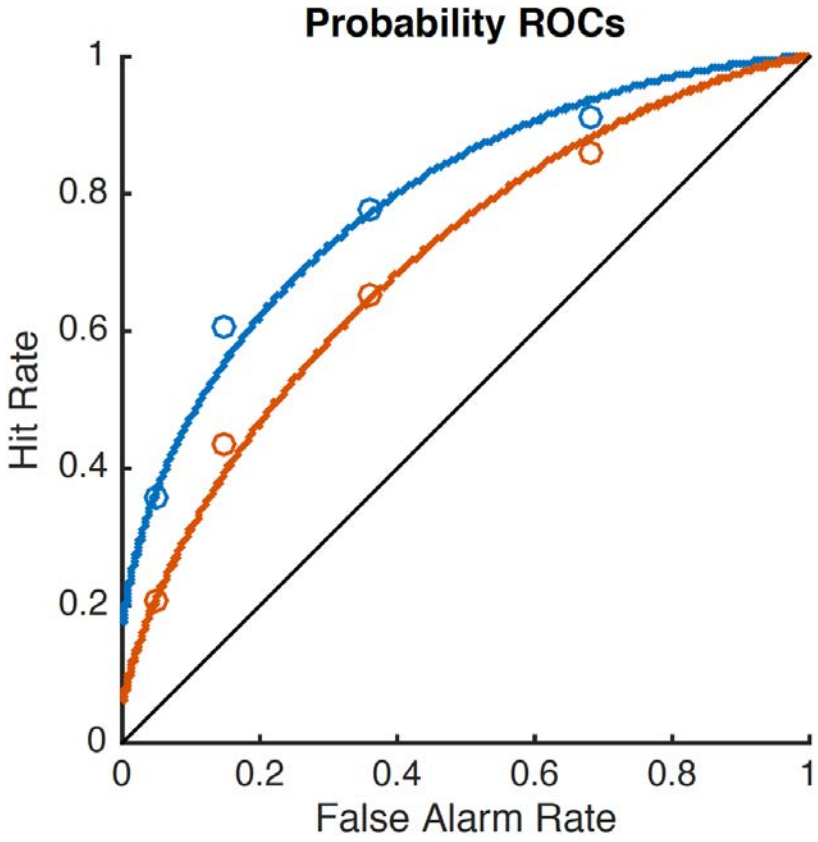
1. “Definitely New”
2. “Maybe New”
3. “Maybe Know”
4. “Definitely Know”
5. “Remember”

Make a remember judgment if you not only remember the word, but also consciously remember the experience of studying the word. For example, perhaps you remember the specific value of the word, something else that happened in the room while you were studying it (like a cough or sneeze), an association that came to mind, or what came just before or after the word in the study phase. To give you a real world example, imagine you are walking across campus and recognize someone, but cannot recall their name or where you have met them. You are certain you have seen this person before, but do not remember anything specifically about them or where you met them. This is would be “knowing.” If you recognize this person and remember that it is John whom you met in Biology class, this would be “remembering.”

VDR details

- **Study phase:** 40 Toronto noun pool words assigned either a high value (7 or 9) or low value (1 or 3)
- **Test phase:** 80 words, including all 40 from the study phase
- 5 study-test blocks

Reward-based enhancement of memory



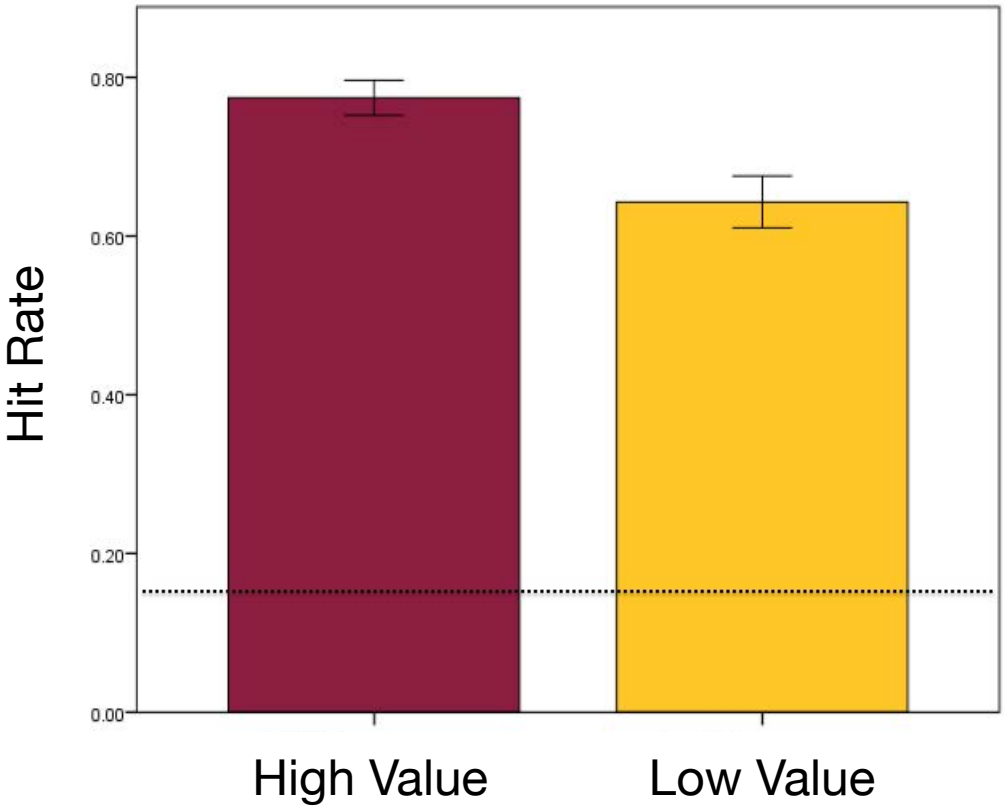
High Value (HV) Hit Rate = 0.60
Low Value (LV) Hit Rate = 0.44
Common False Alarm Rate = 0.14

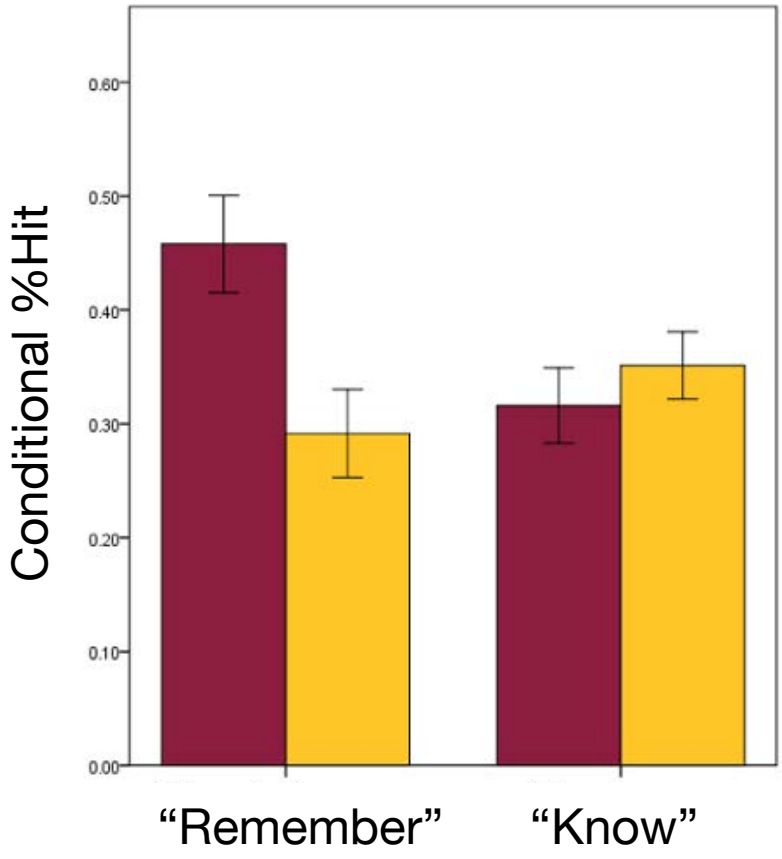
HV d' = 1.33
LV d' = 0.91

HV Recollection = 0.15
LV Recollection = 0.05

HV Familiarity = 0.99
LV Familiarity = 0.69

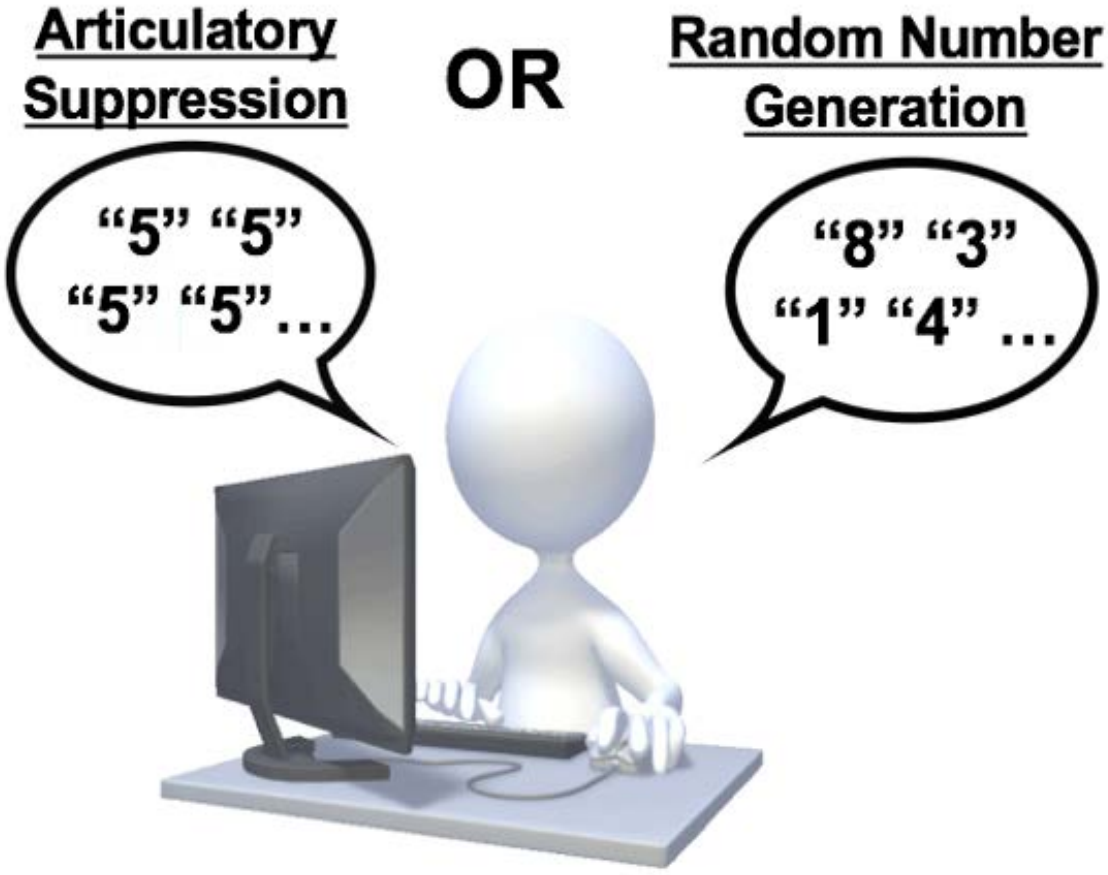
Memory benefits selective to remembering



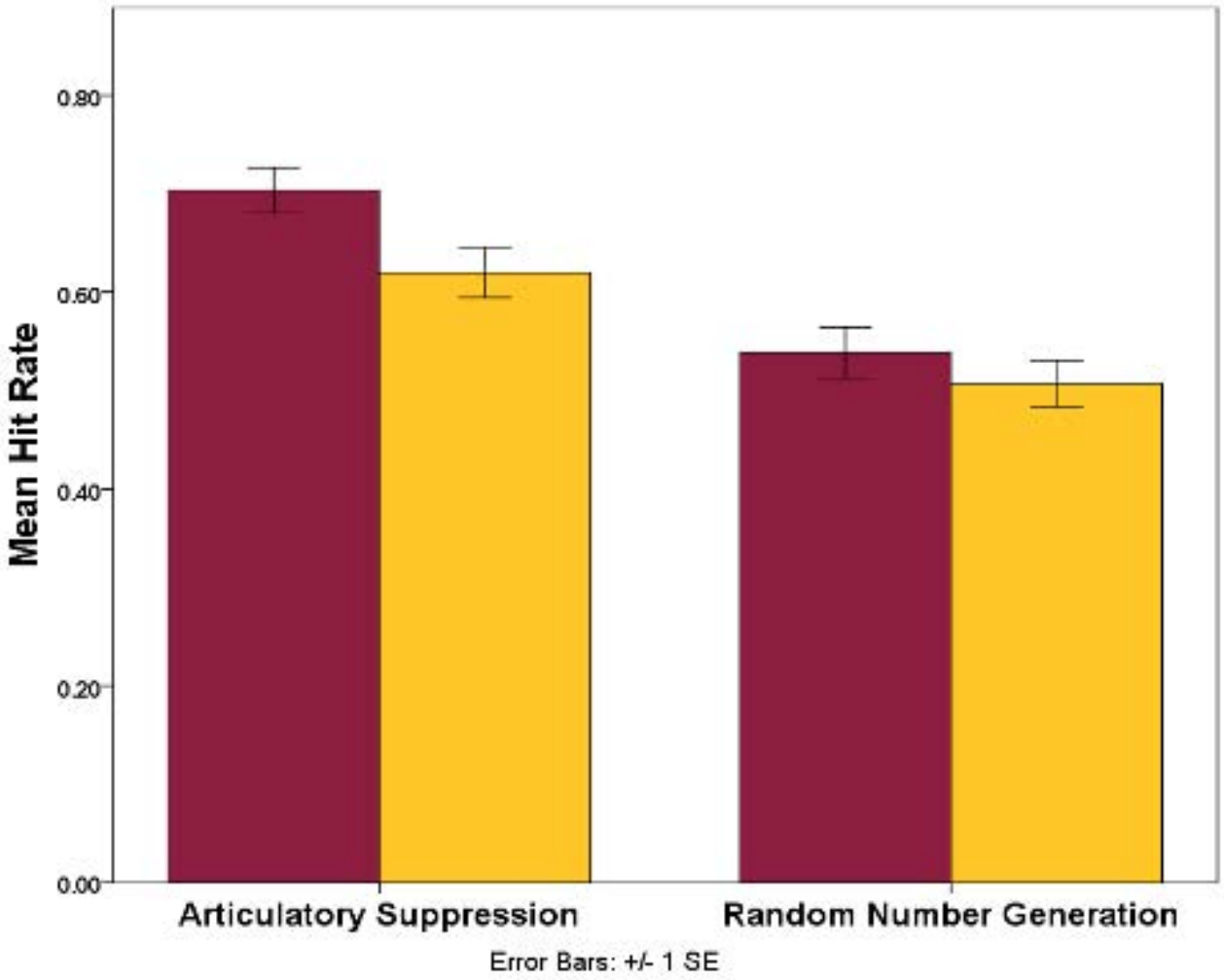


VDR: Divided Attention

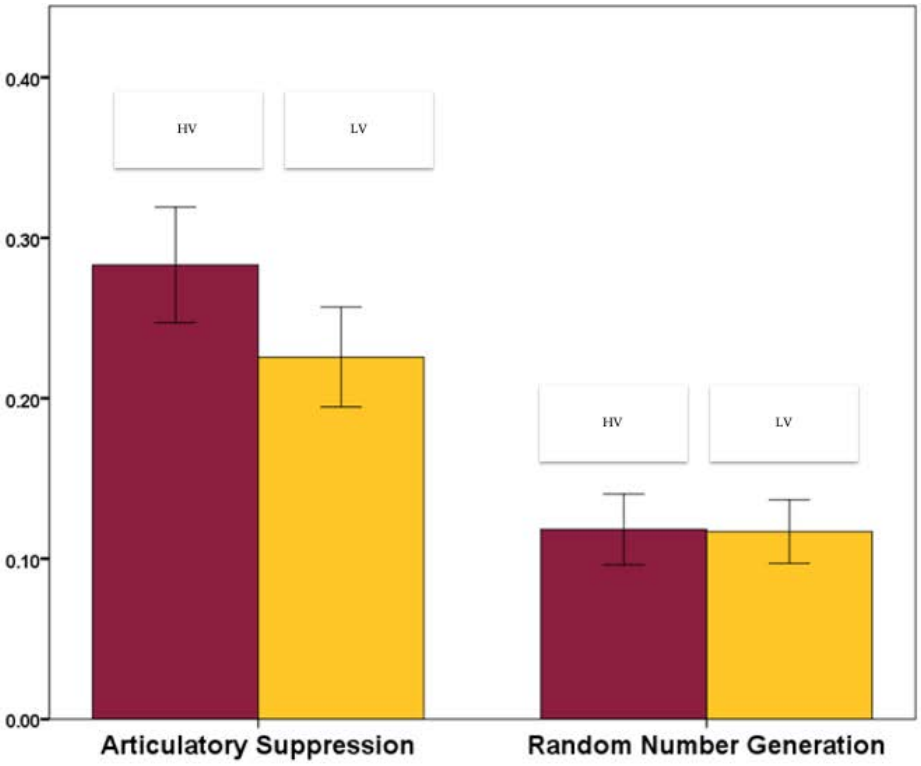
Elliott & Brewer, 2019



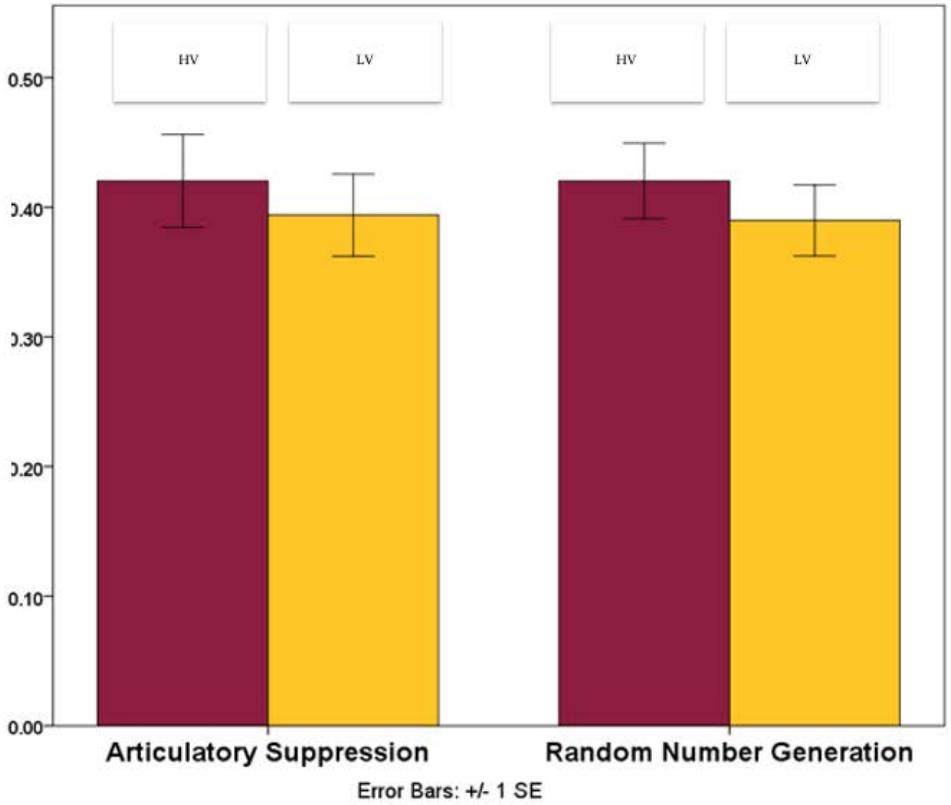
Rehearsal ***Elaboration***


Mean Hit Rate
0.80
0.60
0.40
0.20
0.00
Articulatory Suppression
Random Number Generation
Error Bars: +/- 1 SE

“Remember”

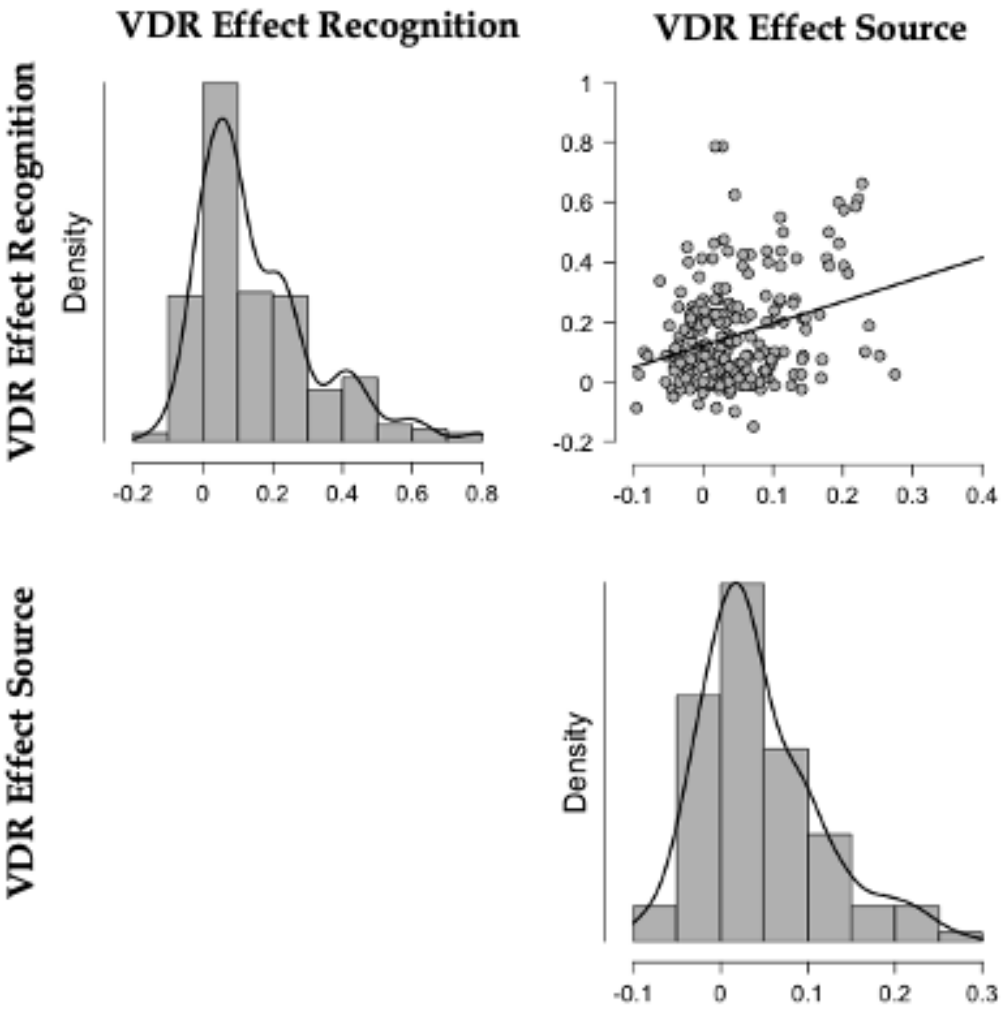


“Know”



Individual Differences

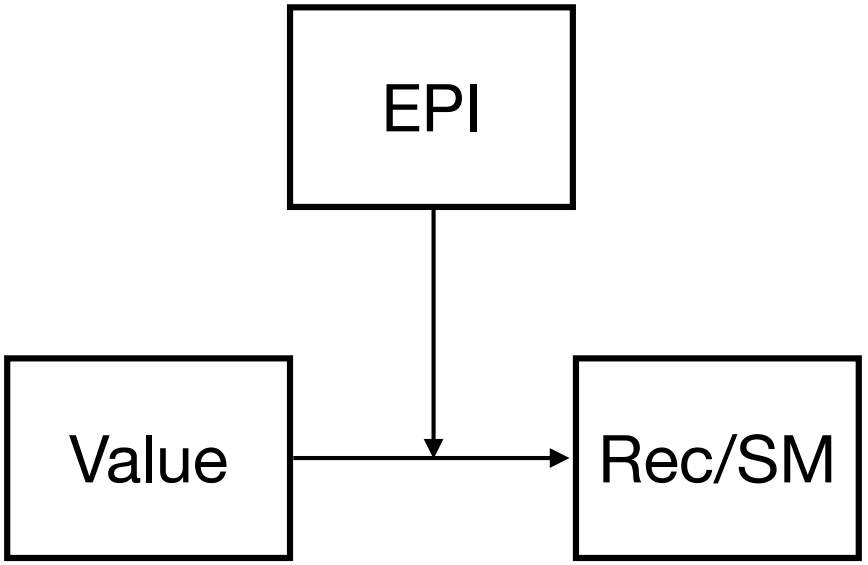
Elliott, McClure, Brewer, 2020

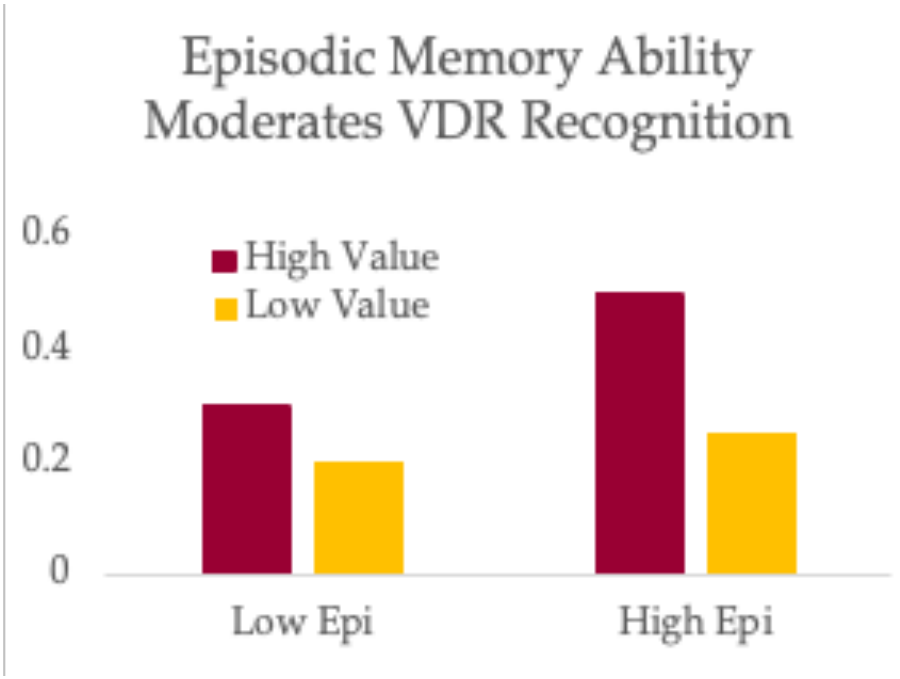


Working Memory, Episodic Memory, and VDR Correlations

	WMC			EPI			VDR	
	Ospan	Rspan	Sspan	DFR	CR	Source	VDRRec	VDRSm
Ospan	1.00							
Rspan	0.44	1.00						
Sspan	0.38	0.36	1.00					
DFR	0.05	0.09	0.12	1.00				
CR	0.09	0.12	0.06	0.22	1.00			
Source	0.19	0.18	0.16	0.18	0.40	1.00		
VDRRec	-0.01	0.06	-0.05	0.14	0.27	0.20	1.00	
VDRSm	0.06	0.01	0.00	0.03	0.27	0.22	0.30	1.00

Moderators of VDR Effect





$F(1,223) = 20.62$, $p<0.001$, $\eta^2 = 0.085$

Value-directed recognition

- Quantifiable measure of memory prioritization based on reward value
- Can be reduced with working memory distractor task
- Stable individual differences related to episodic memory ability

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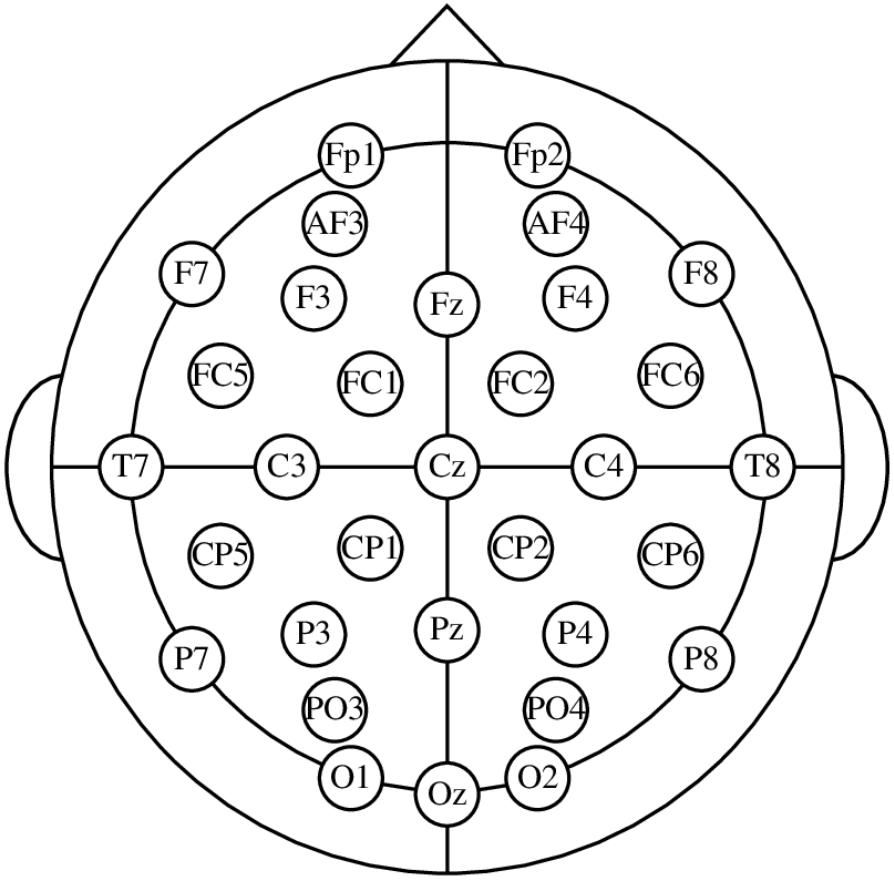
- EEG correlates of VDR
- Diffusion imaging of VTA-hippocampus pathways

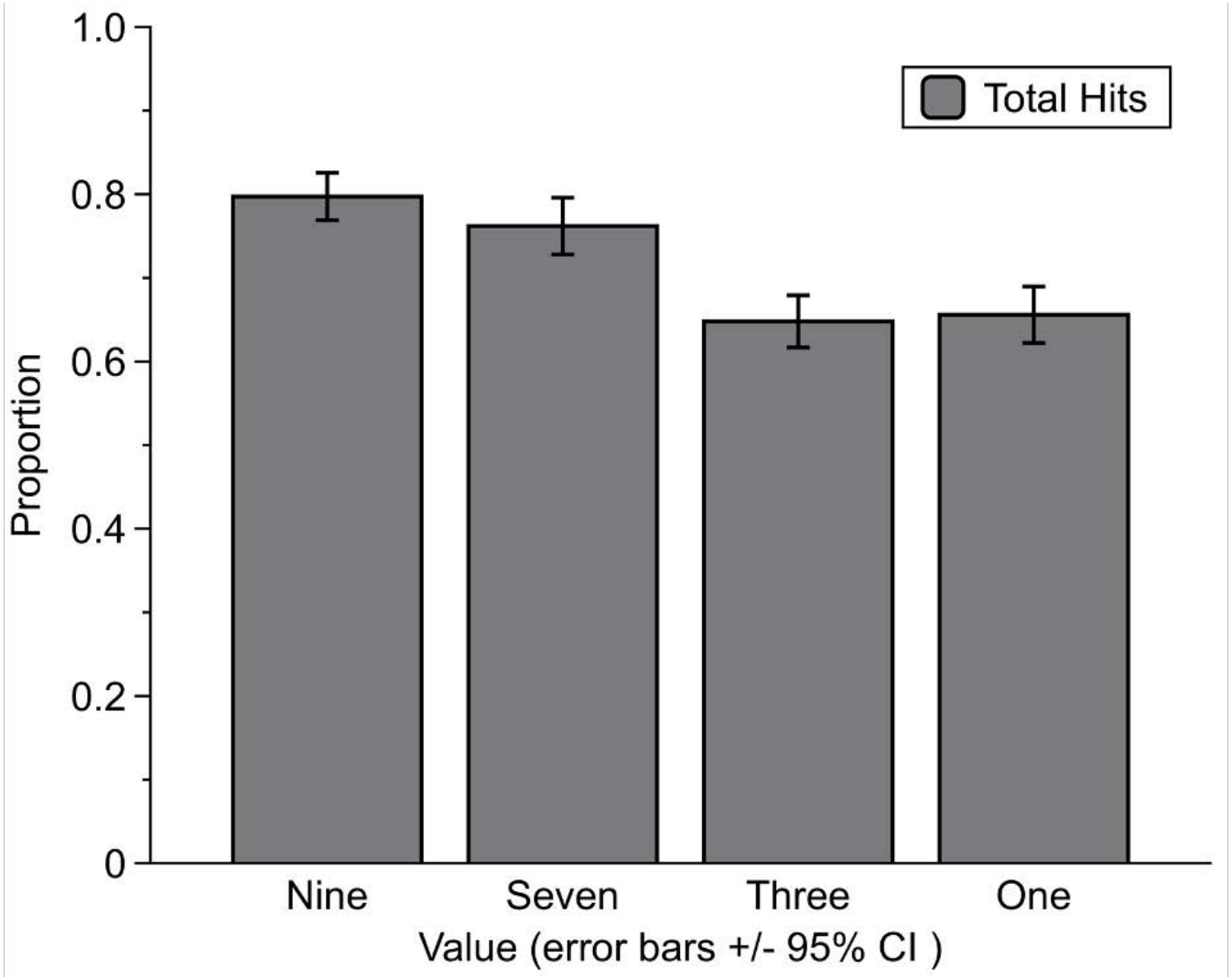
EEG correlates of VDR

Elliott, Blais, McClure, Brewer, 2020

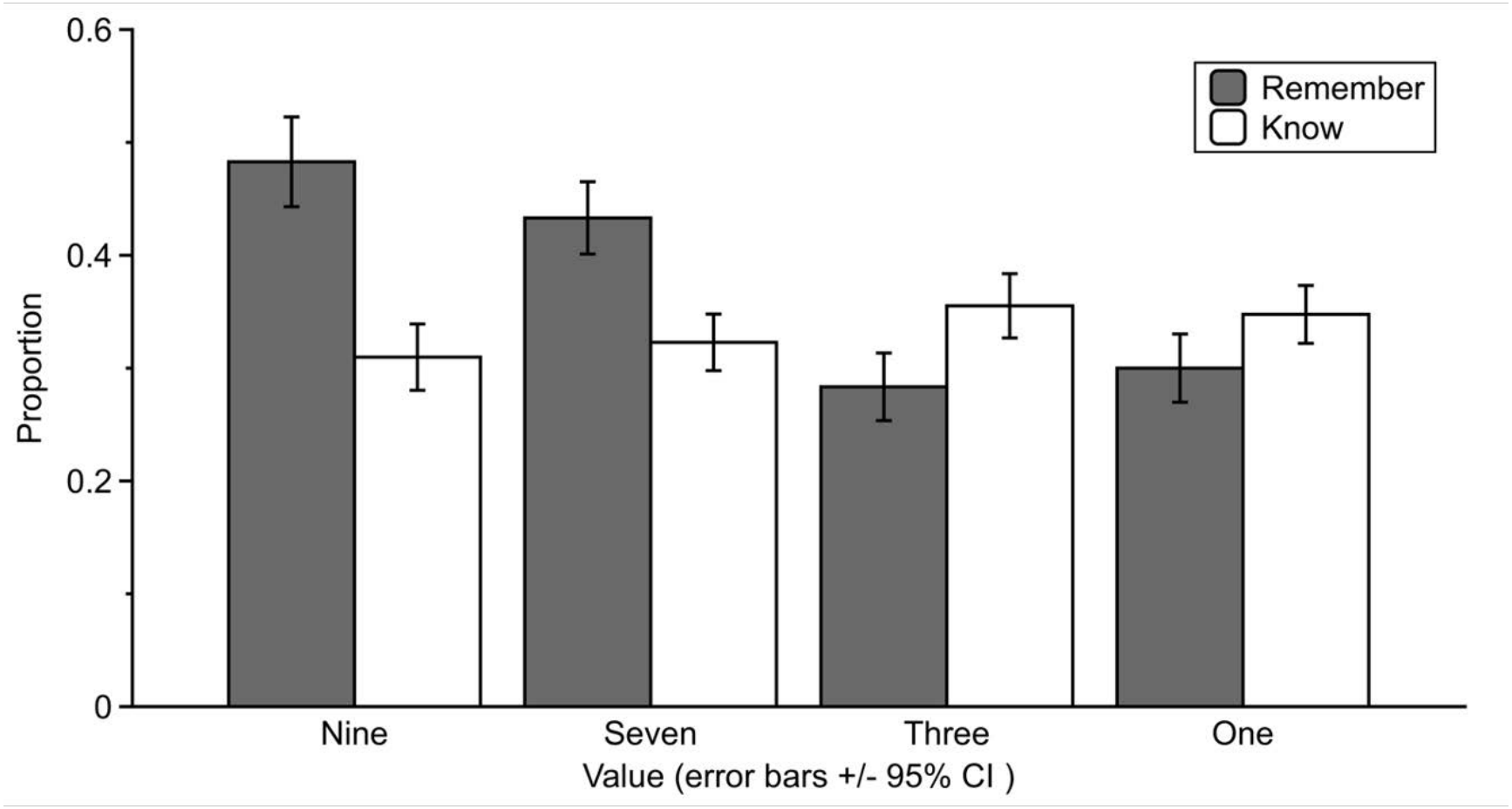
- 30 participants
- Words shown for 2s, ISI jittered between 300-500 ms, 5 study/test blocks
- 5-level remember-know responses
- Neuroscan 32 channel cap sampled at 1 kHz (downsampled to 250 Hz)
- ICA correction of eye movement artifacts
- Average mastoid reference with bandpass filter between .1Hz and 30Hz



Behavior


1.0
0.8
0.6
0.4
0.2
0
Proportion
Total Hits
Nine
Seven
Three
One
Value (error bars +/- 95% CI)

Behavior


0.6
0.4
0.2
0
Proportion
Remember
Know
Nine
Seven
Three
One
Value (error bars +/- 95% CI)

EEG components

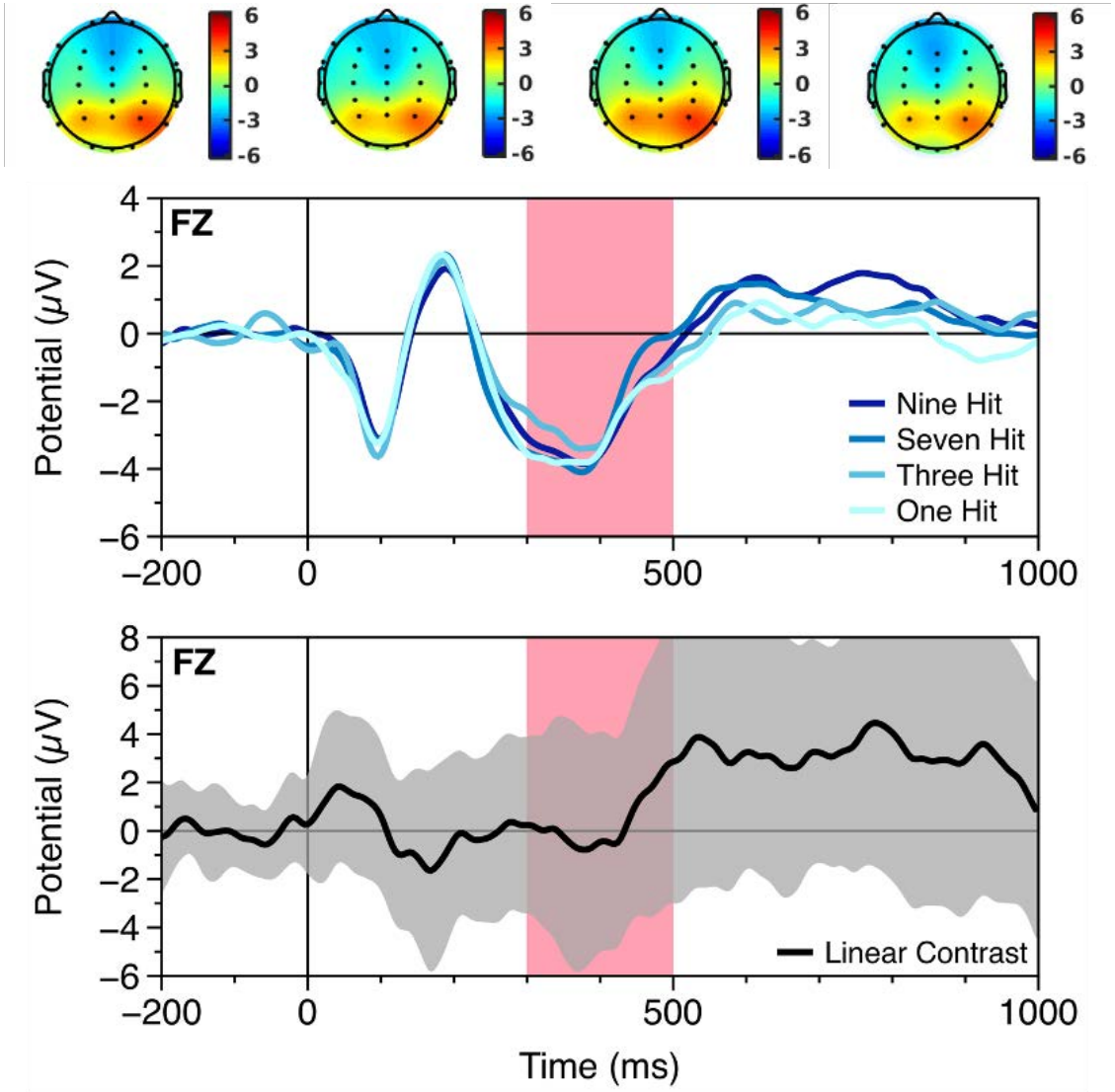
- During recall (Rugg & Curran, 2007):
  - Remember/know difference in mid-frontal FN400, greater for familiar items
  - Later occurring parietal old/new effect (500-800 ms) greater for remembered items

EEG components

- During encoding:
  - Mid-parietal P550: early component associated with attention, stimulus value
  - Frontal slow wave (FSW, 1000-2000ms): executive functions, elaboration, rehearsal

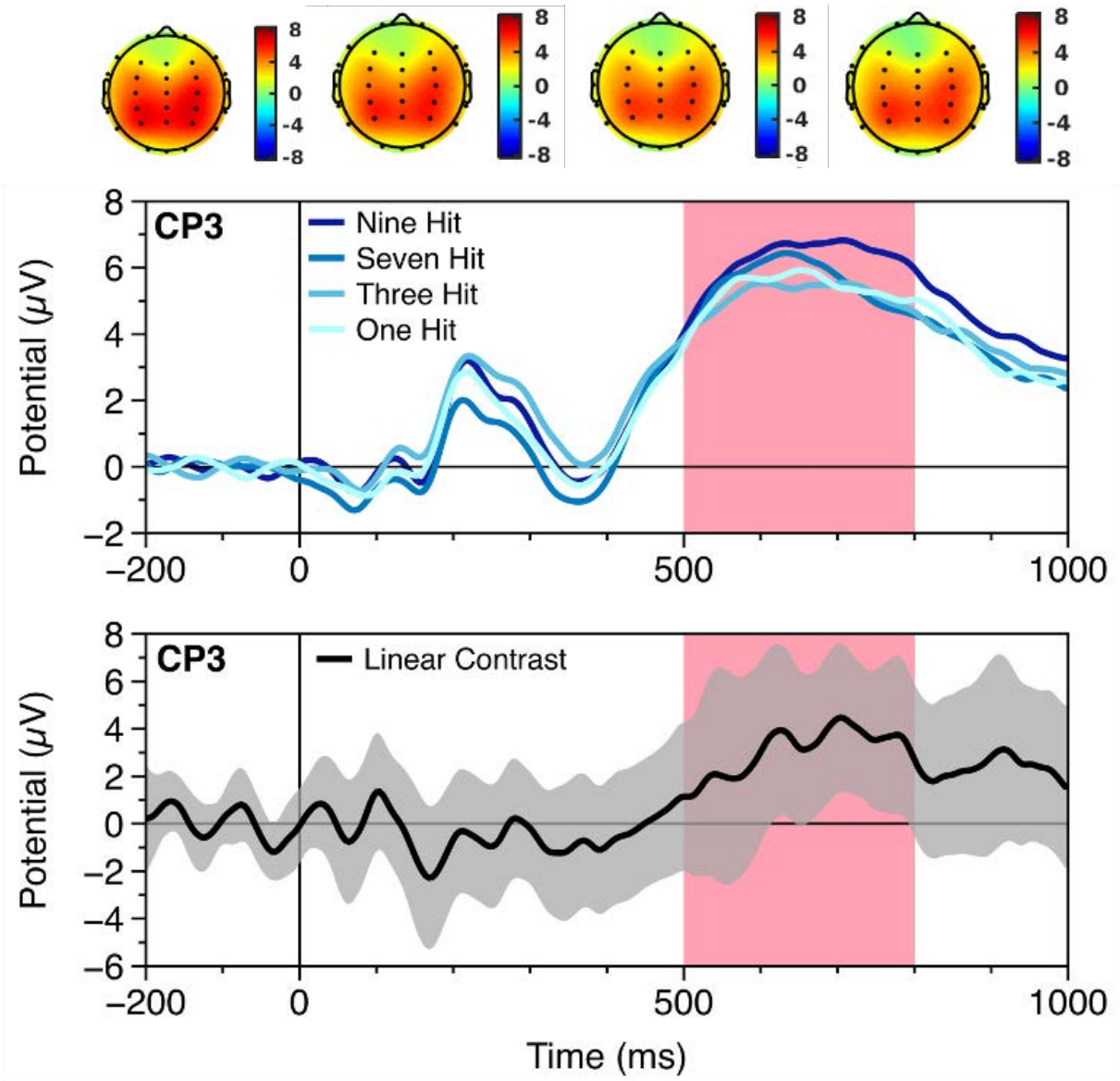
Retrieval

- FN400: frontal negativity associated with familiarity



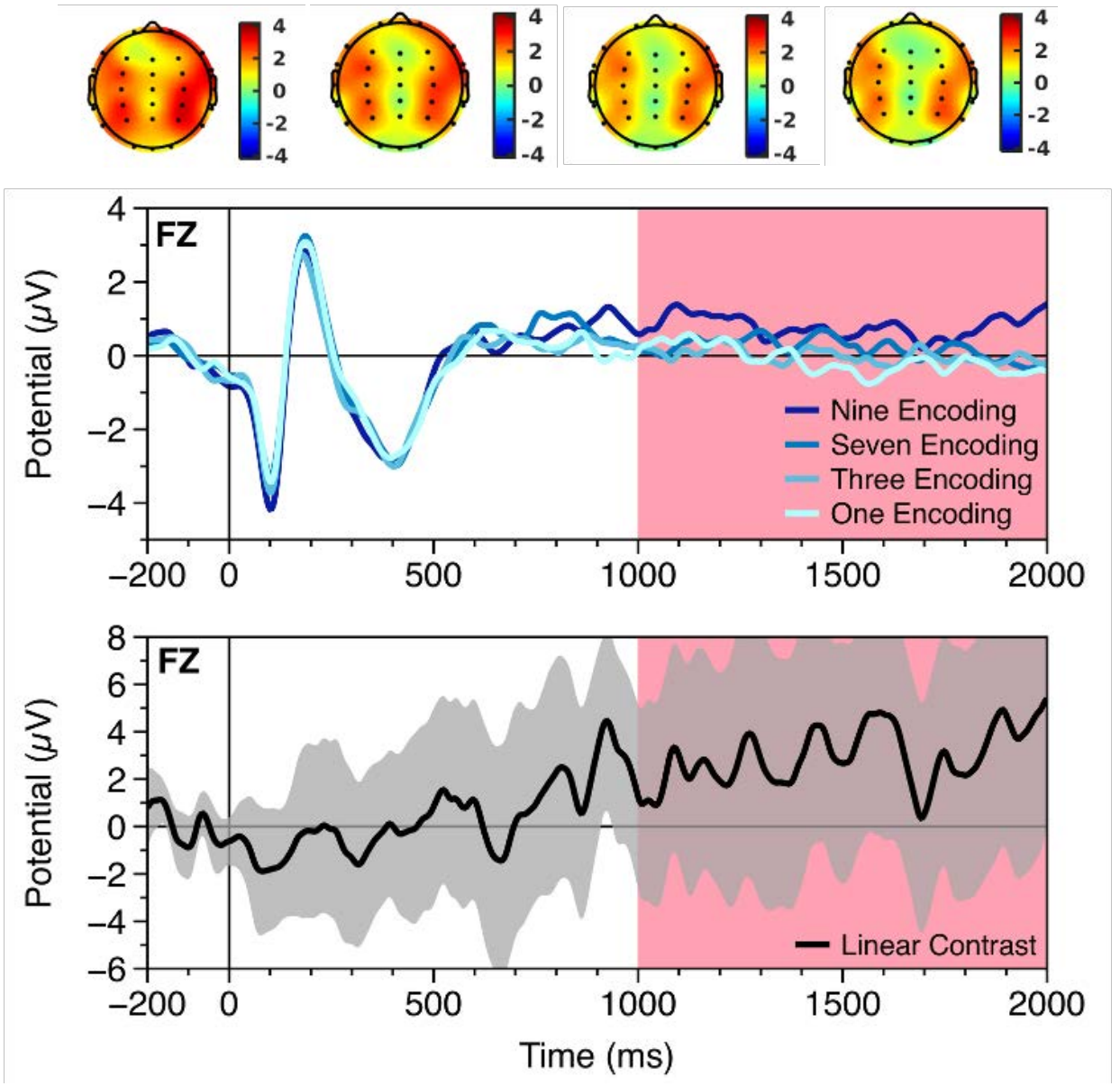
Retrieval

- Parietal old/new: positivity associated with remembering



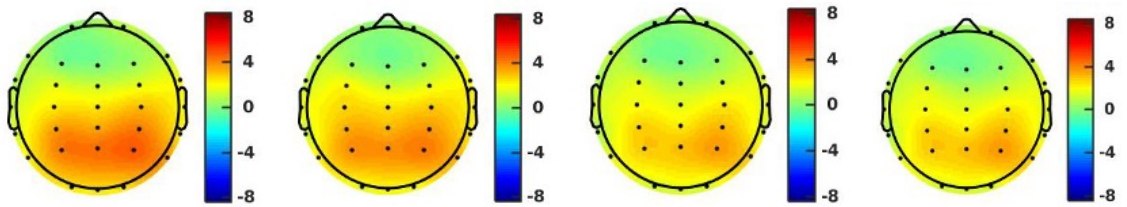
Encoding

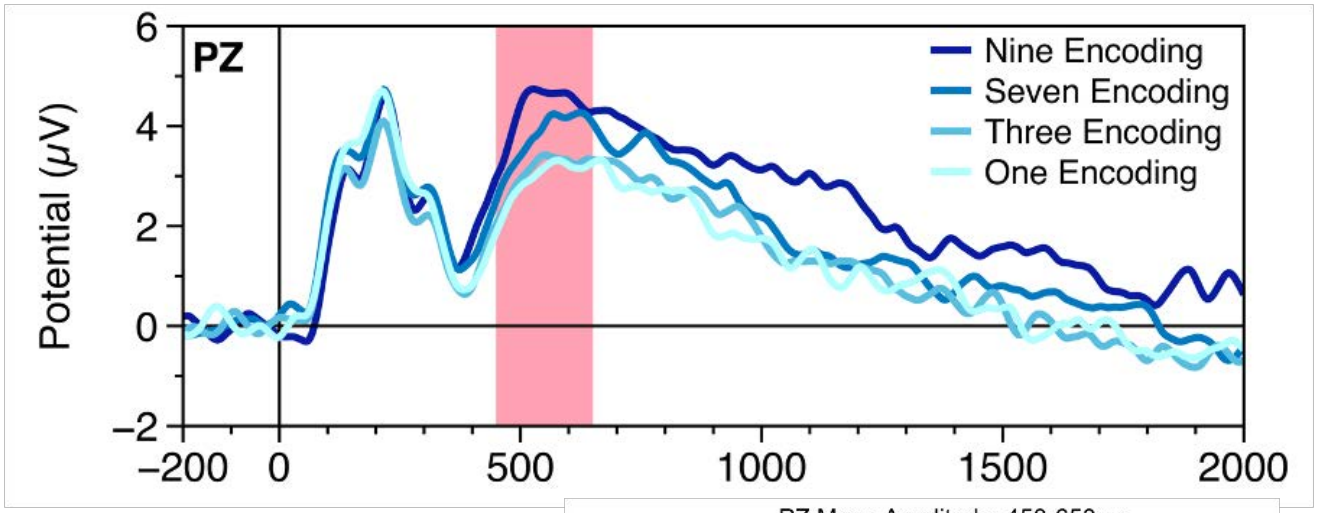
- FSW: Executive control, elaboration

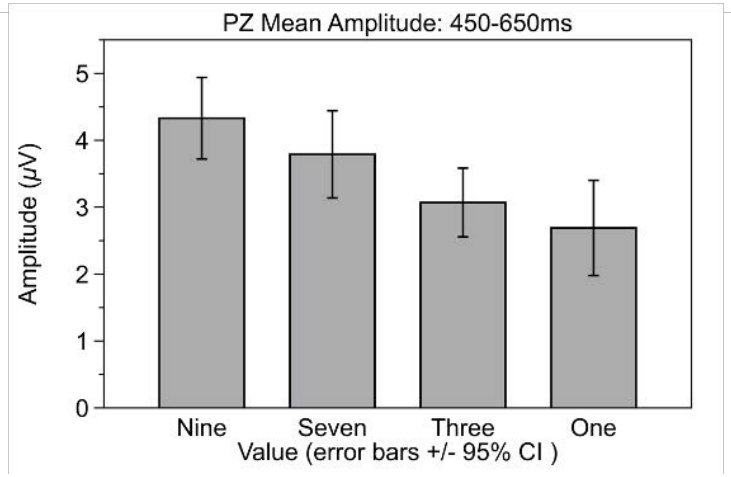


Encoding

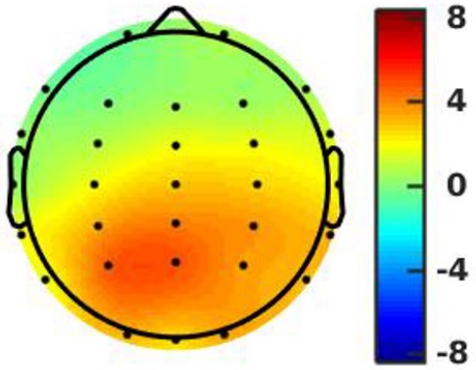
- Parietal 550: attention, value

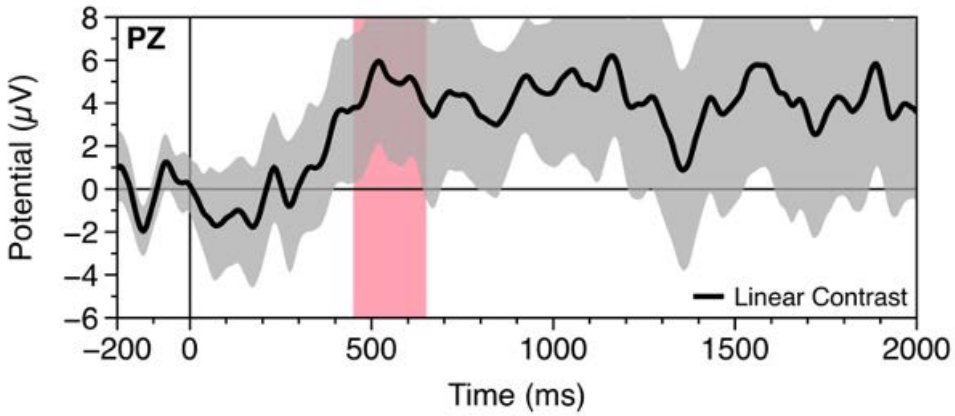






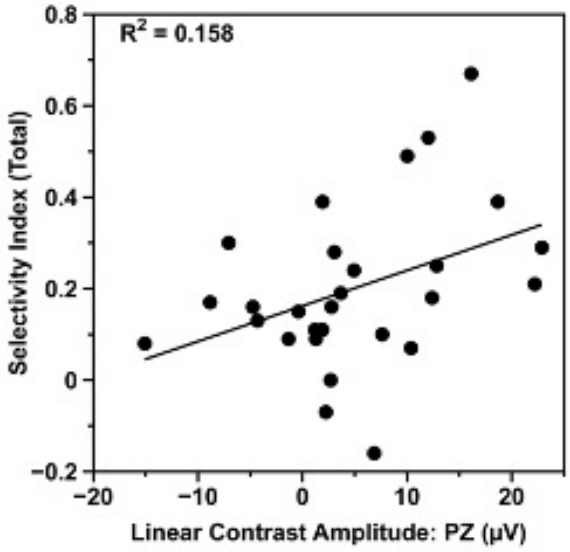
Parietal 550: linear contrast

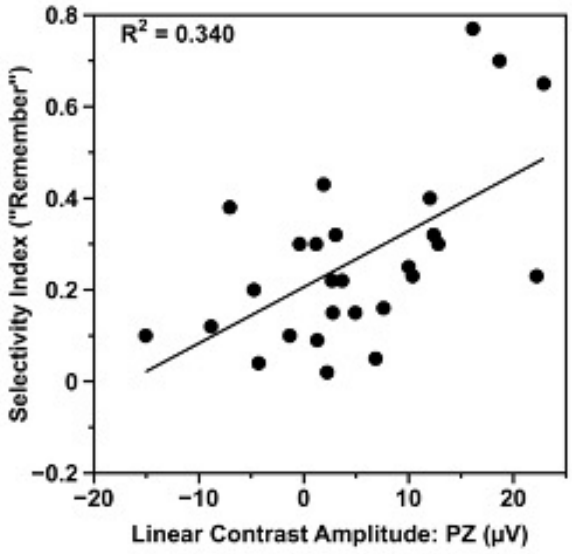


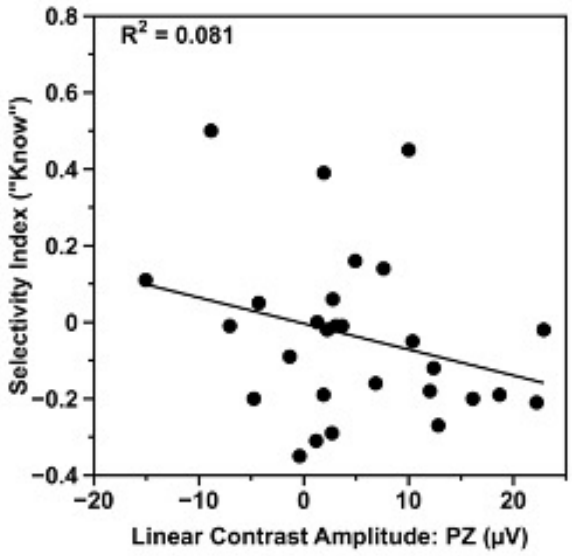


Parietal 550: linear contrast

$$SI = \frac{\text{subject's score} - \text{chance score}}{\text{ideal score} - \text{chance score}}$$







EEG

- ERP components associated with remembering were monotonically related to stimulus value
- During encoding, only early ERP component scales with value
- Suggests that VDR depends on relatively automatic brain processes that facilitate memory?

Break

Questions?

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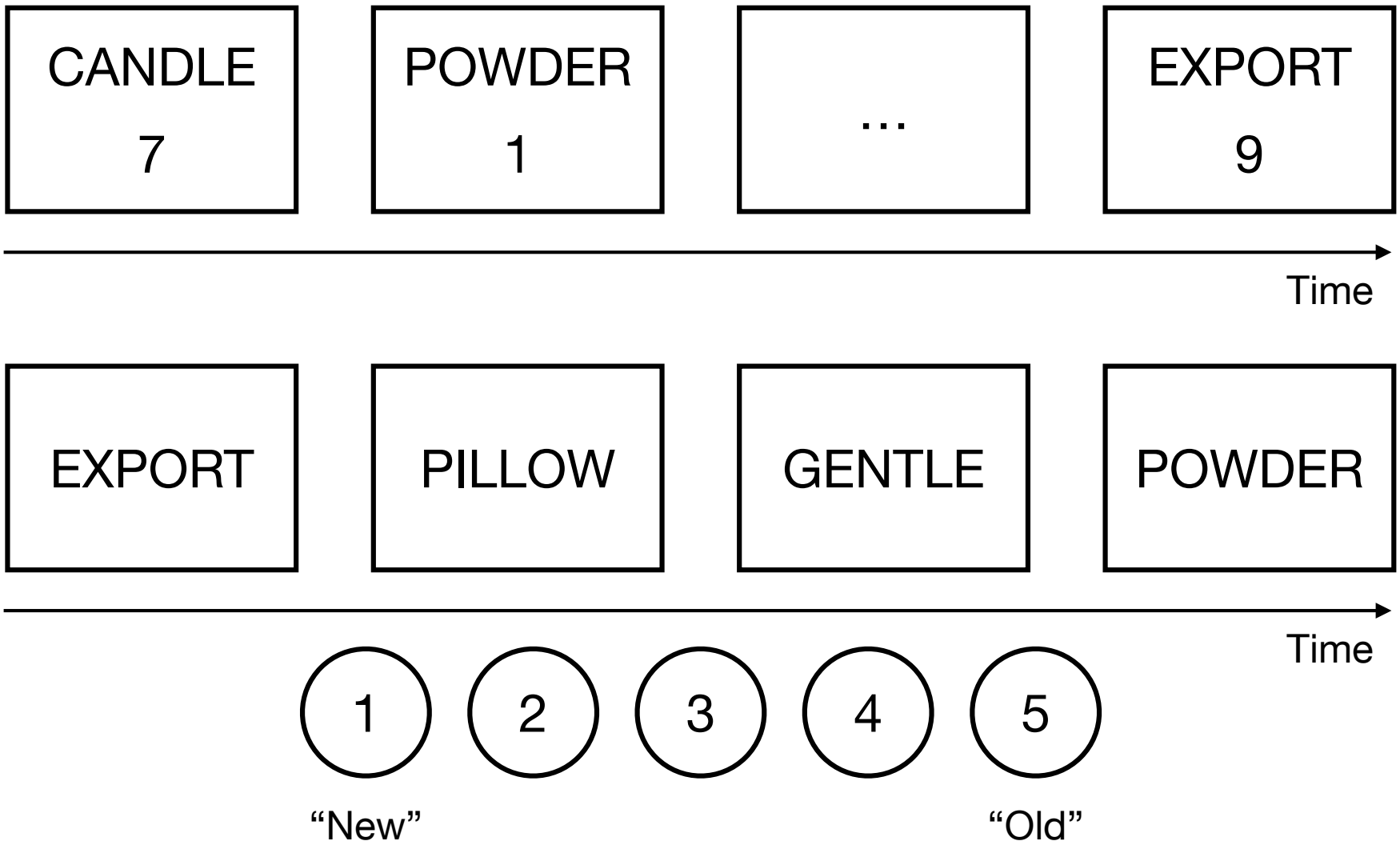
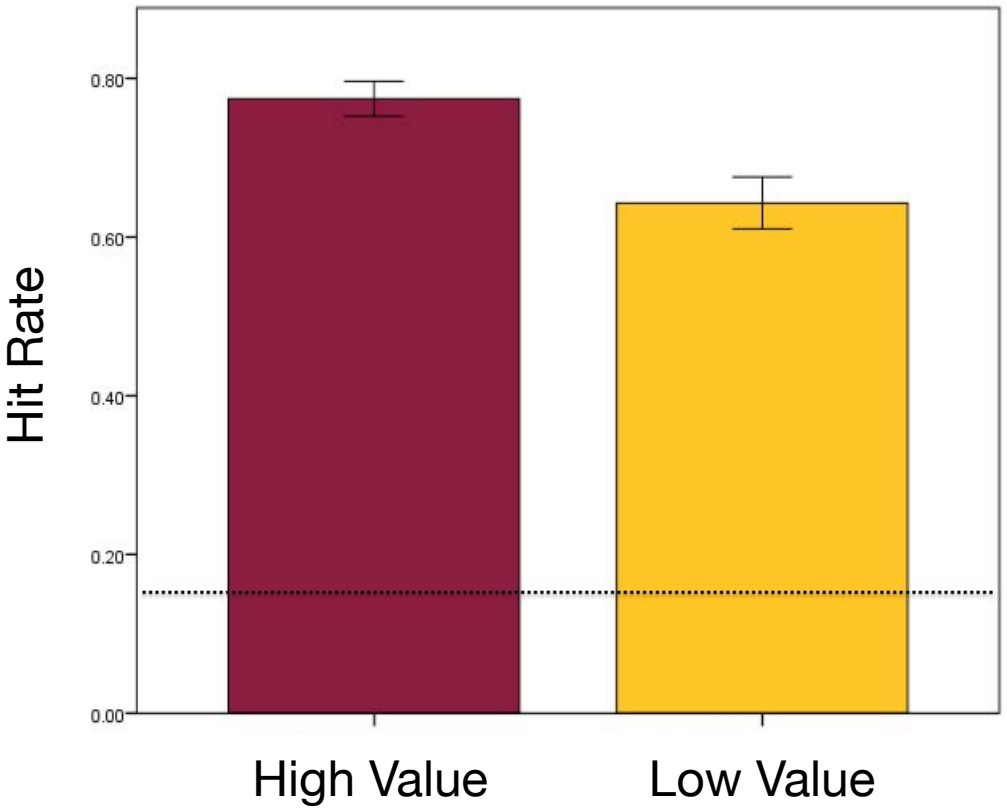
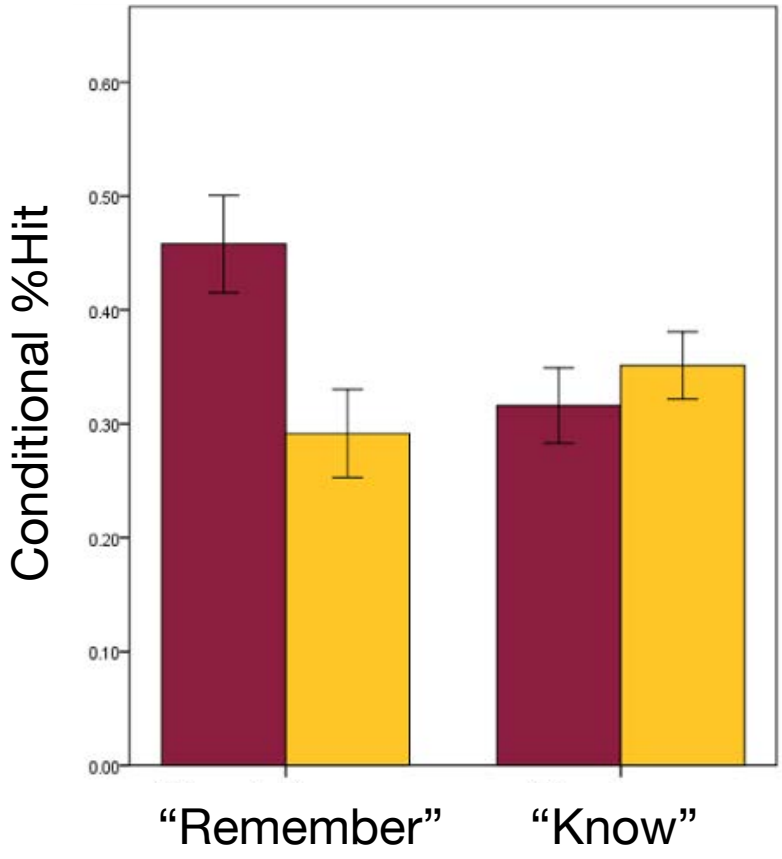
Value-directed remembering task

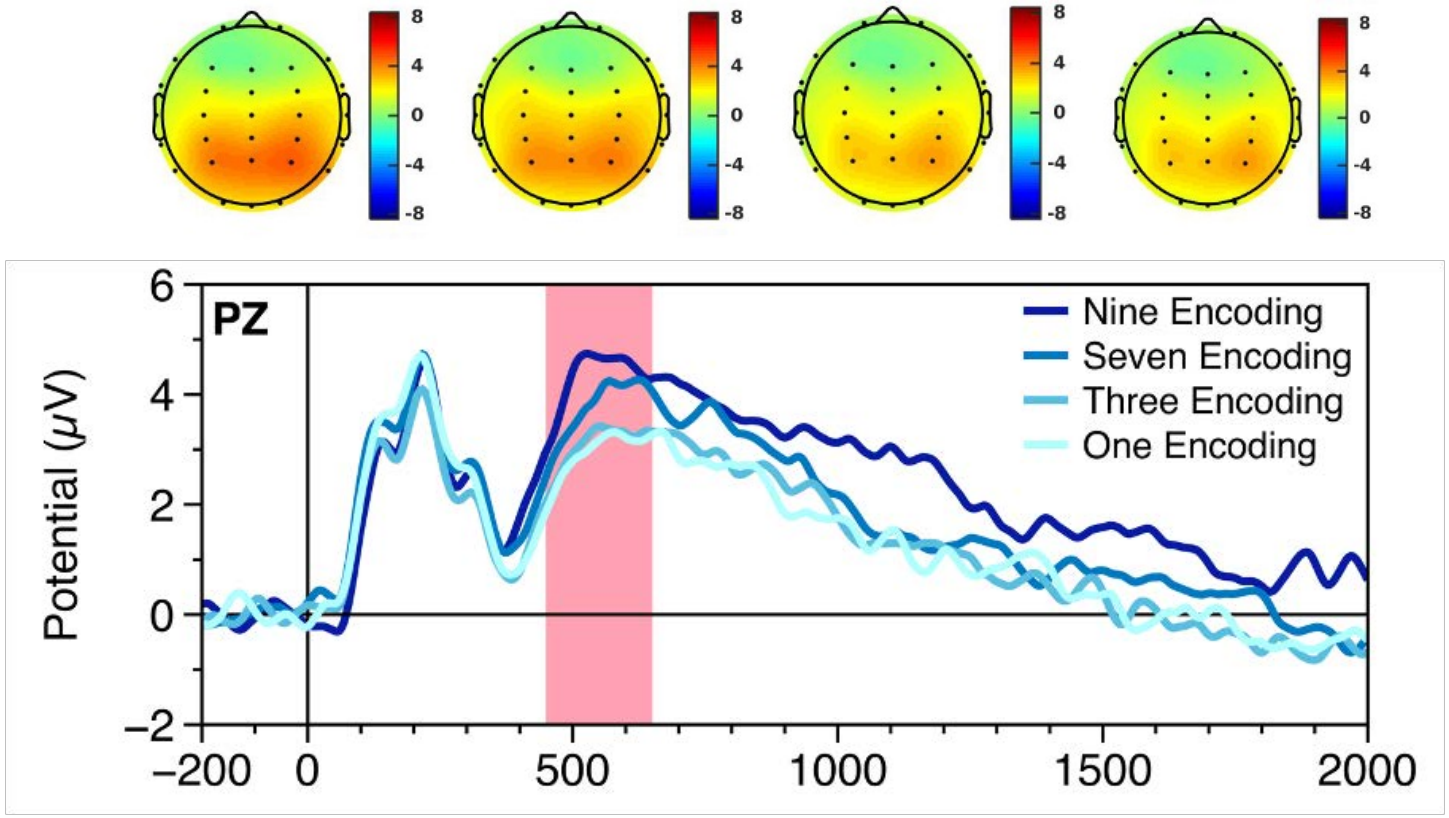


Improved memory

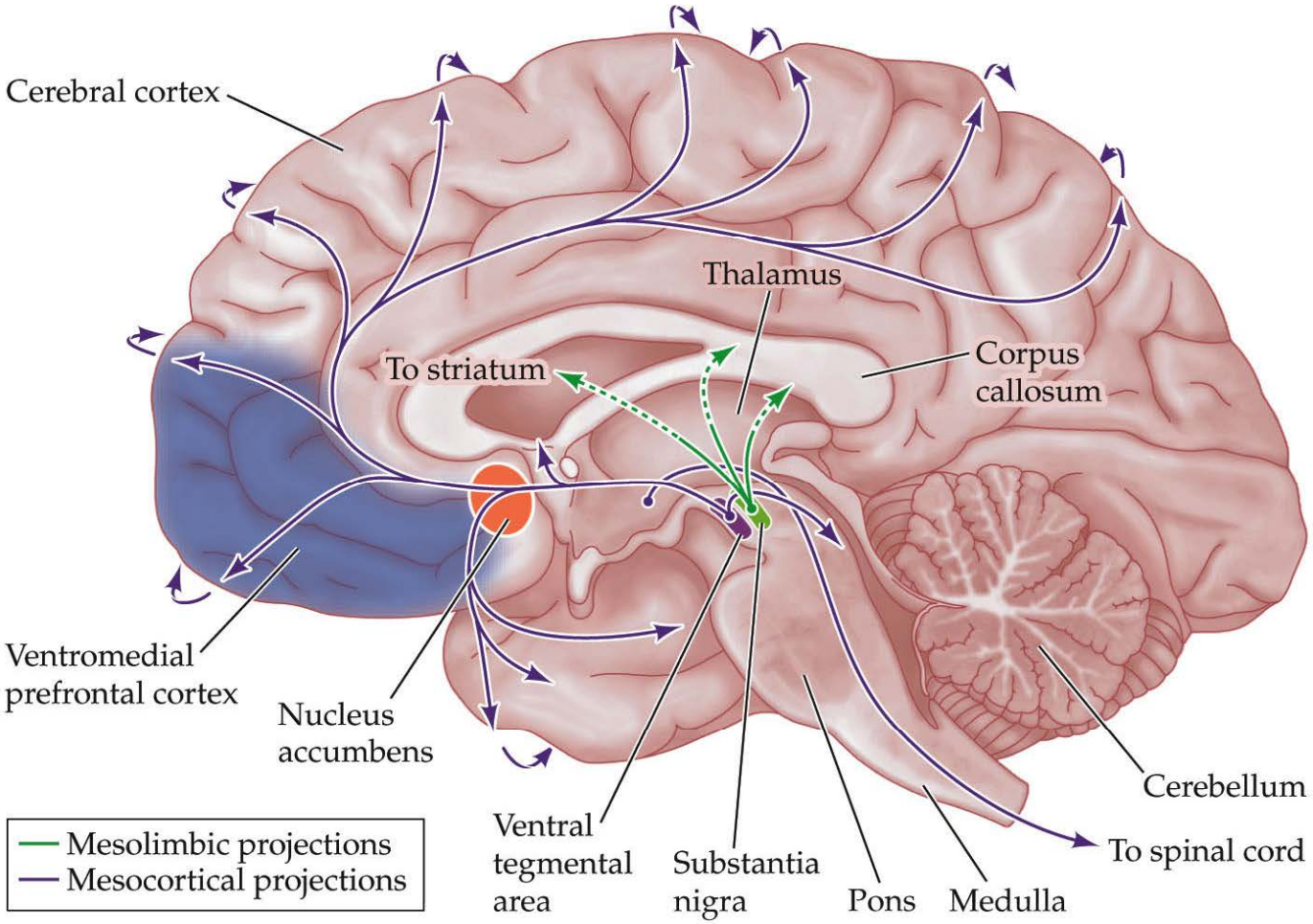




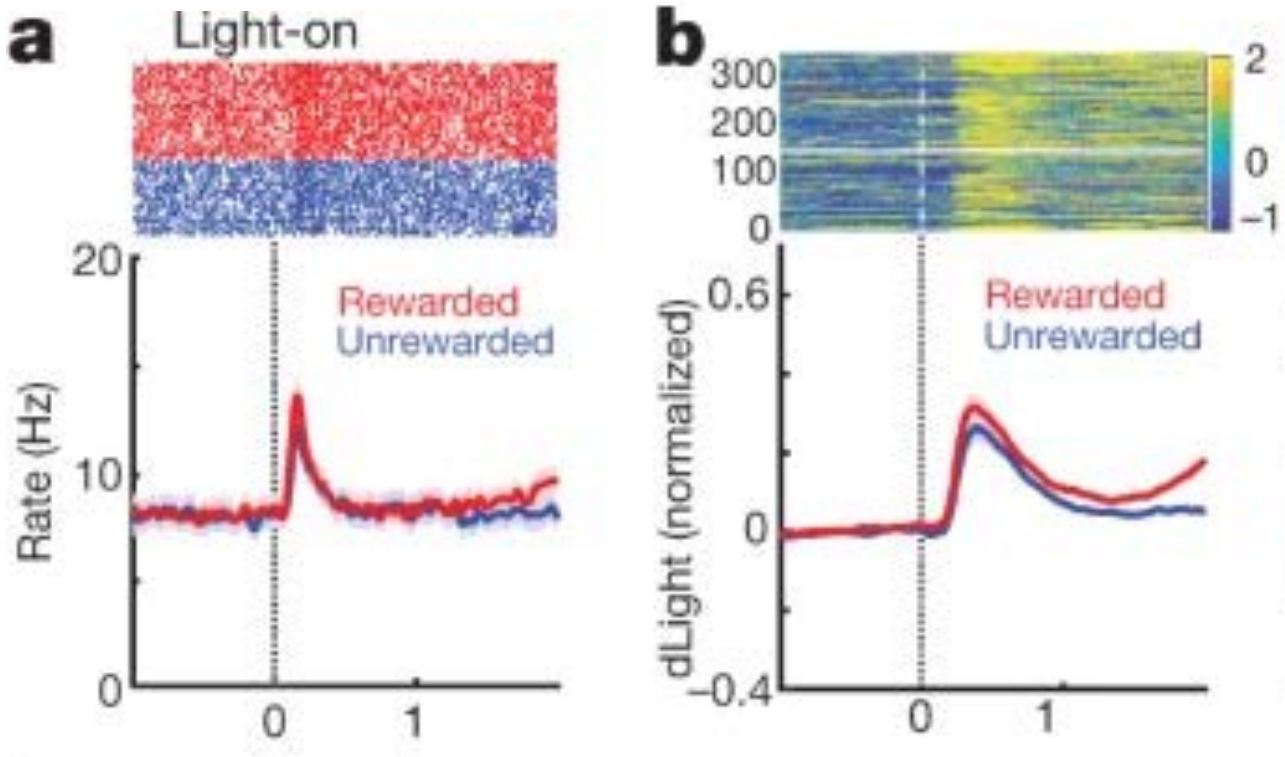
Related to early EEG component



Hypothesis: dopamine



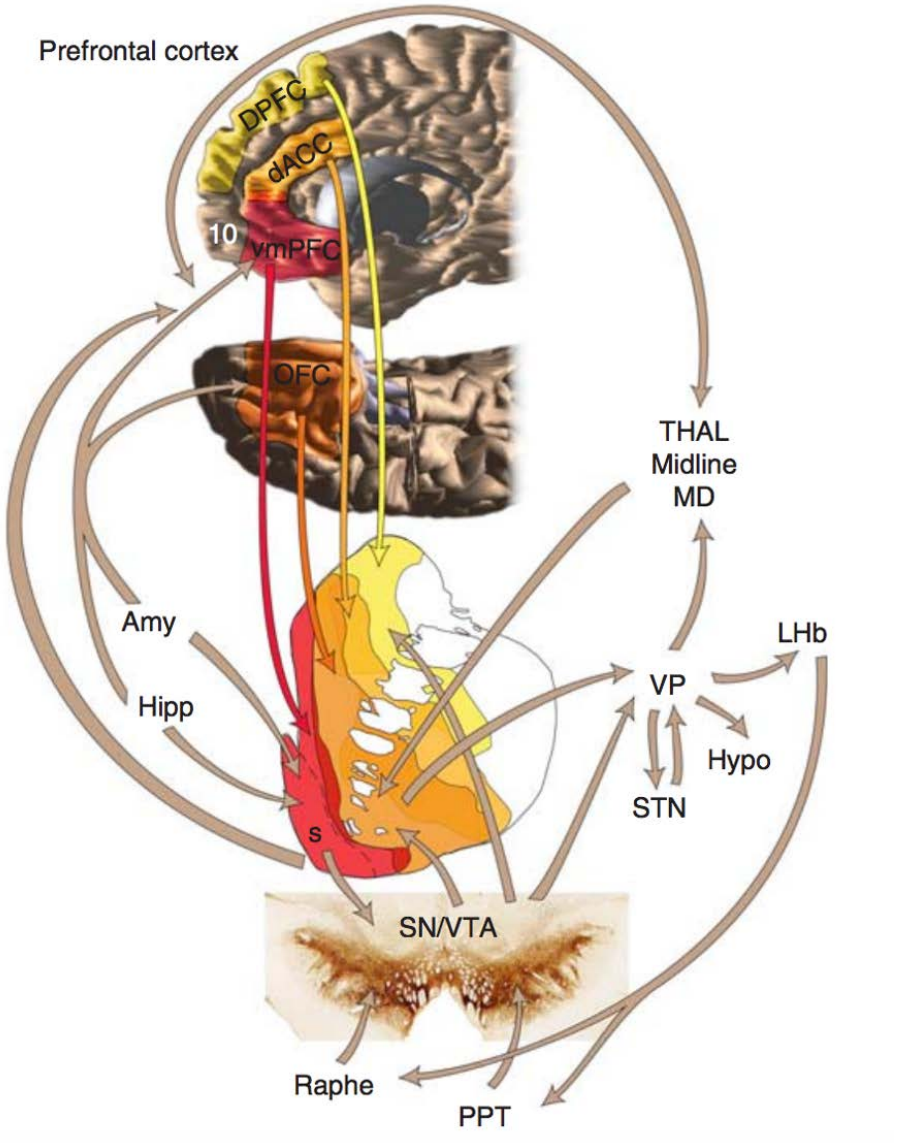
Timing of DA release



Mohebi et al., 2019

Dopaminergic pathways

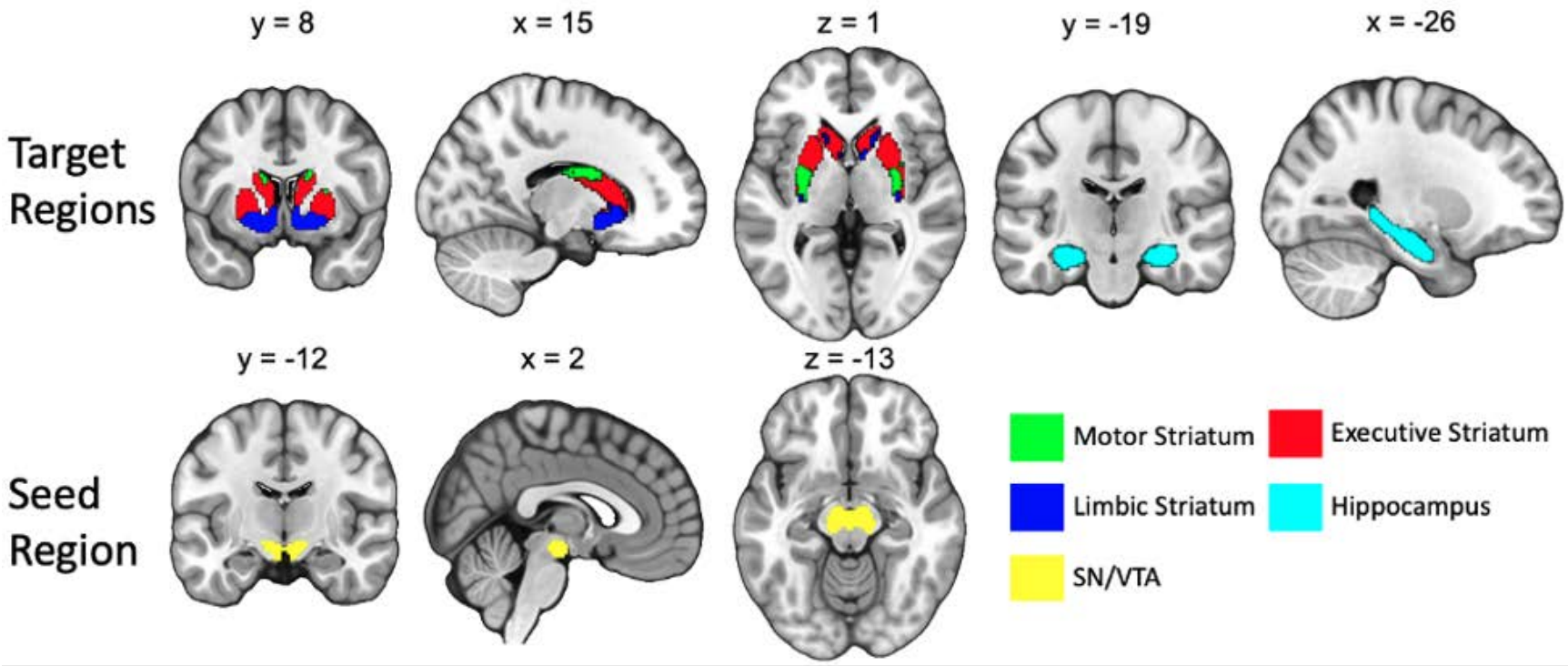
- Topographical organization between midbrain DA nuclei and target forebrain structures



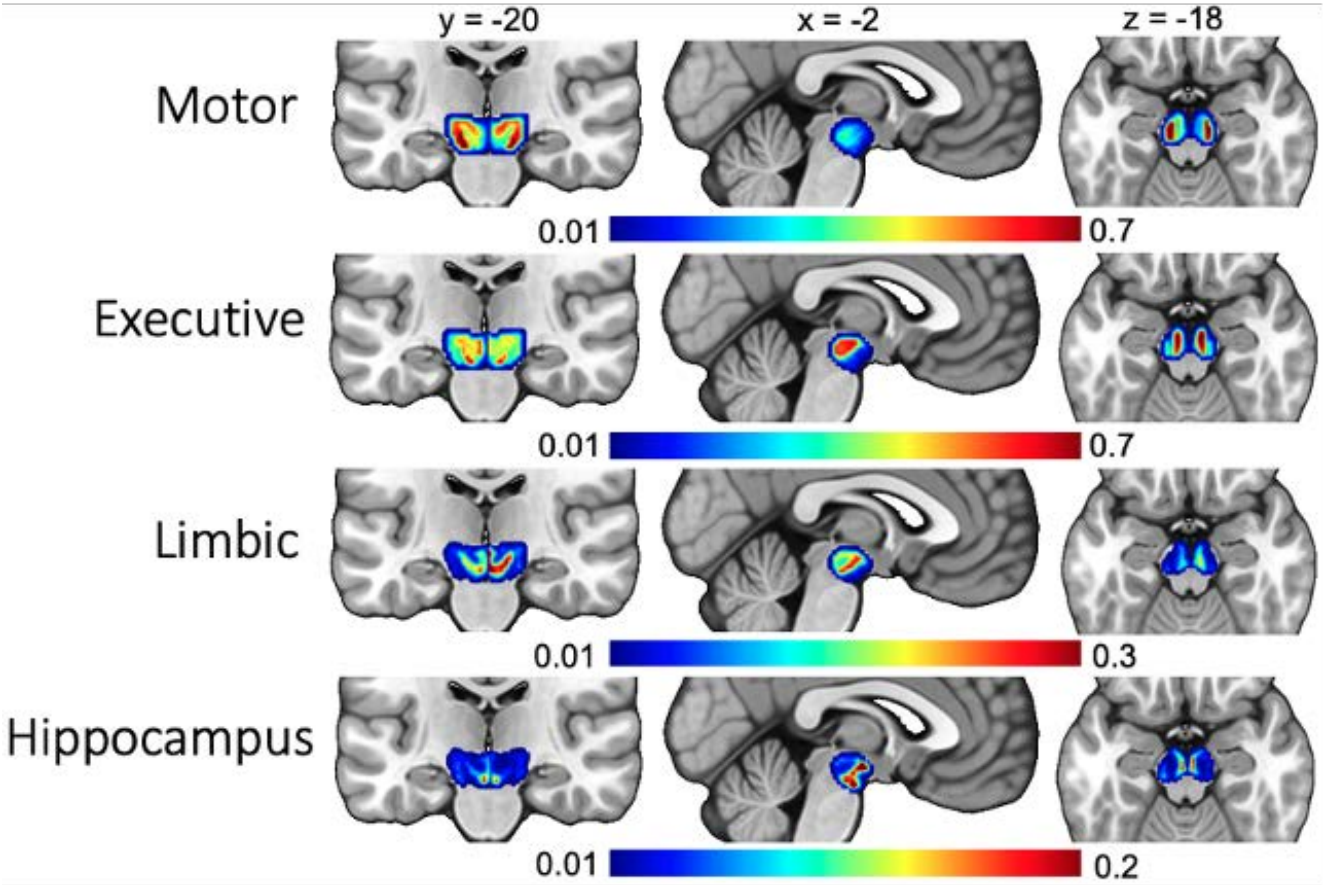
Diffusion imaging

Probabilistic tractography

Elliott, D'Ardenne, Murty, Brewer, McClure, 2022



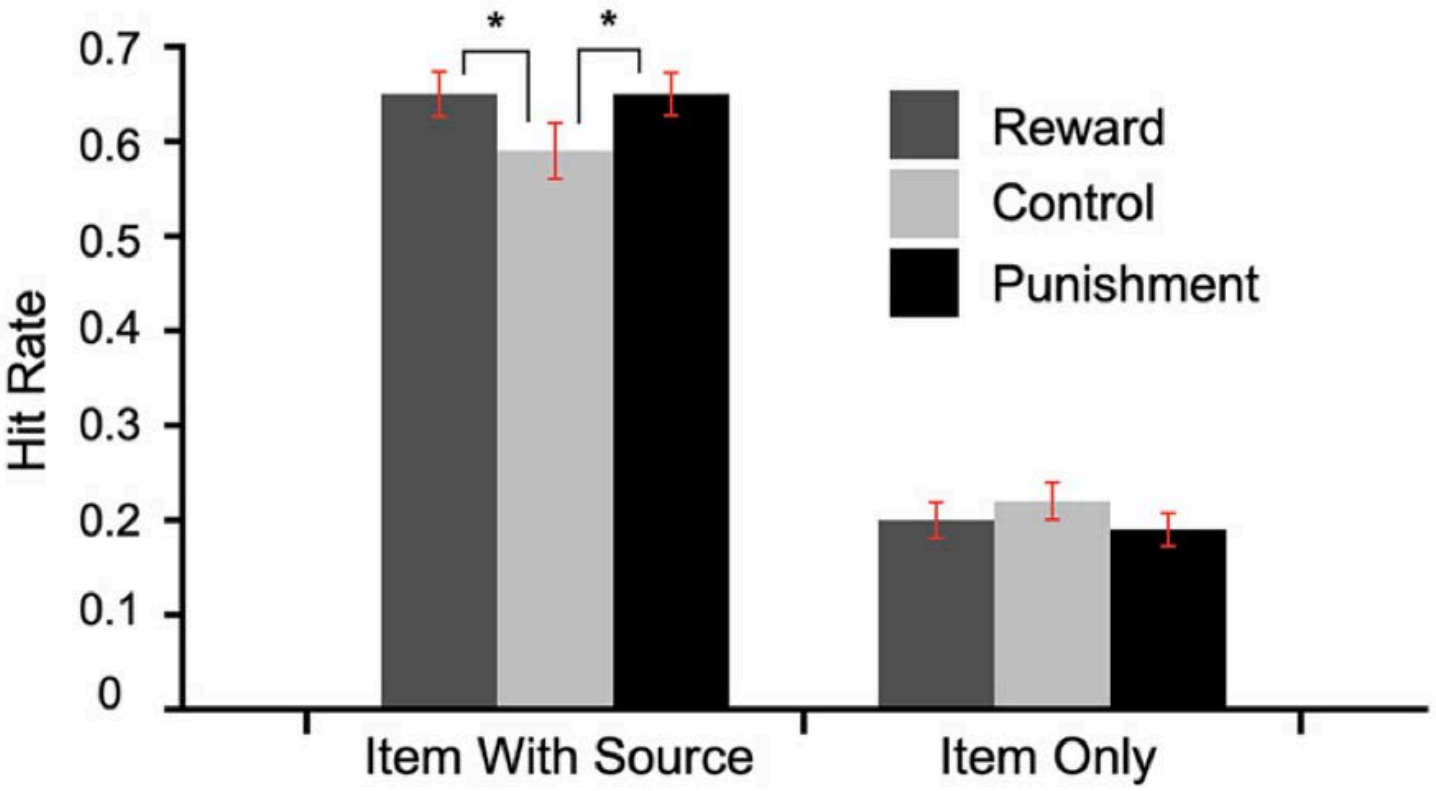
Probabilistic tractography



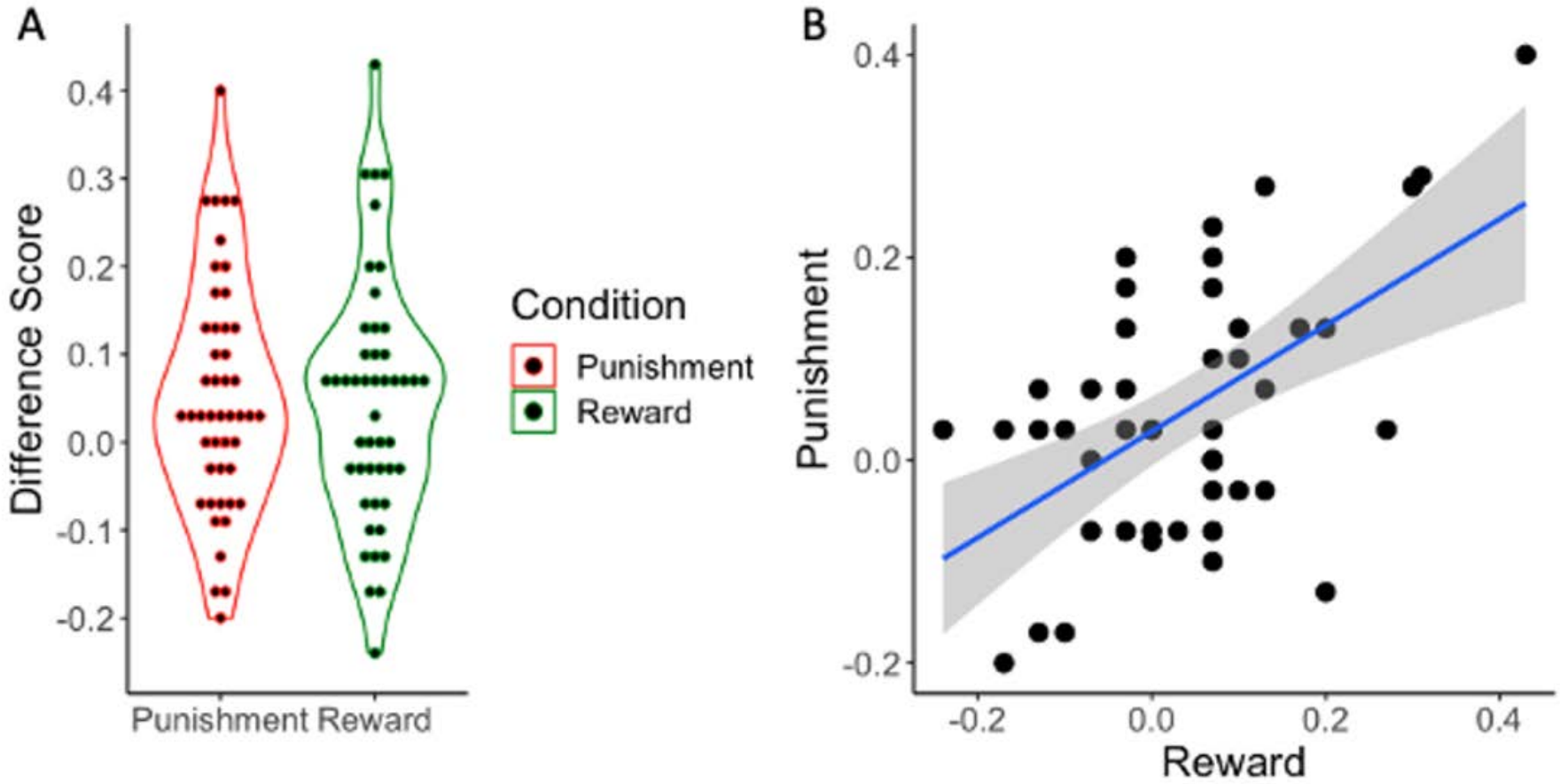
Task

- 3 × 30 training words, 45 test words
- Words presented random on left or right of screen
- Three values: $1, $0, –$1
- Full value earned (or avoid losing) for identifying “old” and correct location. 50¢ penalty for not remembering location.

Behavior

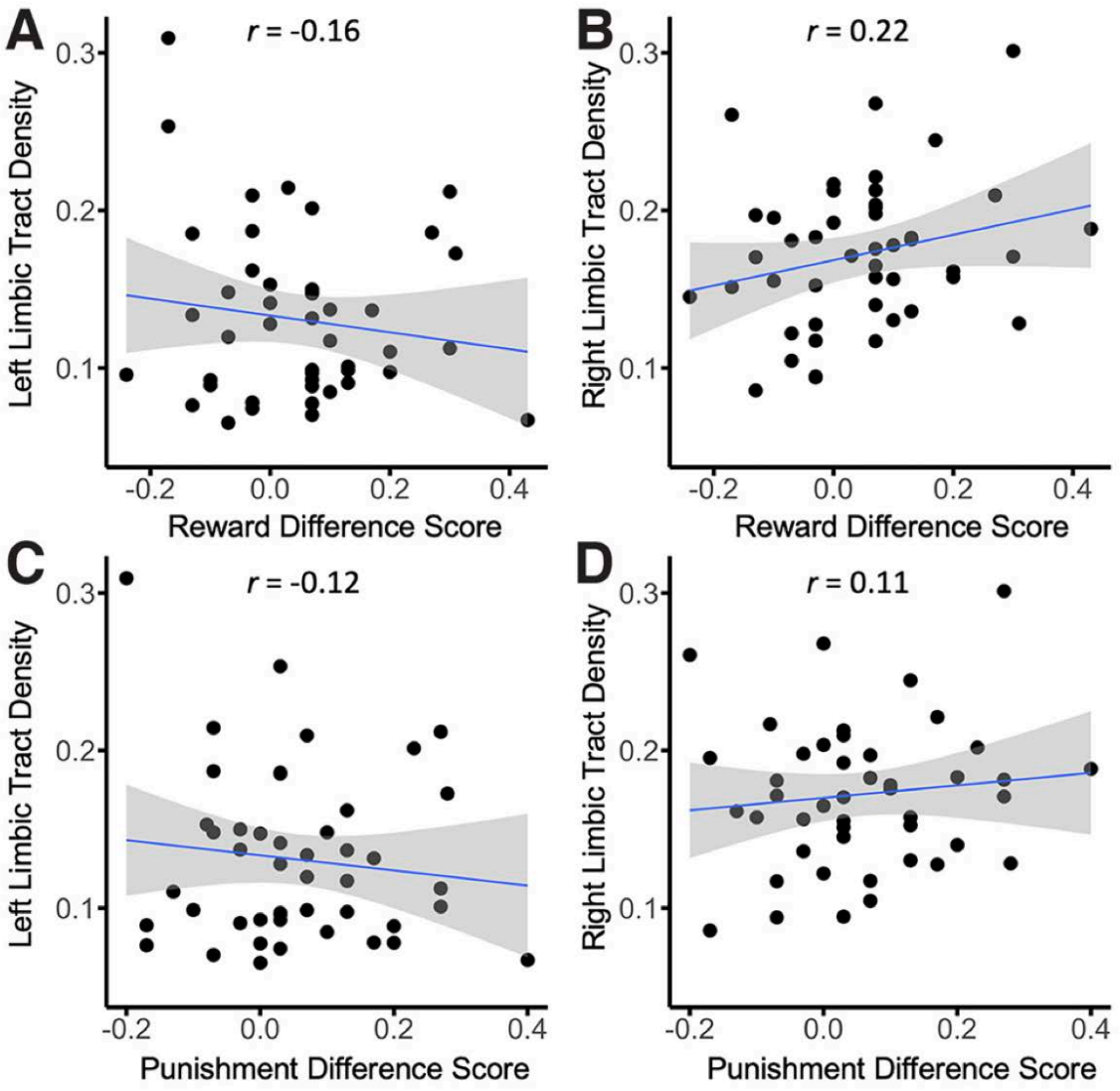

Hit Rate
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
*
*
Reward
Control
Punishment
Item With Source
Item Only

Behavior


A
Difference Score
0.4
0.3
0.2
0.1
0.0
-0.1
-0.2
Punishment Reward
Condition
Punishment
Reward
B
Punishment
0.4
0.2
0.0
-0.2
-0.2
0.0
0.2
0.4
Reward

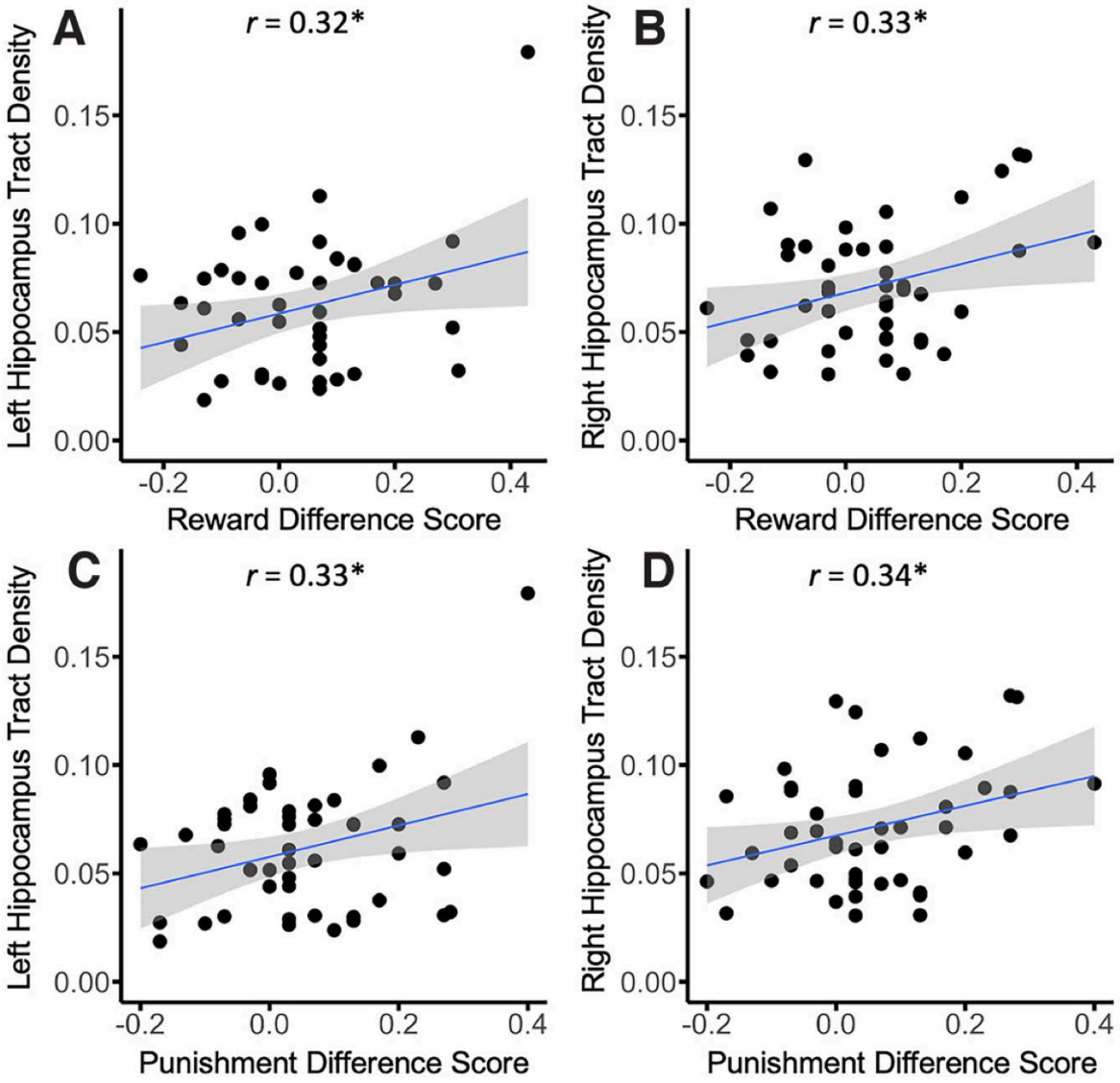
Correlation with tract likelihoods

- No relationship with most tracts



Correlation with tract likelihoods

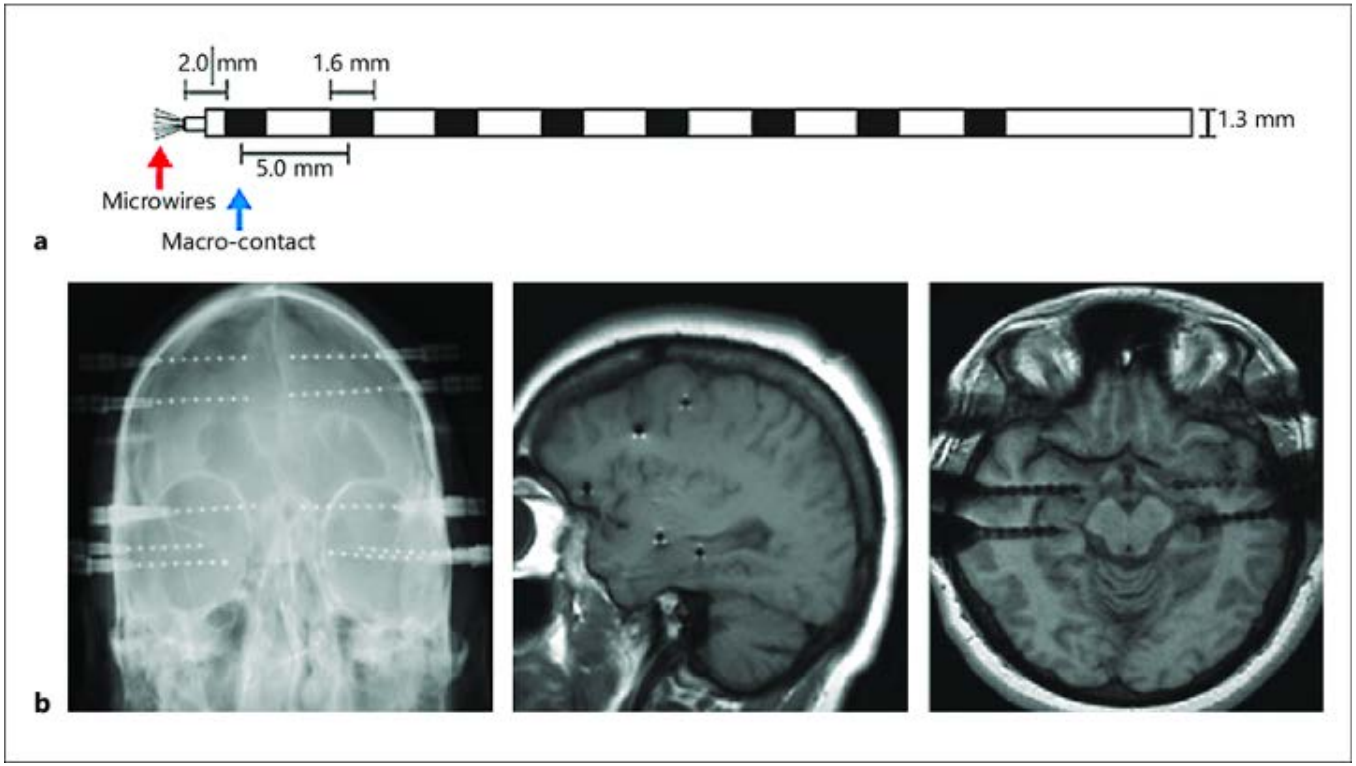
- Except for VTA-hippocampus tracts

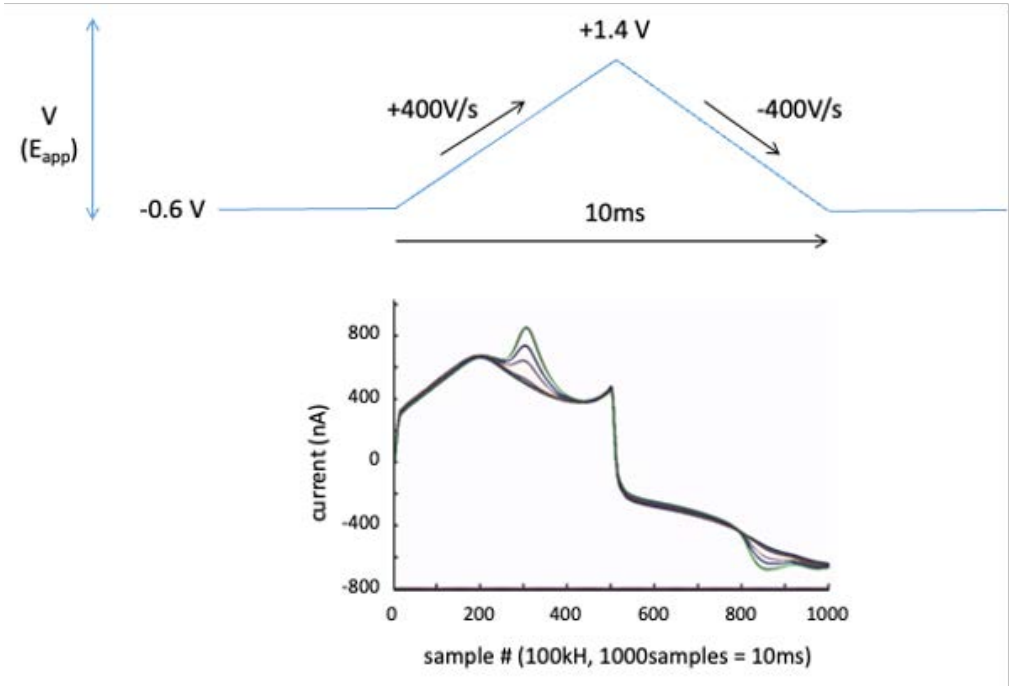


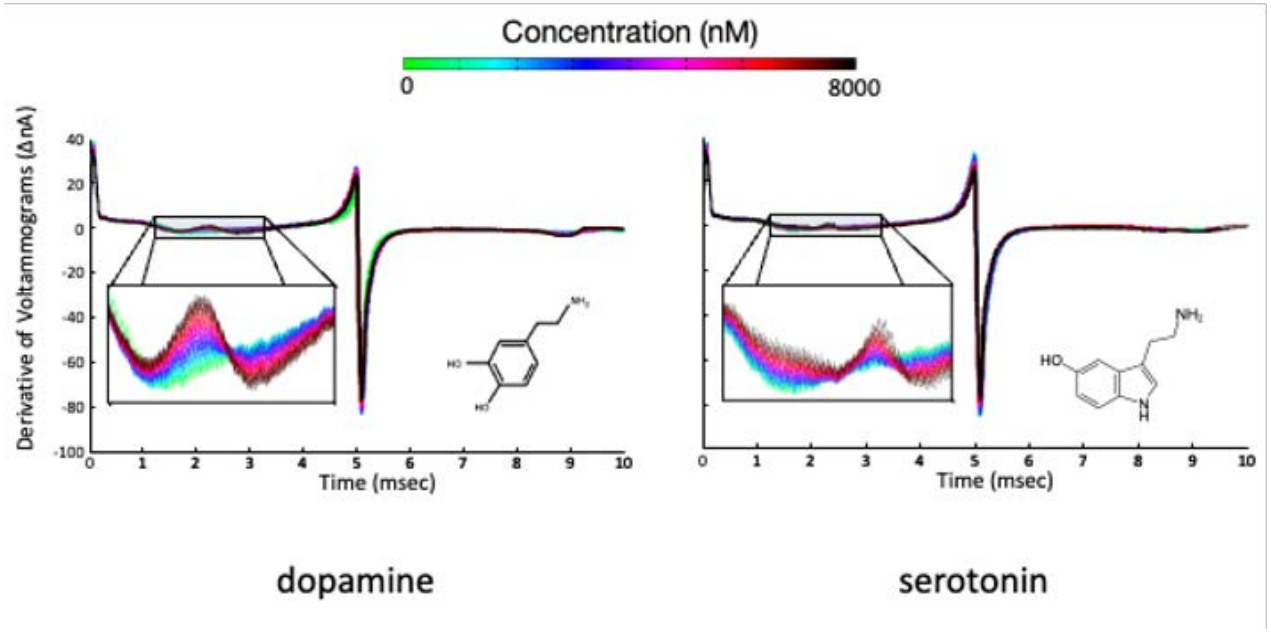
Summary

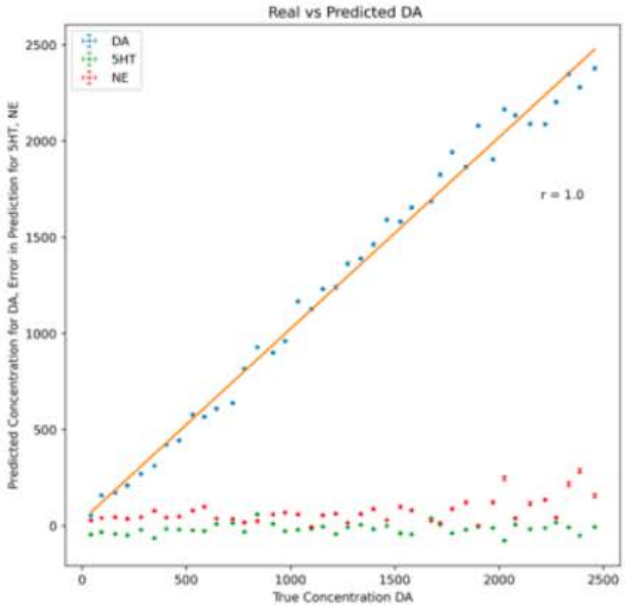
- Memory prioritization based on value is measurable, reliable, and related to other measures of episodic memory ability.
- The hypothesis that prioritization depends on dopamine function supported by non-invasive data: EEG, MRI.
- Suggests that a direct projection between VTA and hippocampus underlies some forms of preferential memory encoding.
- Direct tests using intracranial recordings are ongoing.

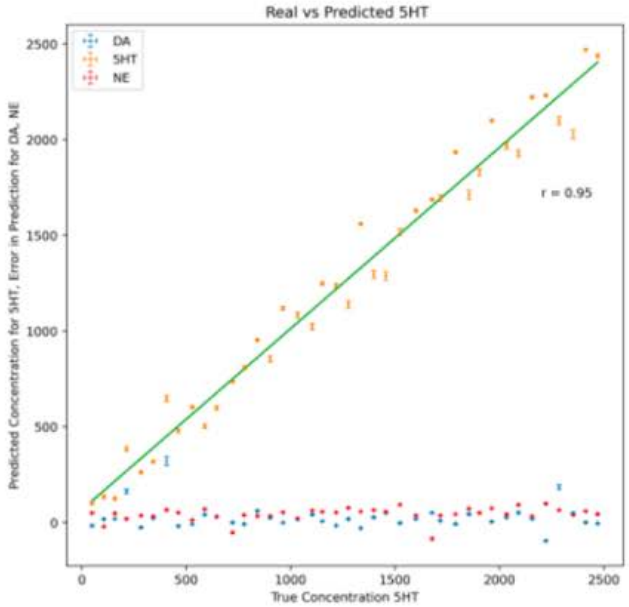
Thank you!

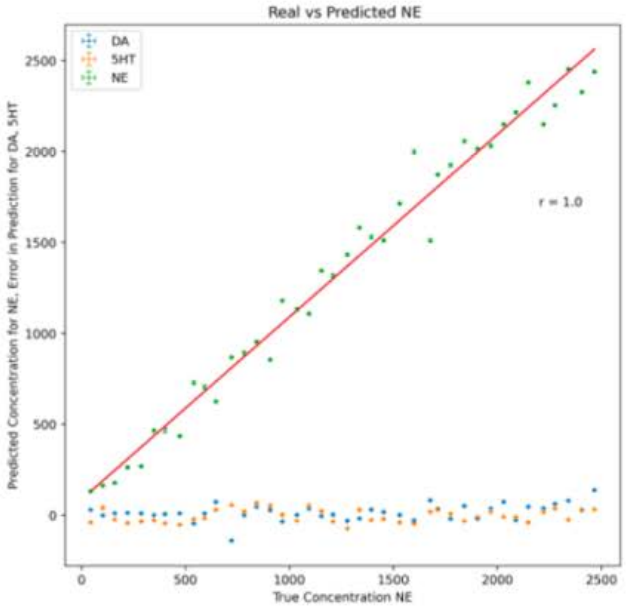

2.0 mm
1.6 mm
1.3 mm
5.0 mm
Microwires
Macro-contact
a
b


+1.4 V
V
(E_app)
+400V/s
-400V/s
-0.6 V
10ms
800
400
0
-400
-800
current (nA)
0
200
400
600
800
1000
sample # (100kH, 1000samples = 10ms)


Concentration (nM)
0
8000
Derivative of Voltammograms (Δ nA)
Time (msec)
Time (msec)
dopamine
serotonin


Real vs Predicted DA
DA
5HT
NE
r = 1.0
Predicted Concentration for DA, Error in Prediction for 5HT, NE
True Concentration DA


Real vs Predicted 5HT
DA
5HT
NE
r = 0.95
Predicted Concentration for 5HT, Error in Prediction for DA, NE
True Concentration 5HT


Real vs Predicted NE
DA
5HT
NE
r = 1.0
Predicted Concentration for NE, Error in Prediction for DA, 5HT
True Concentration NE