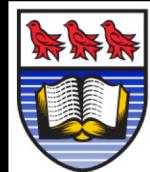


The Neuroscience of Learning

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



**University
of Victoria**

Theoretical and Applied
Neuroscience Laboratory

How do we learn?

FEEDBACK

Definition: Learning

Changes in internal processes that are reflected by relatively stable changes in performance.

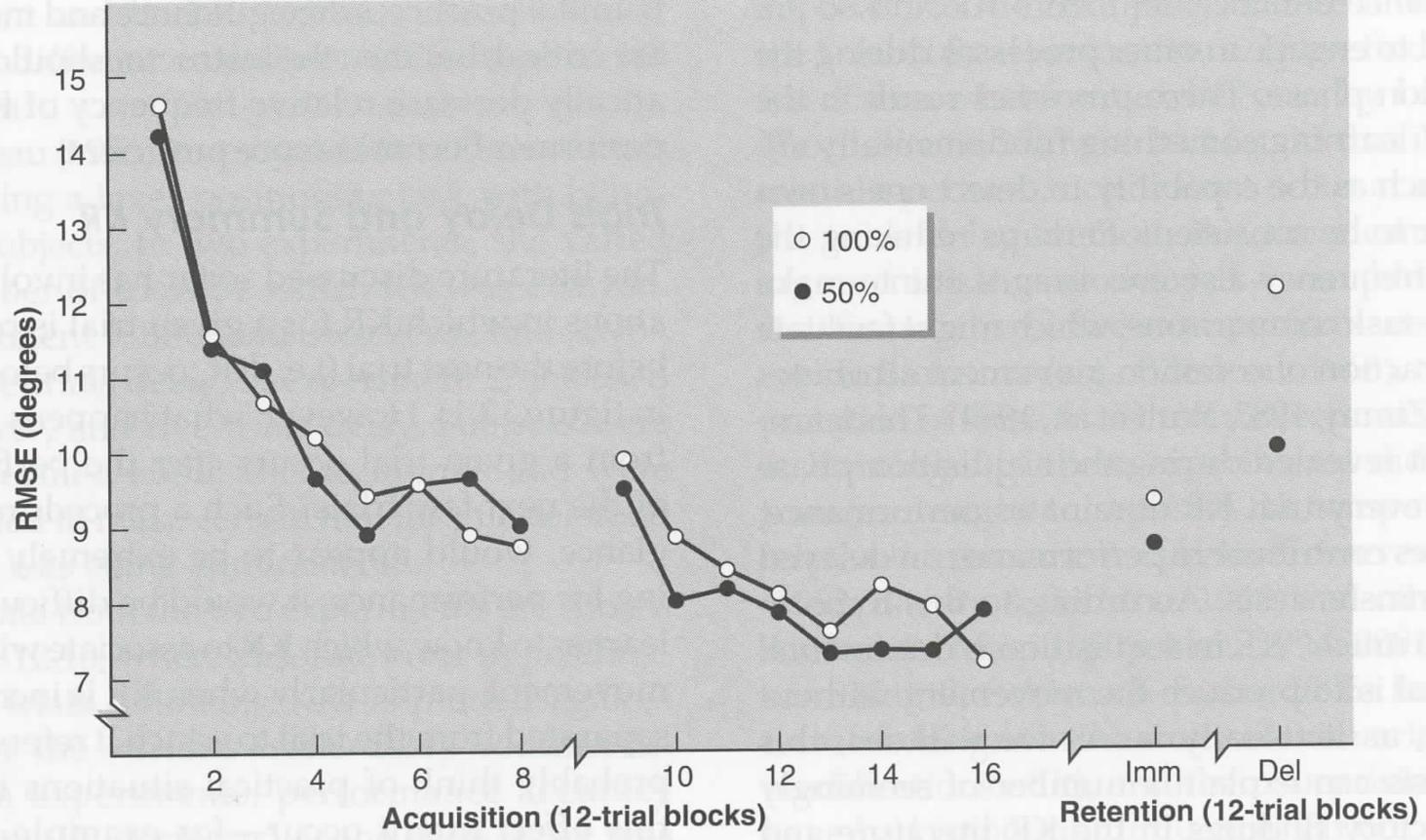


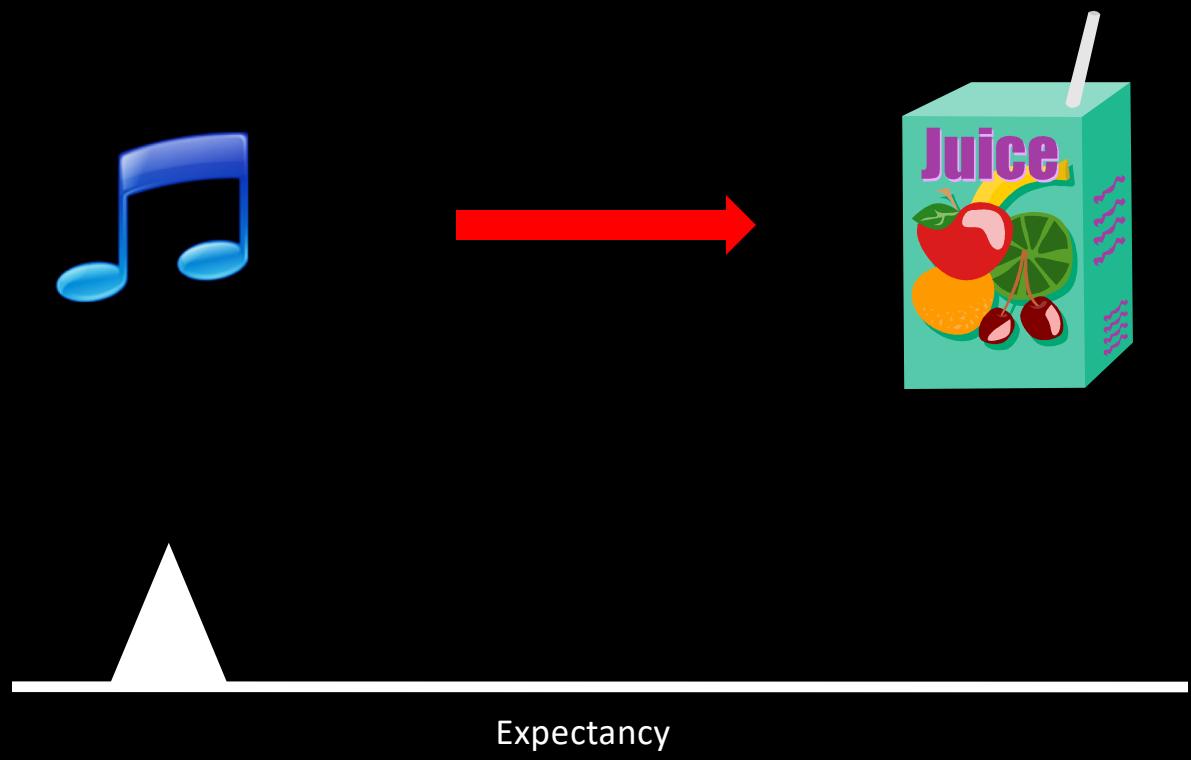
FIGURE 12.8 Effects of 100% versus 50% relative frequency of knowledge of results (KR) in acquisition and retention.

Reprinted, by permission, from C.J. Winstein and R.A. Schmidt, 1990, "Reduced frequency of knowledge of results enhances motor skill learning," *Journal of Experimental Psychology: Learning, Memory, and Cognition* 16; 910. Copyright © 1990 by the American Psychological Association.

Rescorla - Wagner



Expectancy



$$PE = (V_{\text{reward}} - V_{\text{cue}})$$

$$PE = (V_{\text{outcome}} - V_{\text{expectation}})$$

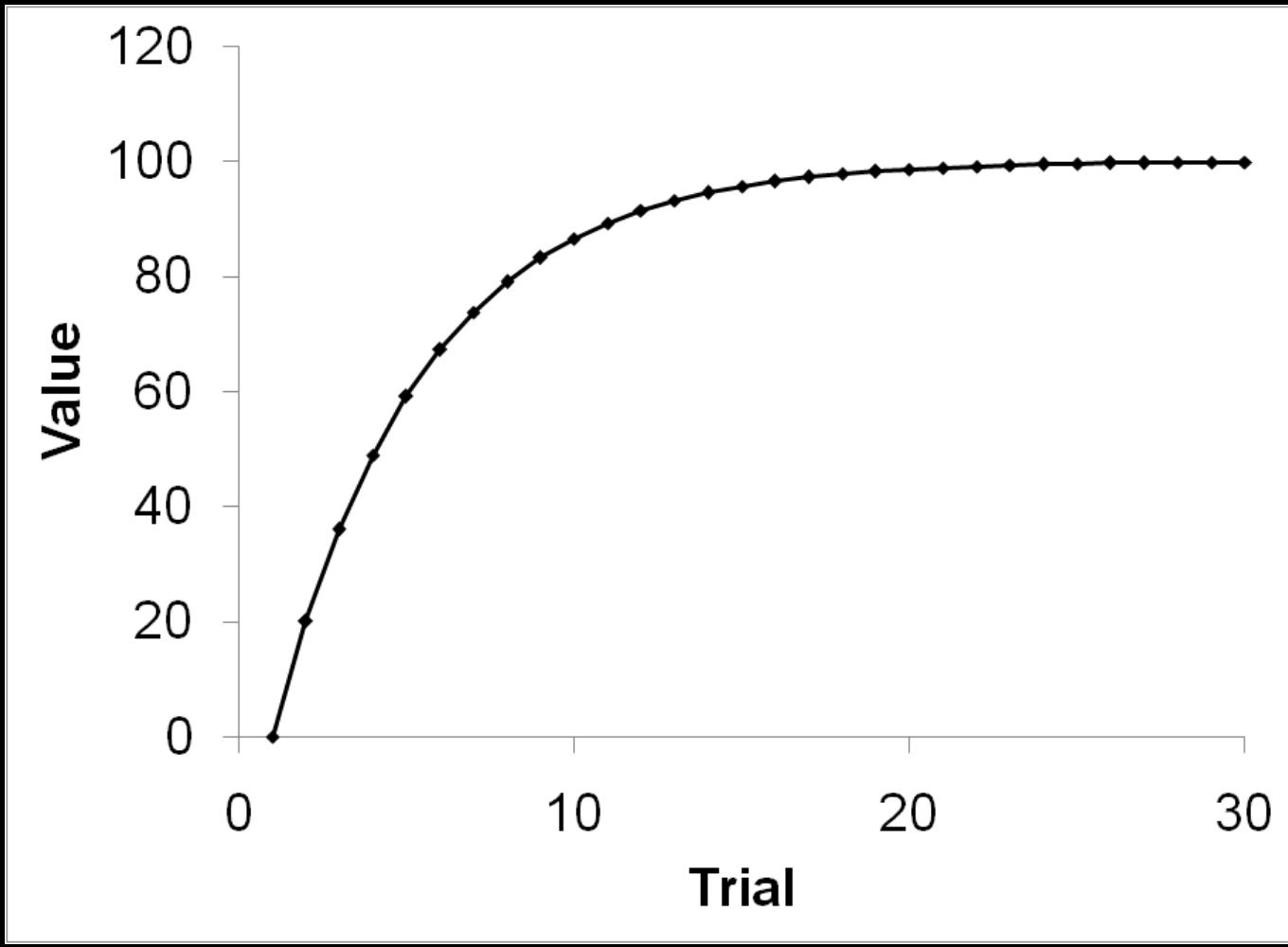
Learning IS ALWAYS a two step process.

At each point in time we:

- 1) Calculate a prediction error
- 2) Update the previous value

$$V_{\text{cue new}} = V_{\text{cue old}} + PE$$

V_{cue}



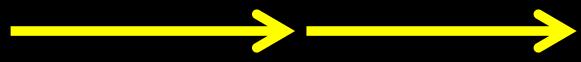
This applies to what is learned!

Recall that a memory is a collection of neurons being activated.

PE's can be used in principle to strengthen the connections between these neurons to “learn” the correct pattern.









$$PE = V_{\text{outcome}} - V_{\text{action}}$$

PE = +

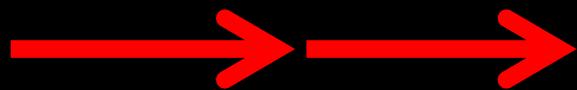




$$V_{\text{action}} = V_{\text{action}} + PE * LR$$

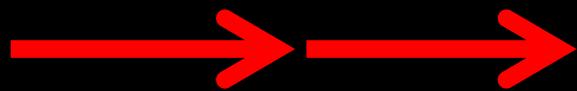
V_{action} ↑





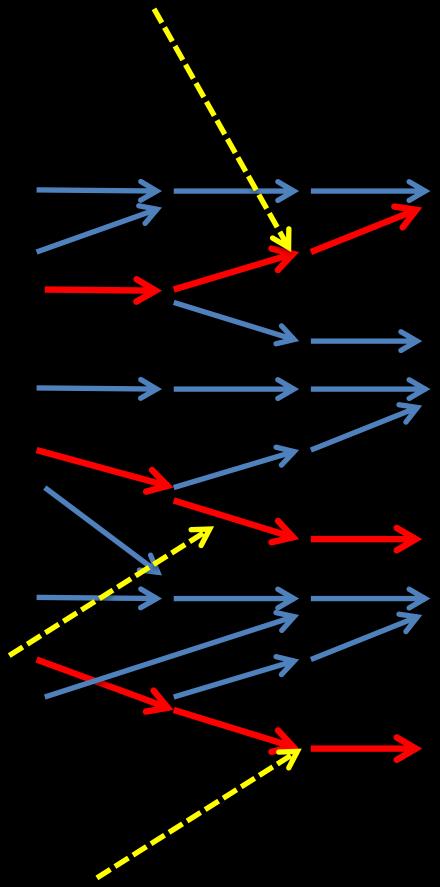
Thus, we choose/remember the top set of neurons because this choice
has a higher VALUE





This is a basic principle of decision making – always choose
the highest value option





Hebbian Learning &
Reinforcement Learning



So what does feedback actually do?

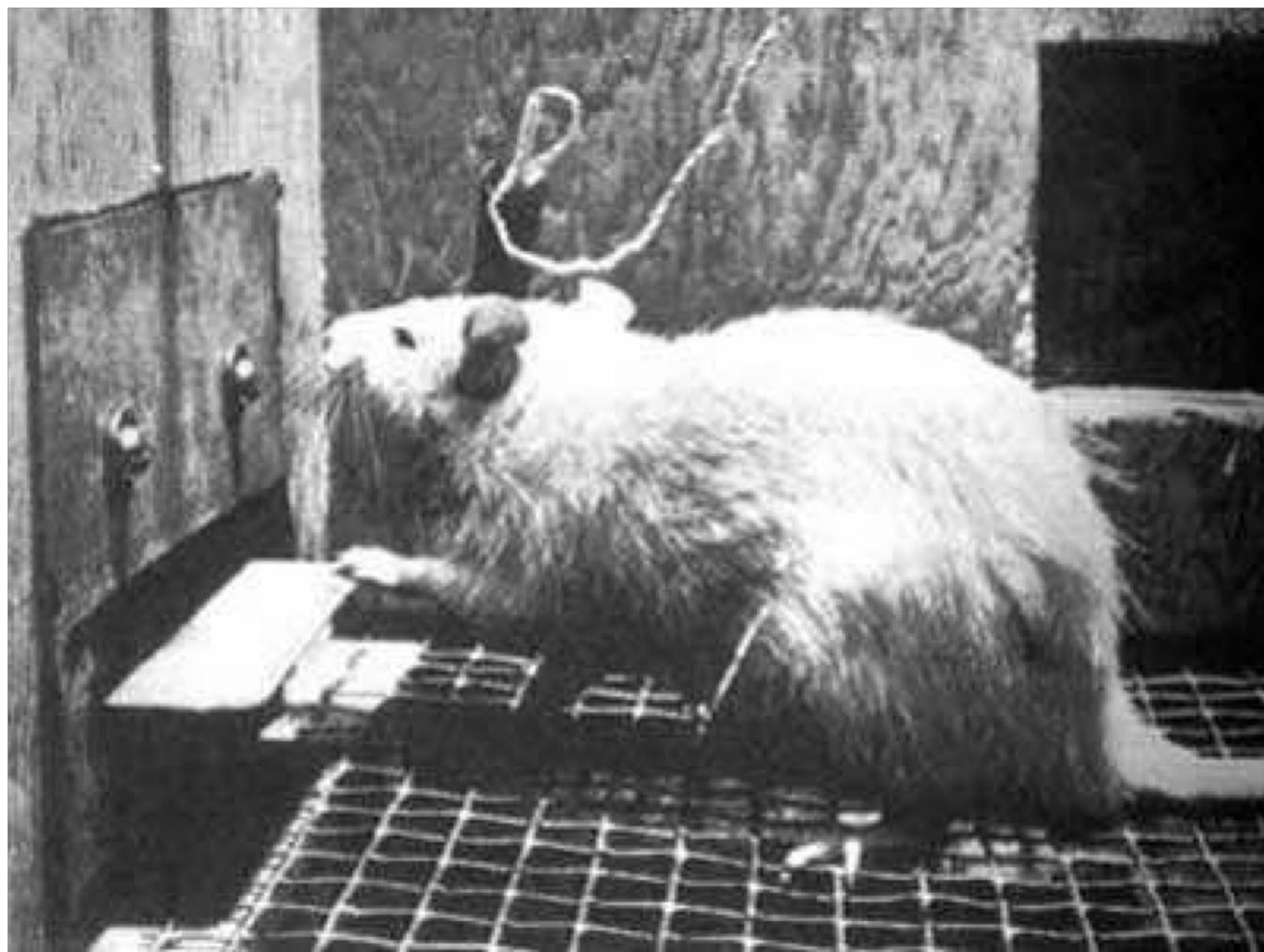
Thorndike's Law of Effect

Actions that are followed by feelings of satisfaction have a greater likelihood of being generated again in the future, whereas actions that are followed by feelings of dissatisfaction have a lesser likelihood of being generated again in the future.

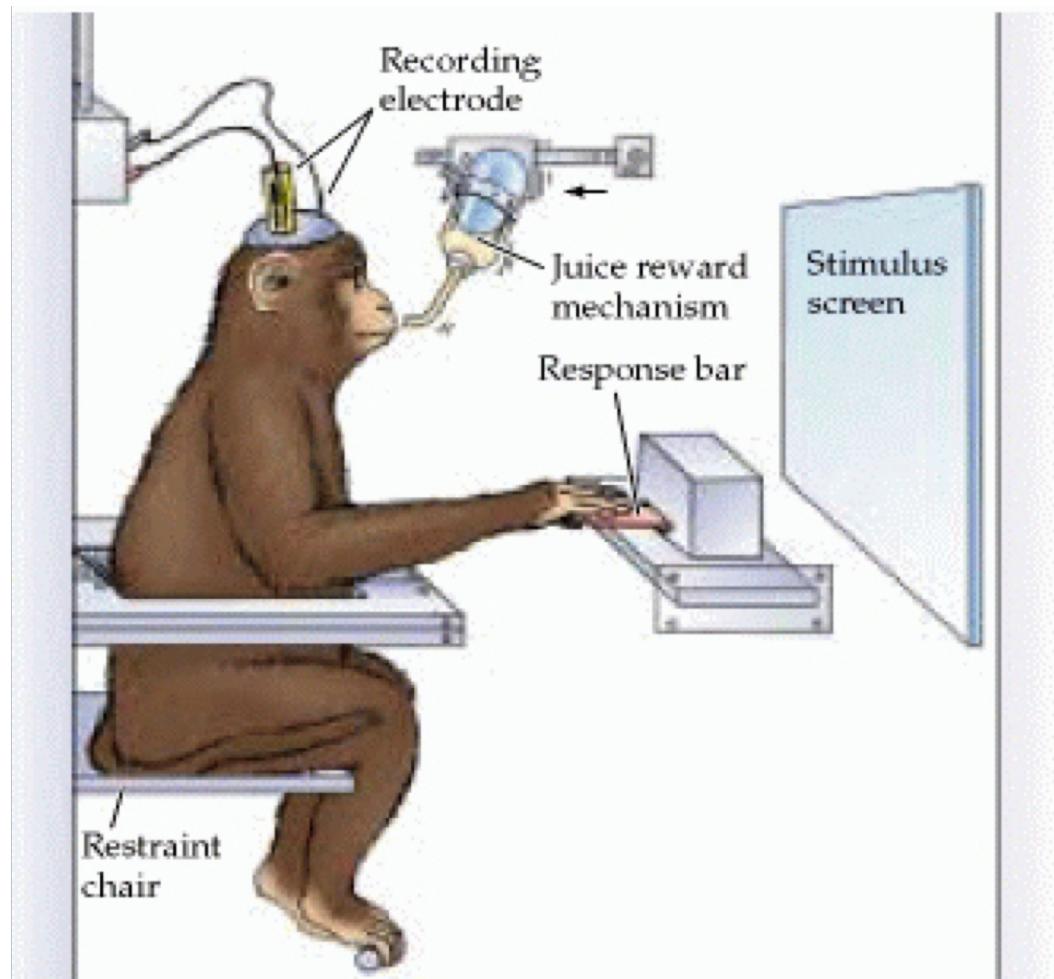
What is a prediction error?

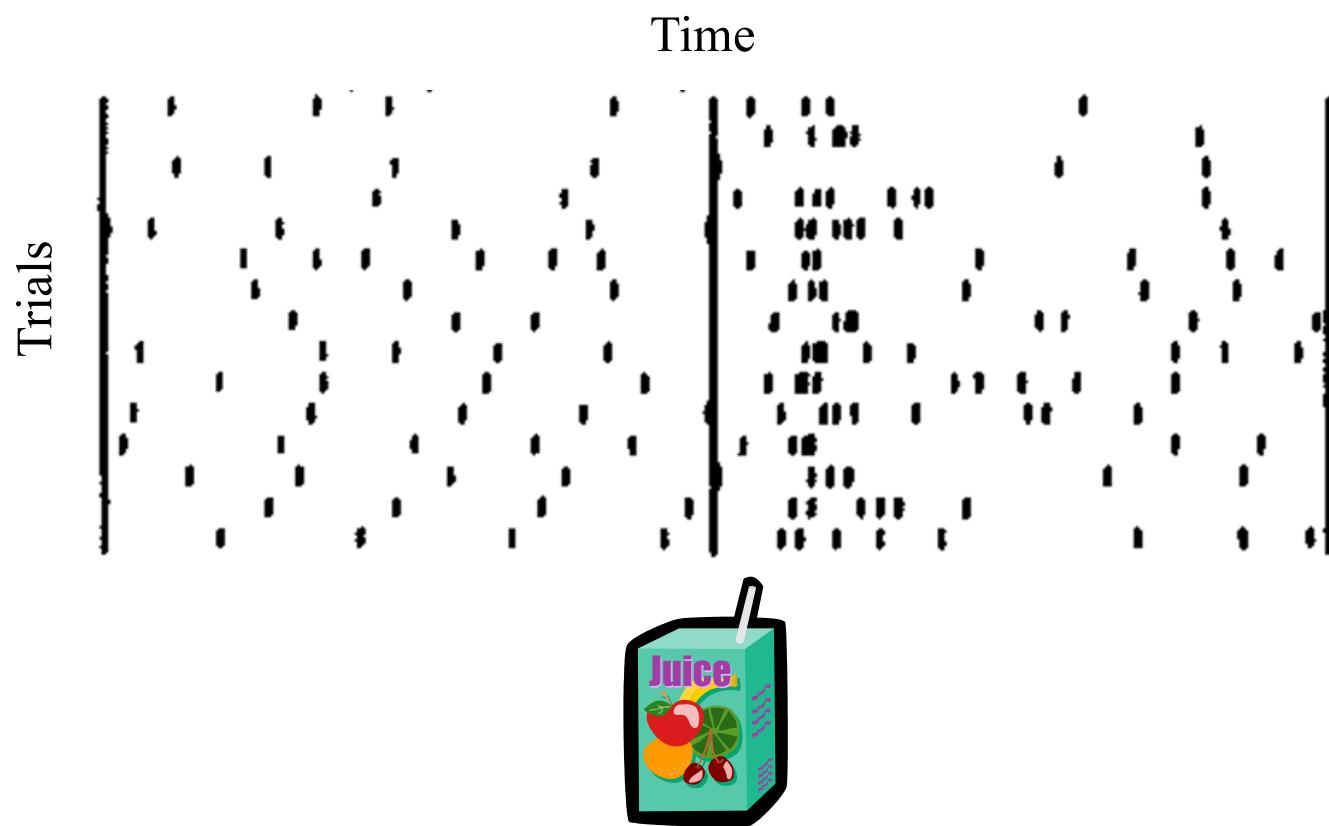
$\text{PE} = \text{Outcome} - \text{Expectation}$

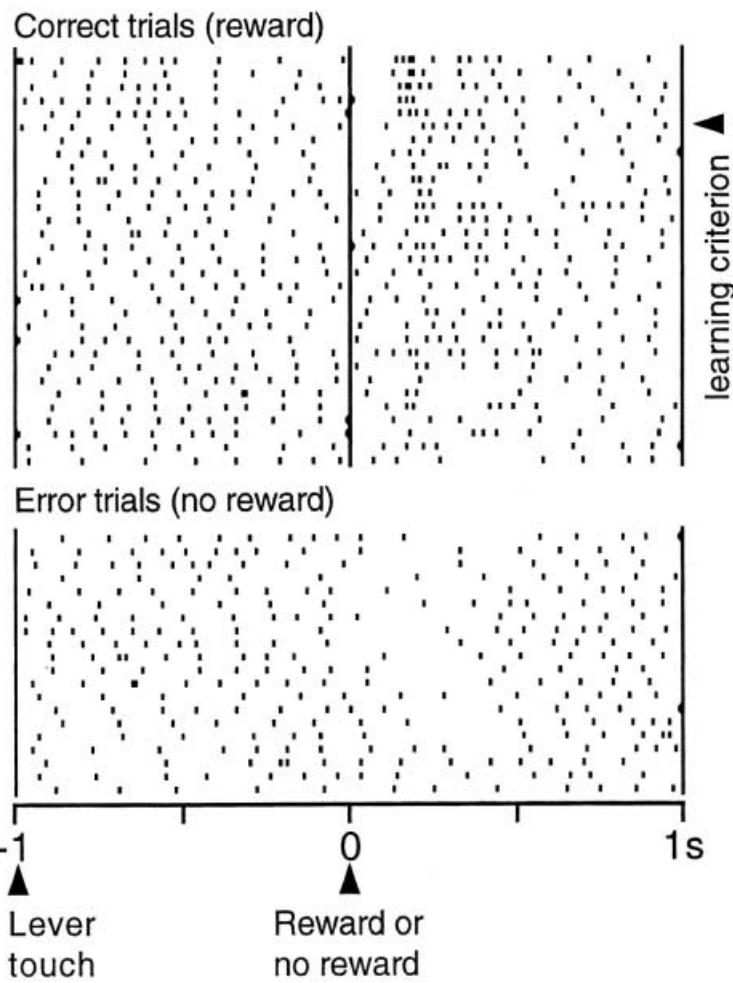
$\text{New Value} = \text{Old Value} + \text{Prediction Error}$

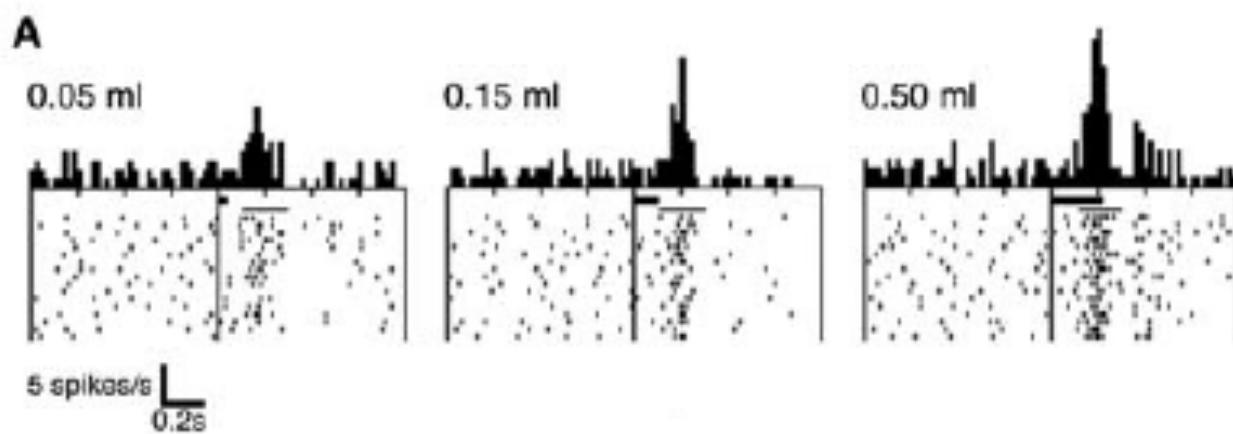


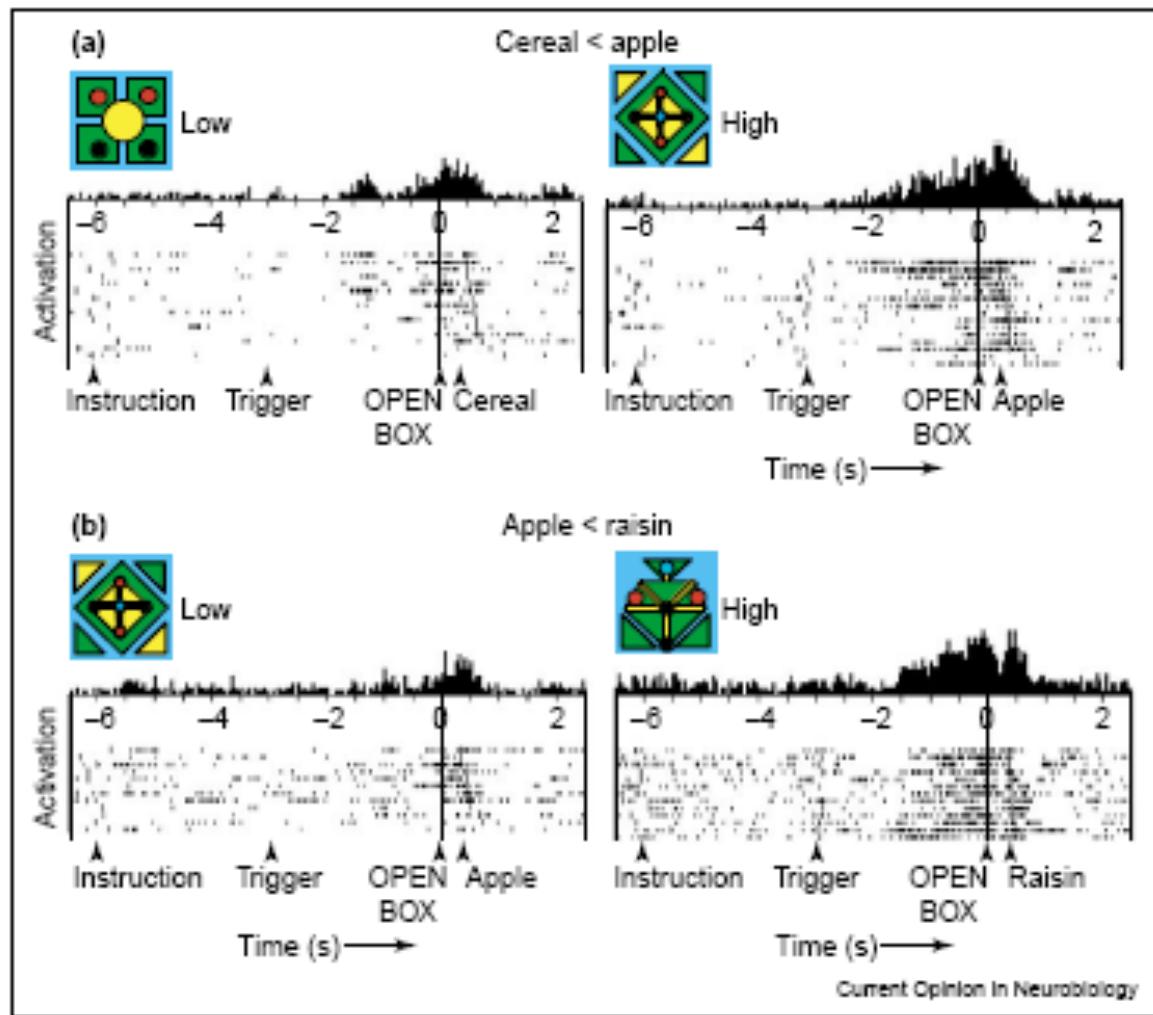
Olds & Milner, 1954

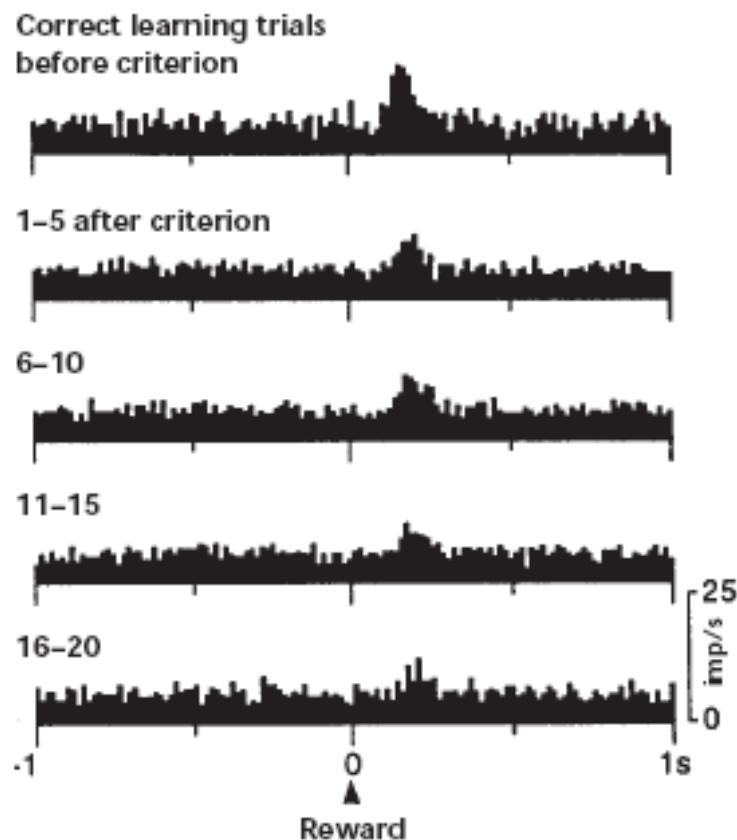




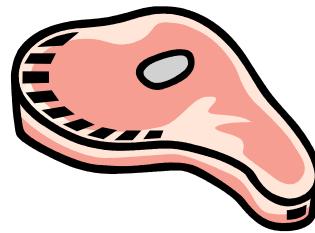
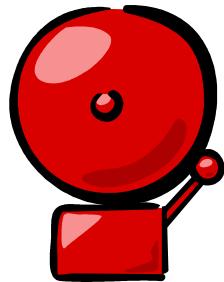




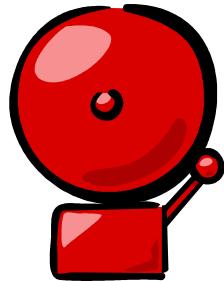


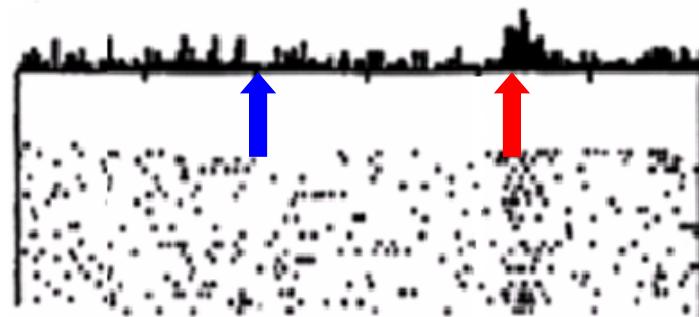


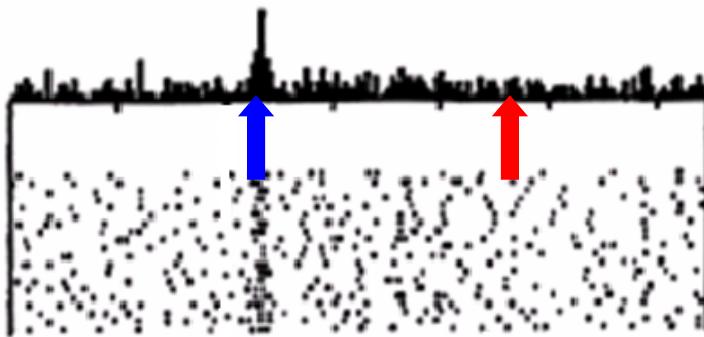
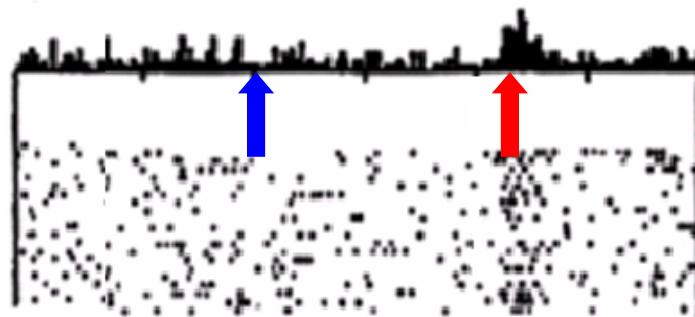
Classical Conditioning

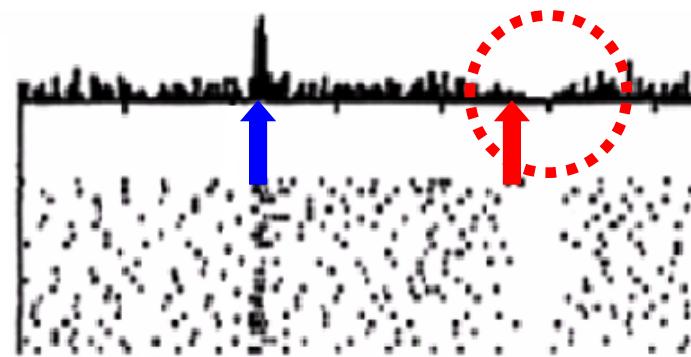
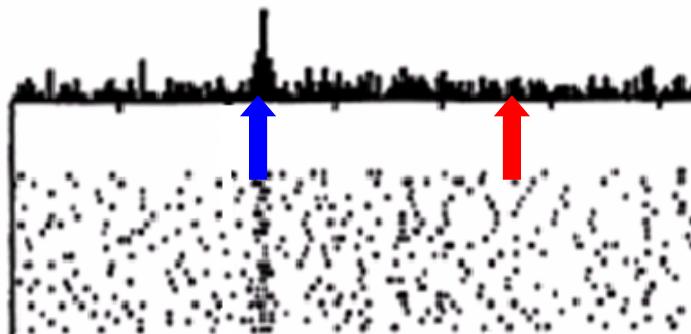
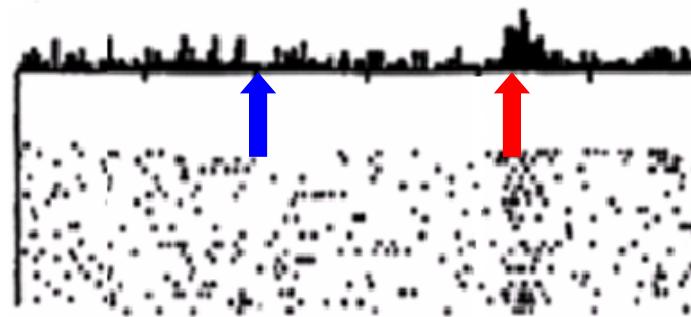


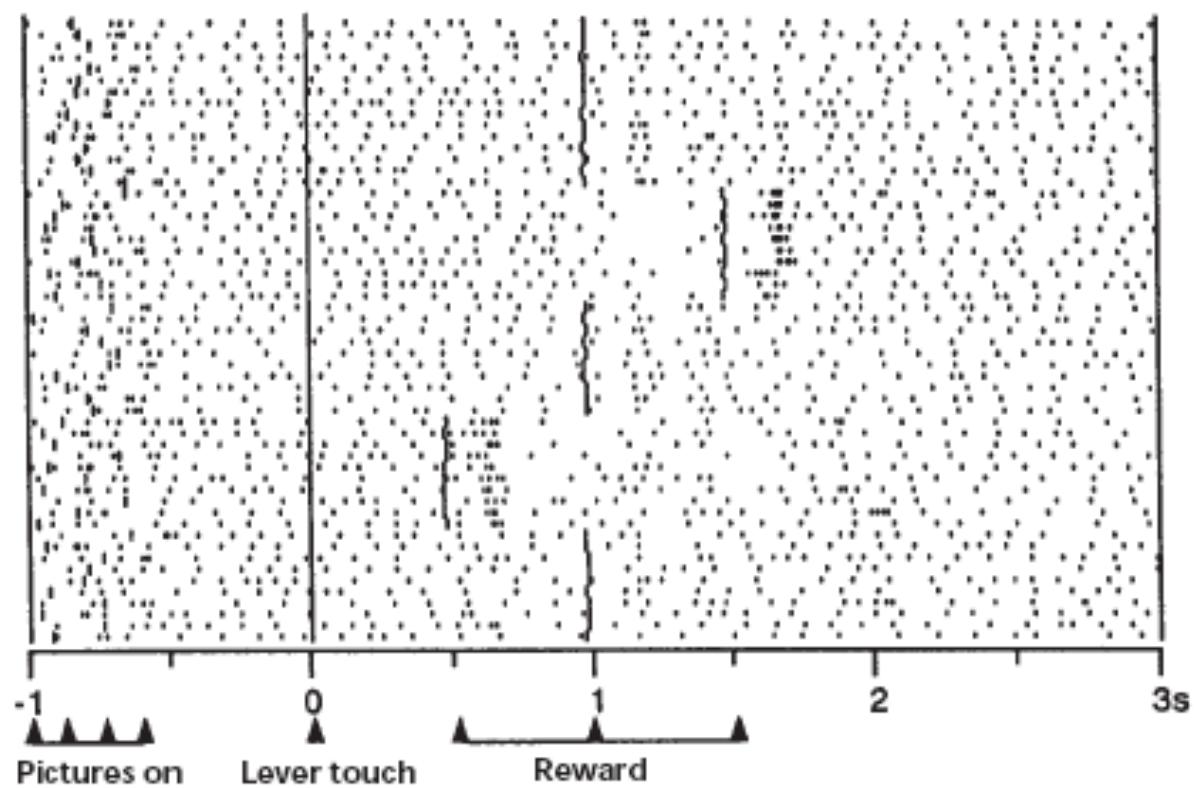
Classical Conditioning

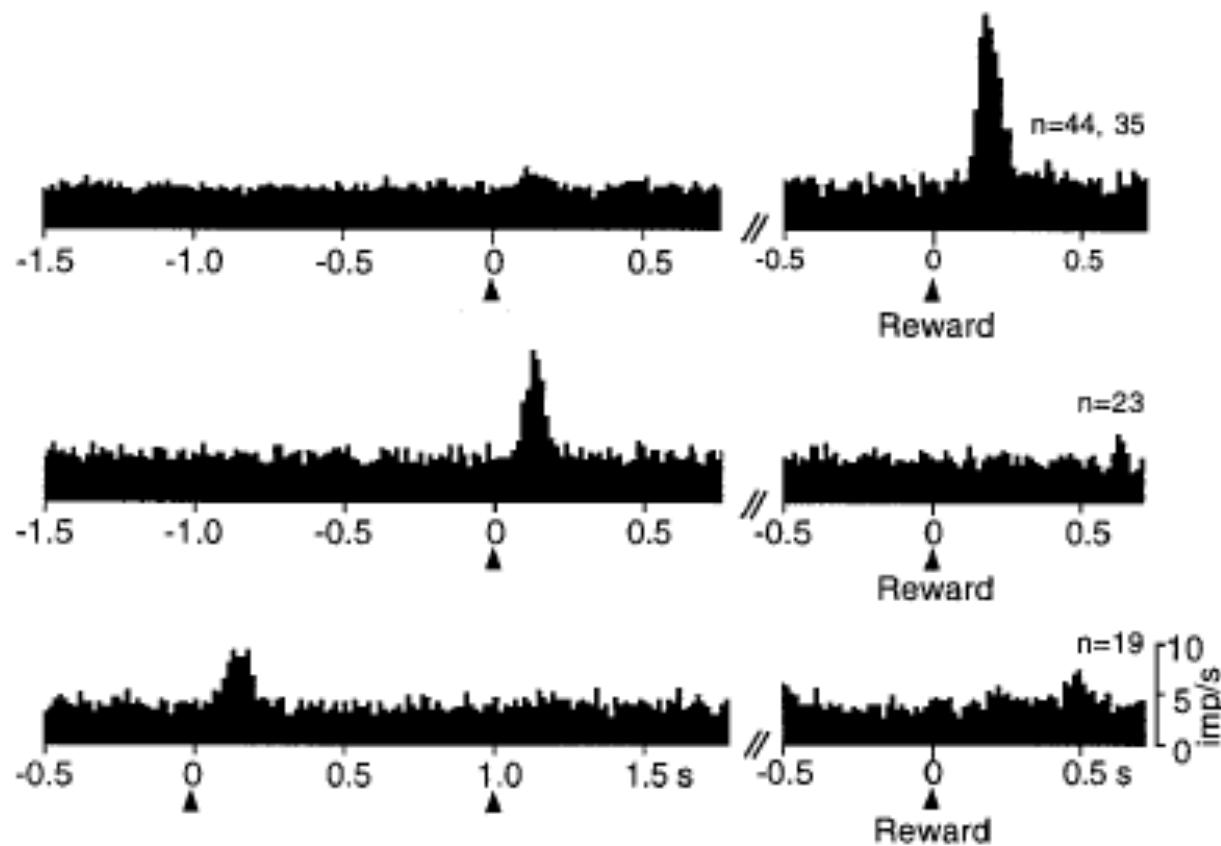


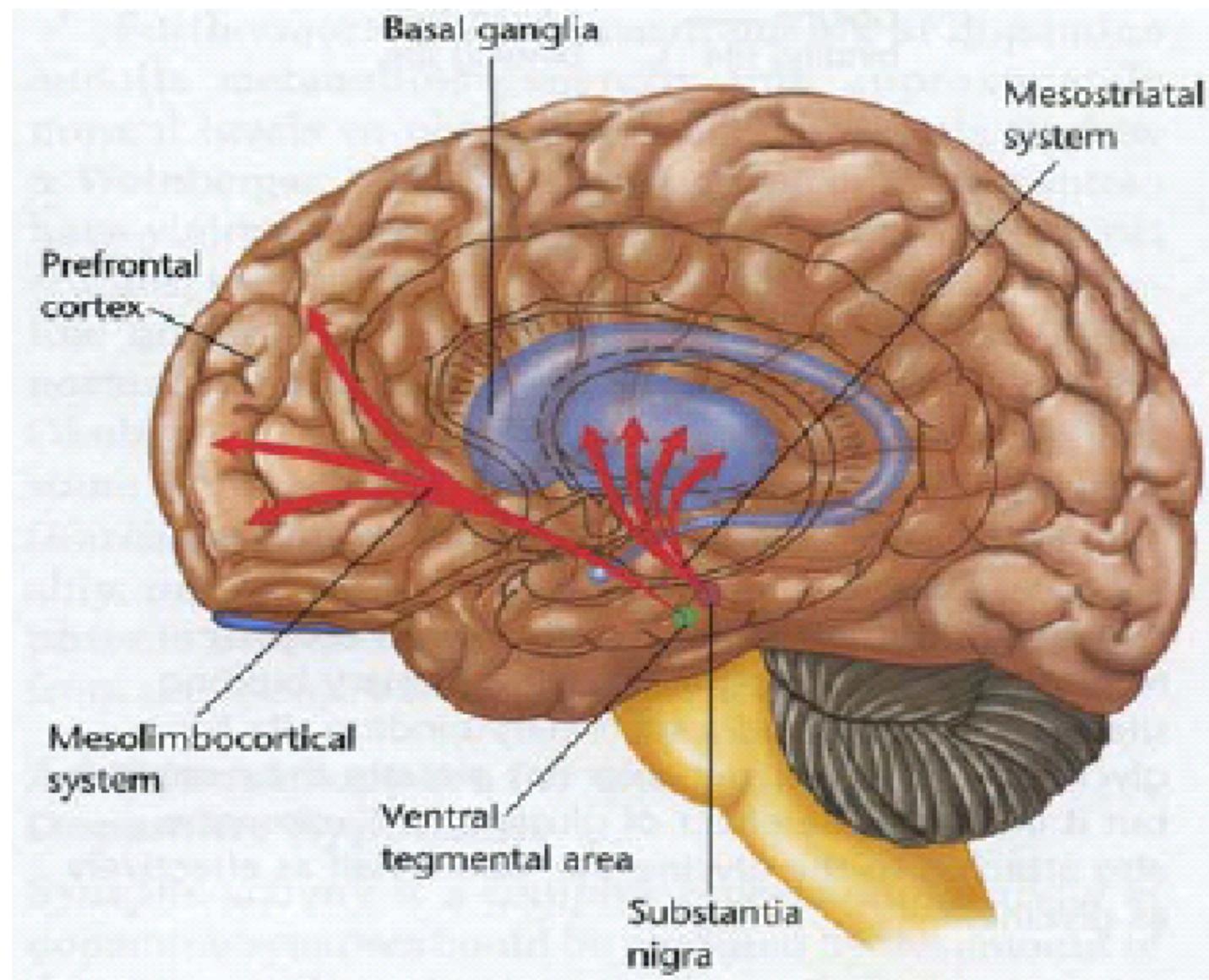


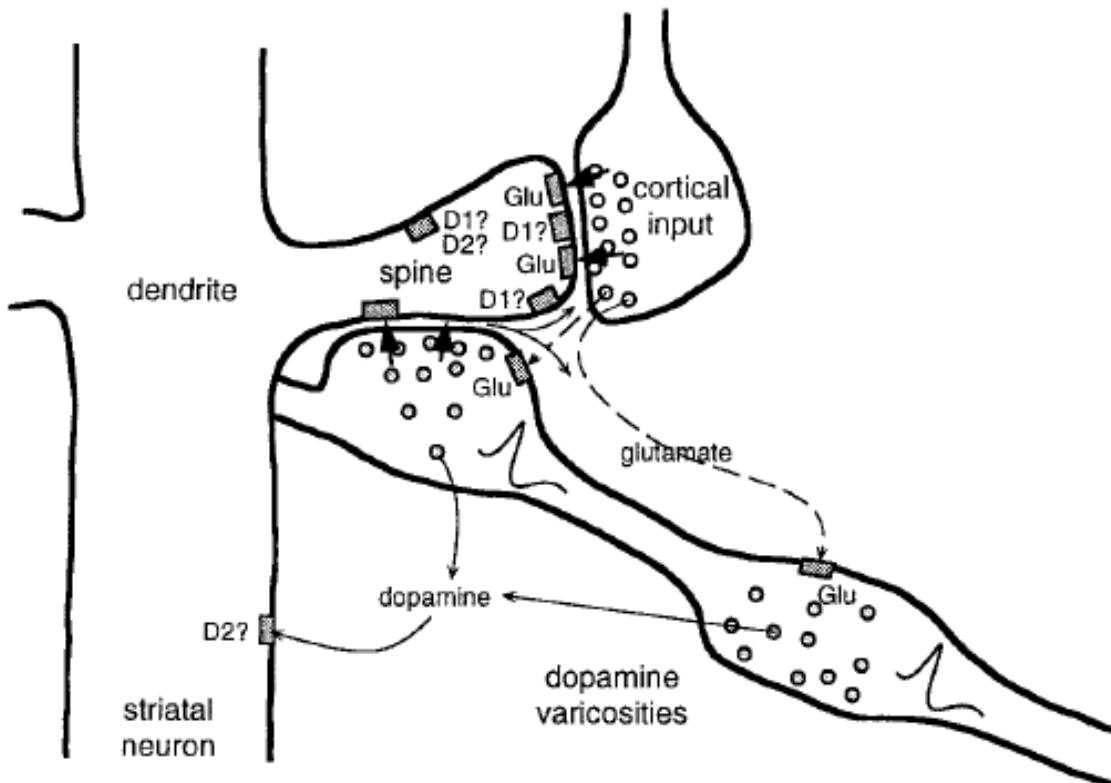


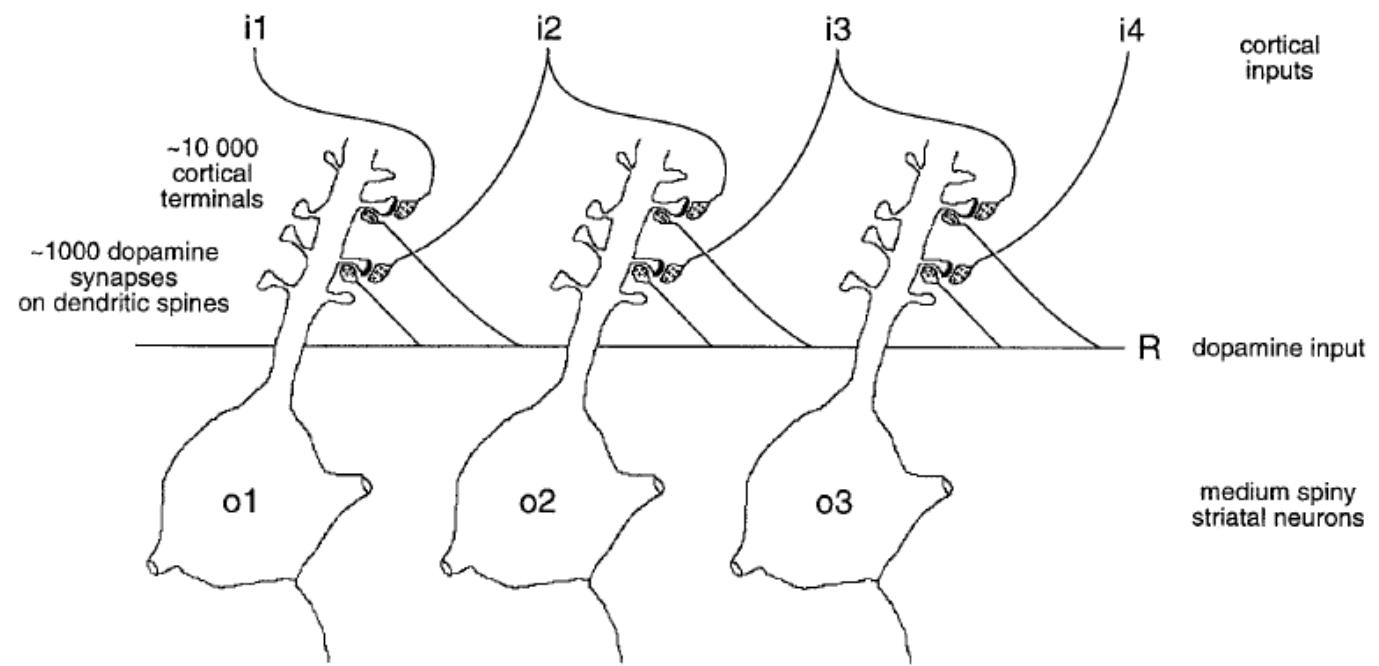


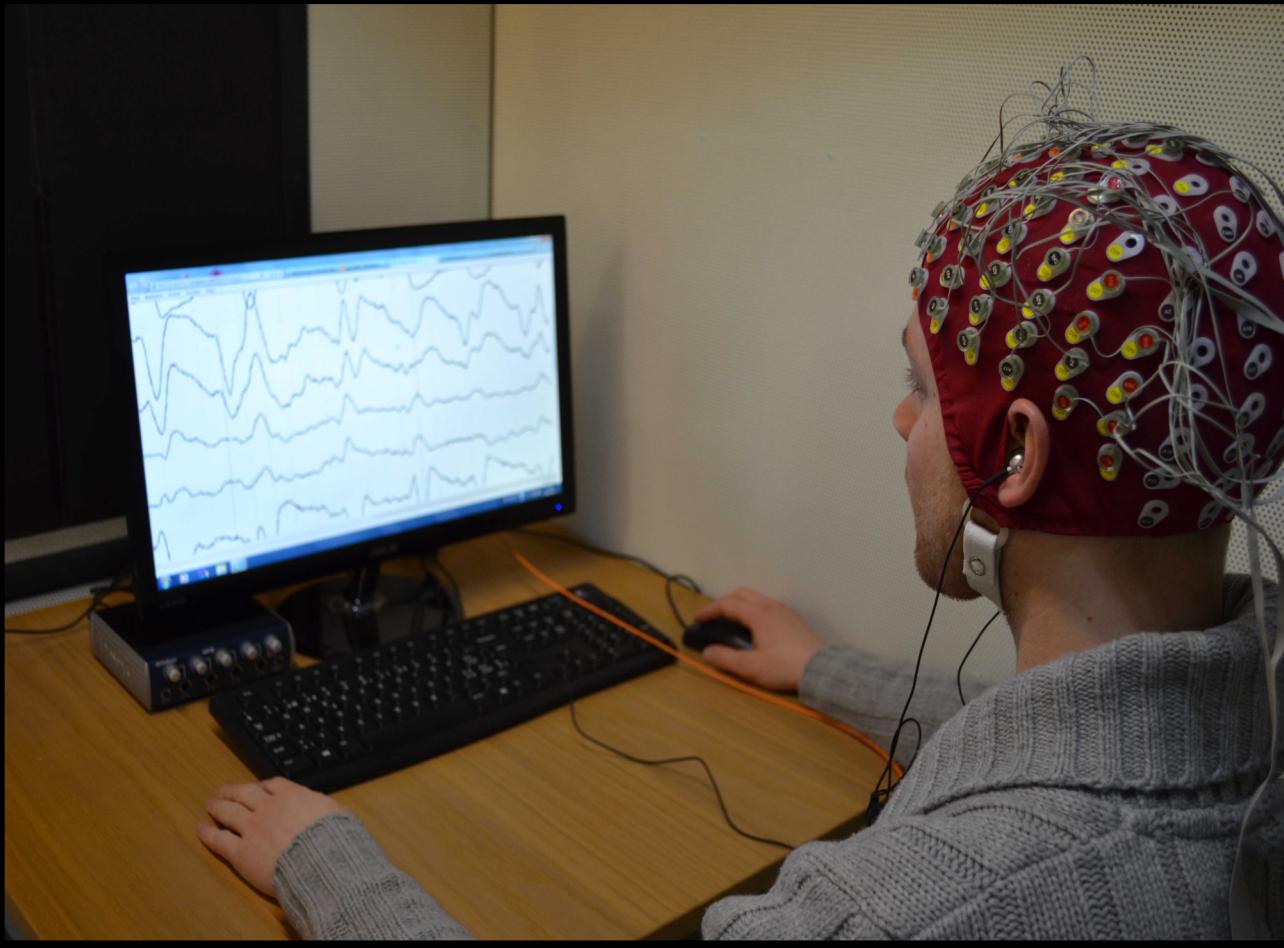


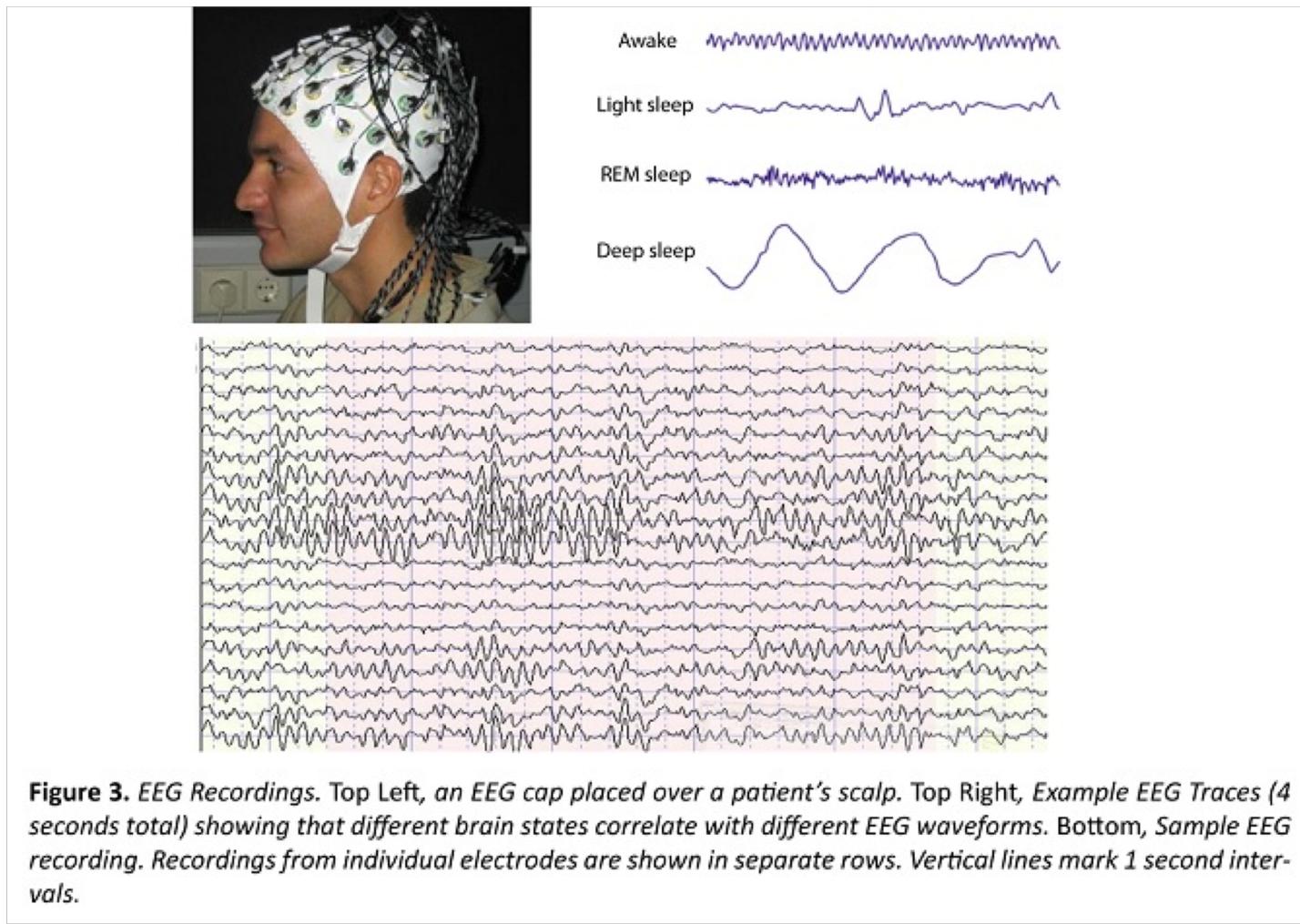












Human Models





- a. Dog
- b. Cat
- c. Horse
- d. Fish



- a. Dog
- b. Cat
- c. Horse
- d. Fish



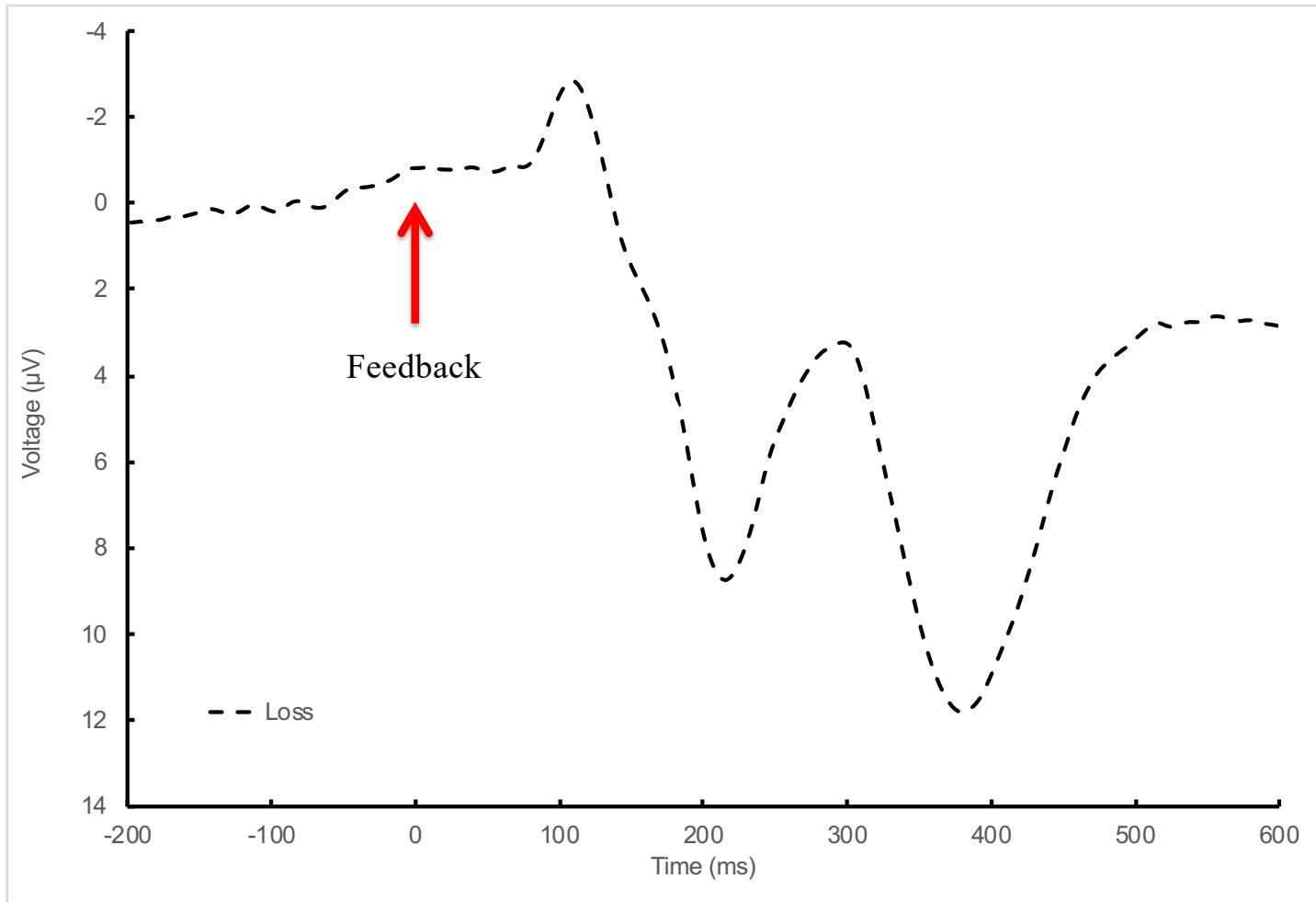
- a. Dog
- b. Cat
- c. Horse
- d. Fish

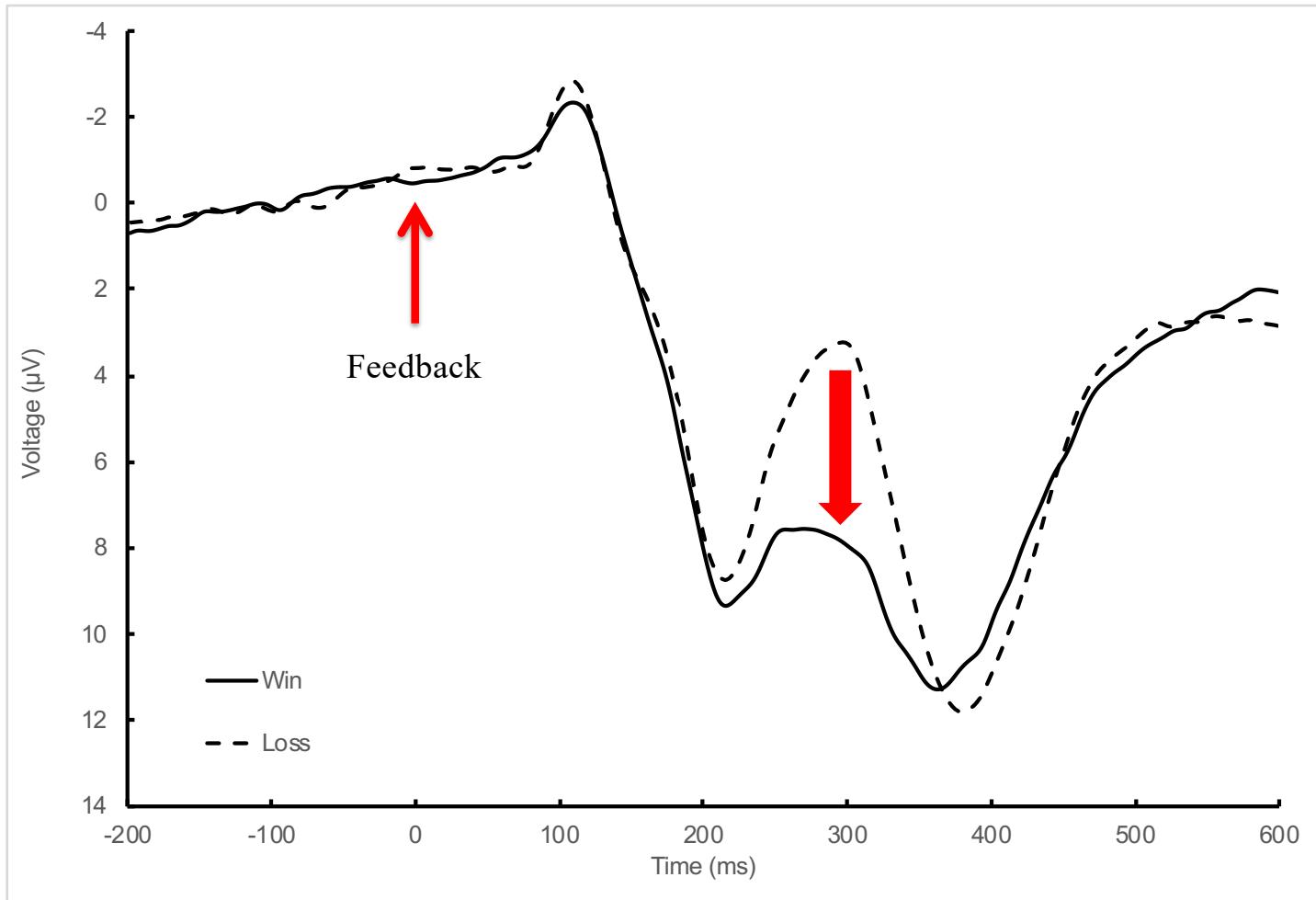
Correct!

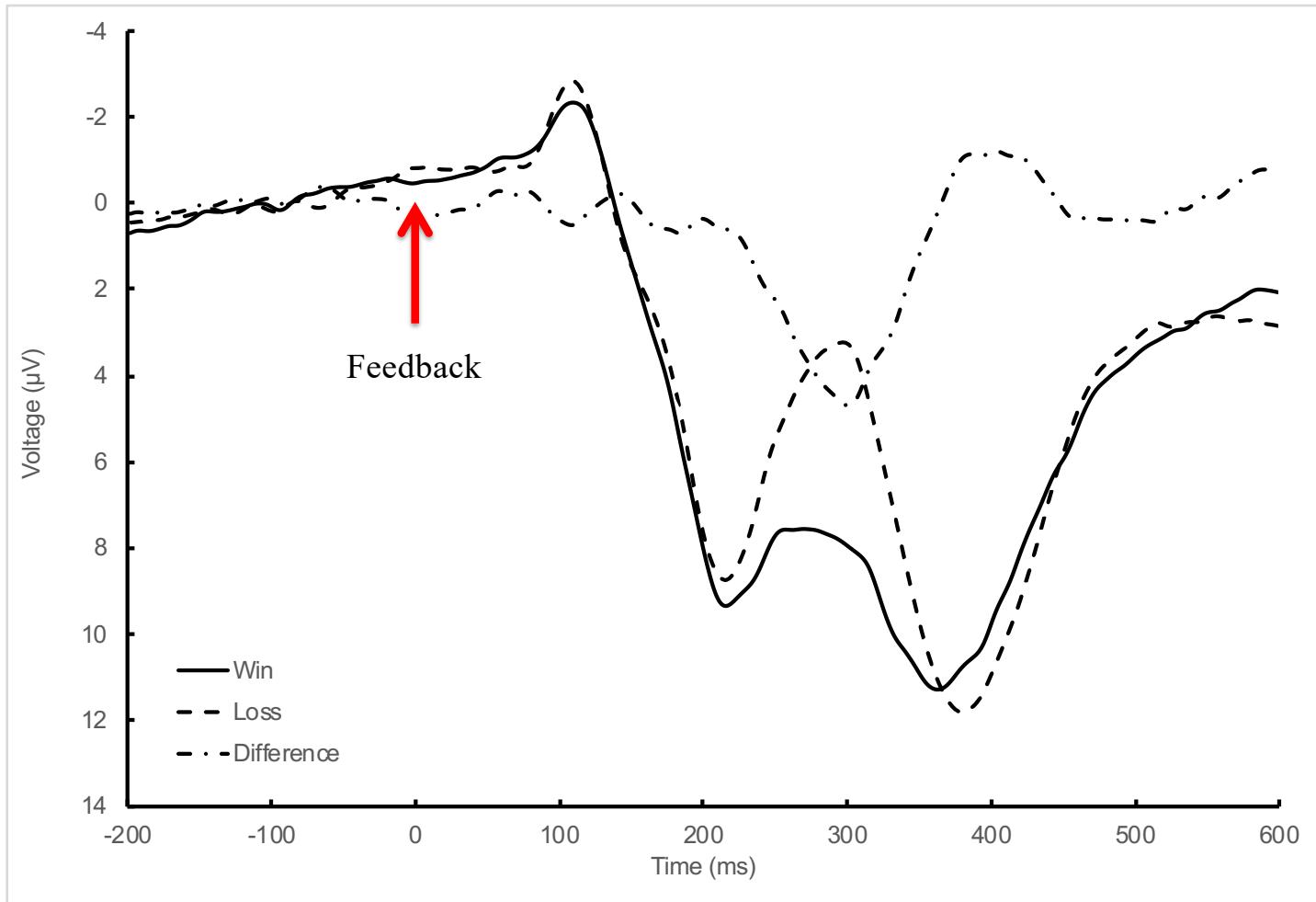
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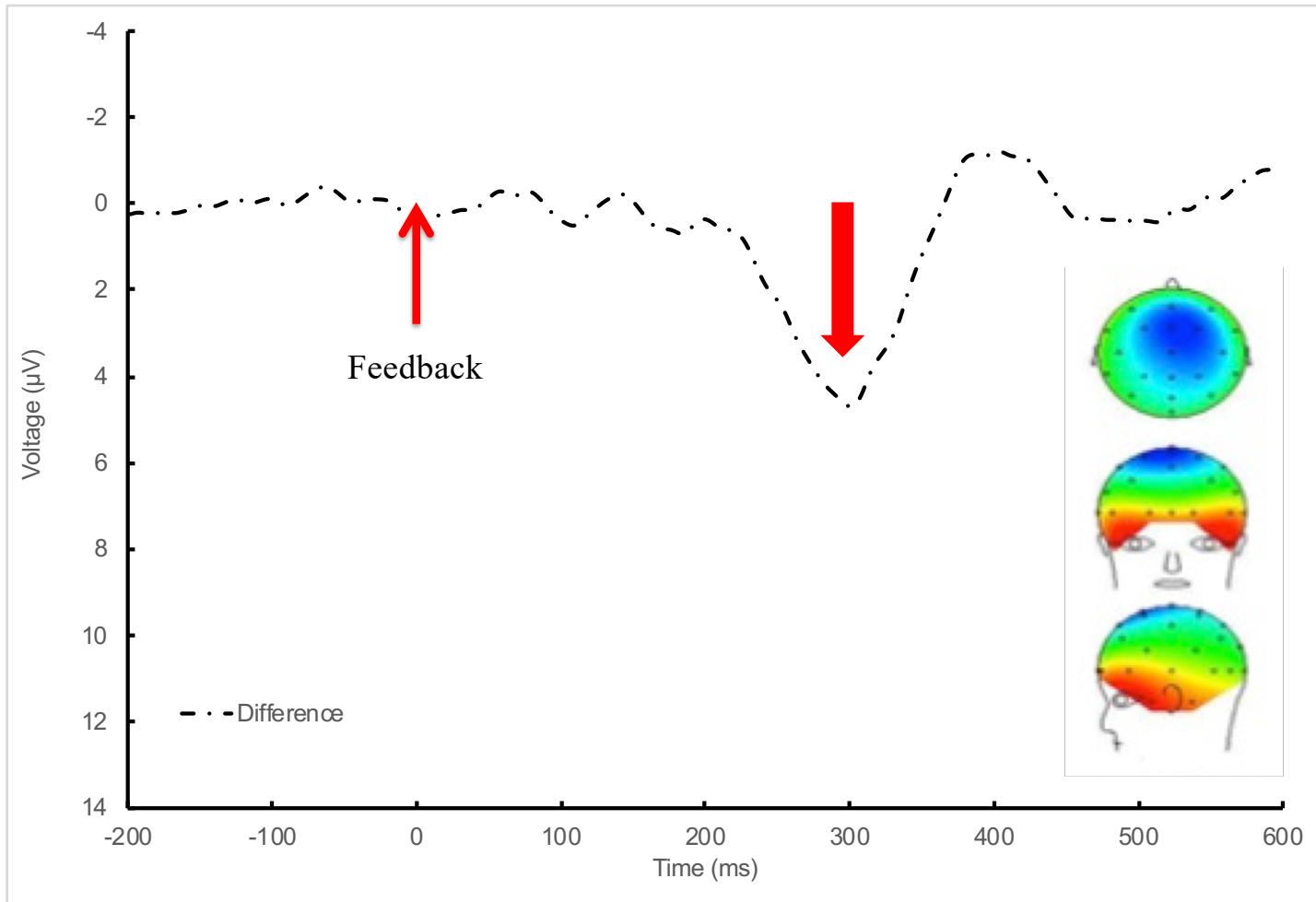


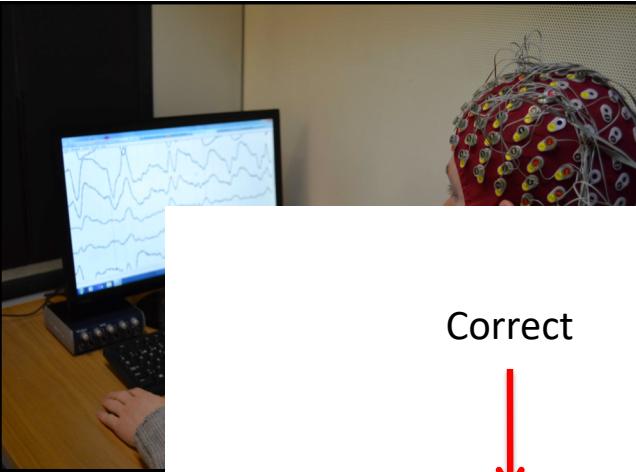
Correct!



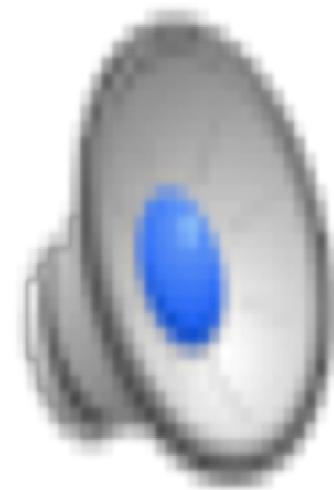


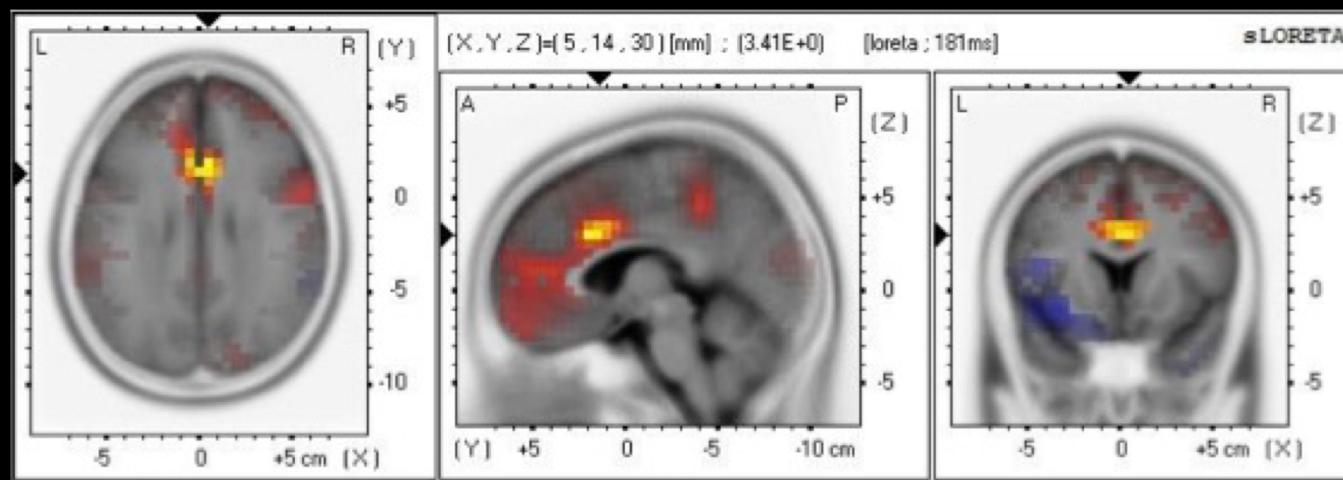
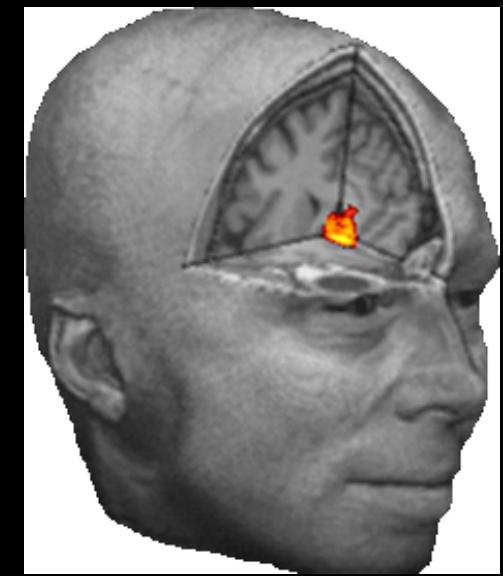
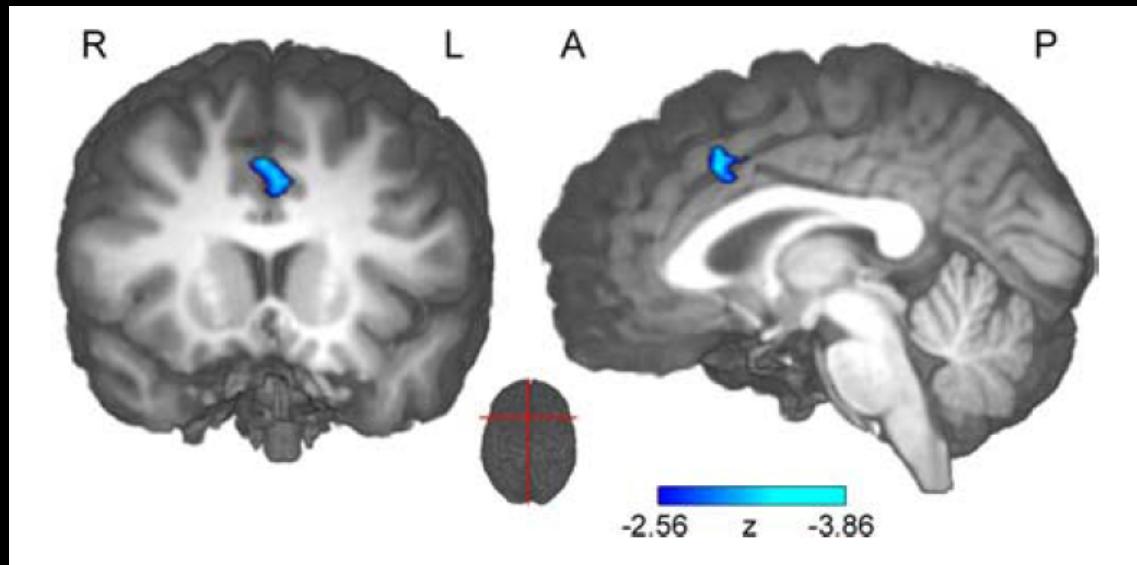






Correct



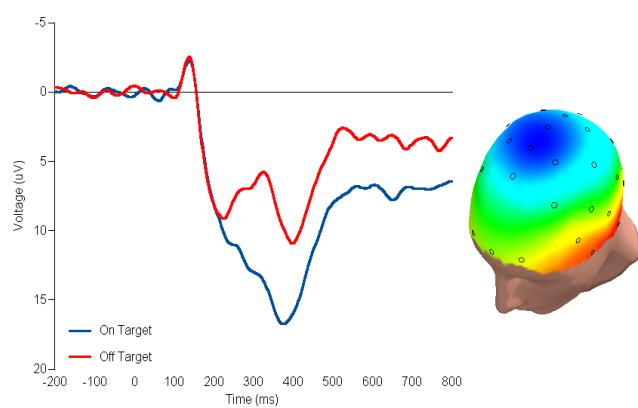




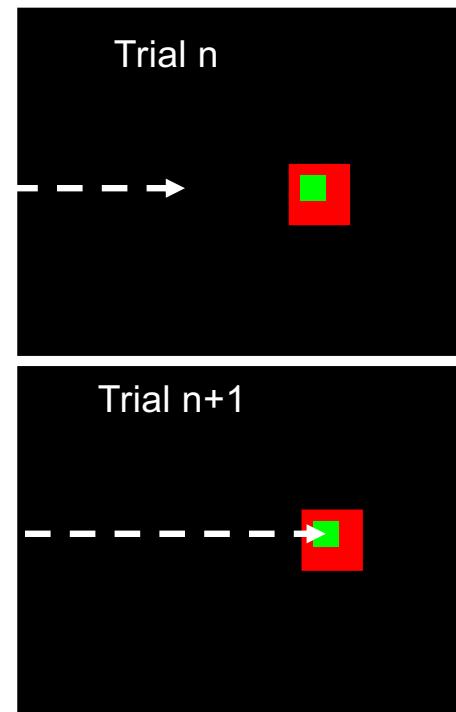
- Hands
 - Feet
 - Visual
 - Auditory
 - Somatosensory
- } error responses
- } error feedback

Miltner et al., 1997; Holroyd et al., 1998

Modification of Behaviour

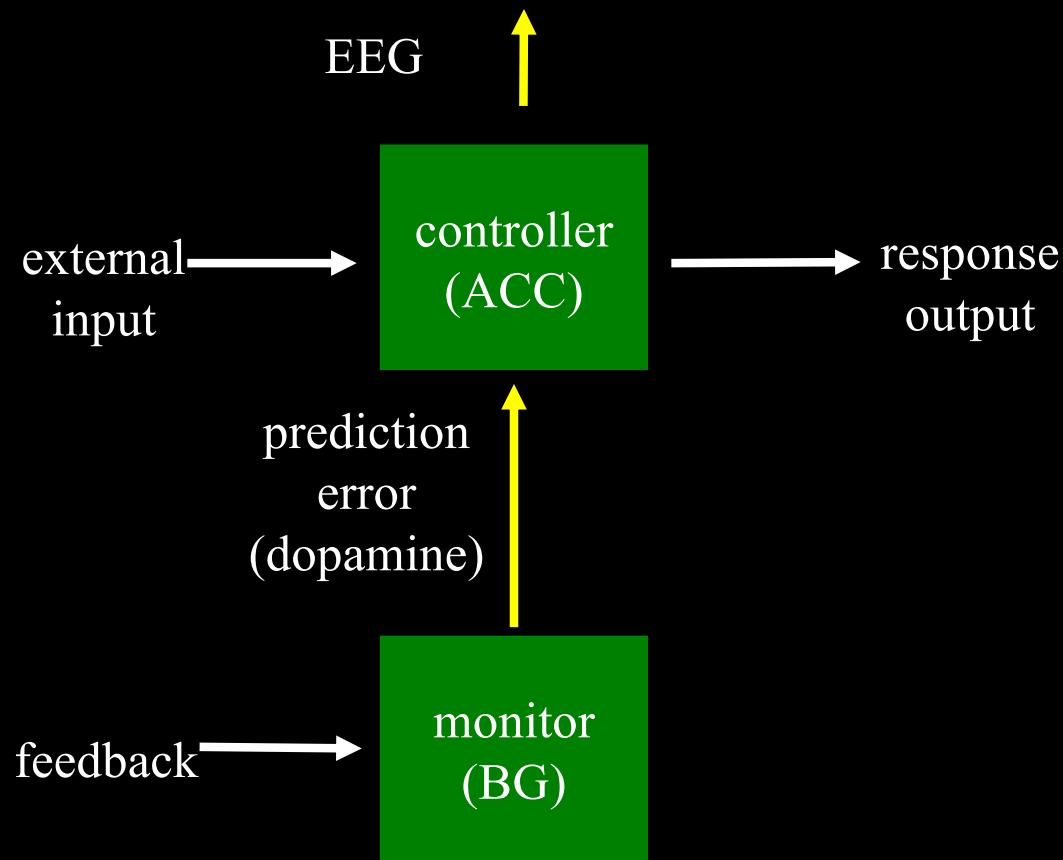


Δ Movement Amplitude

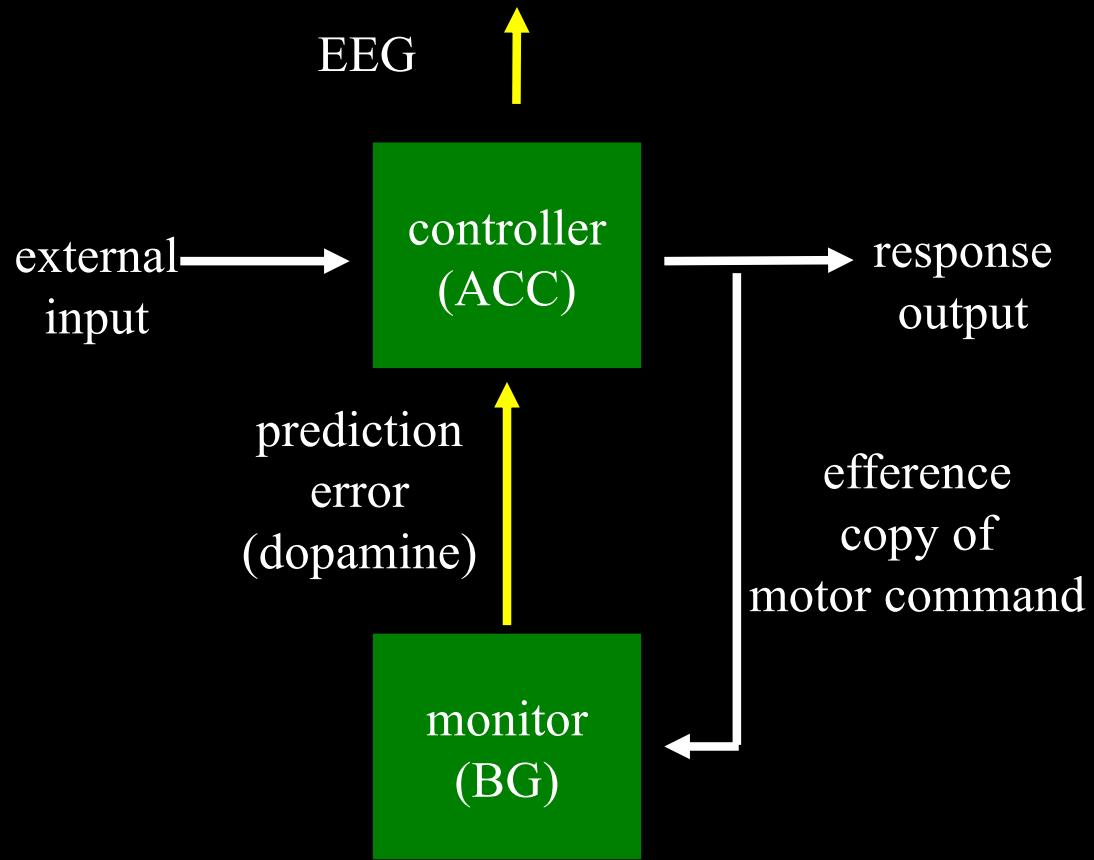




(Holroyd & Coles, 2002)

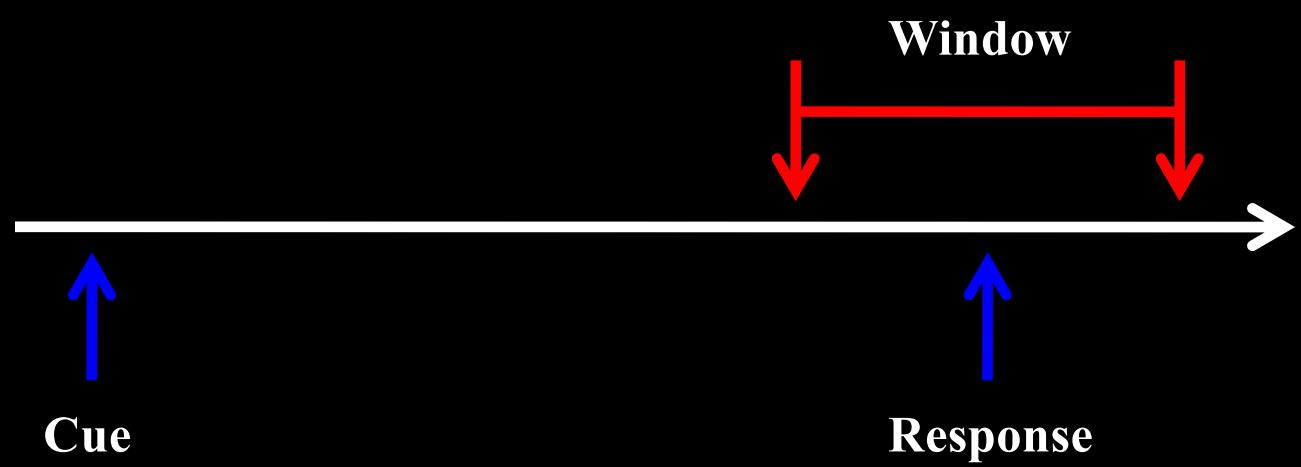


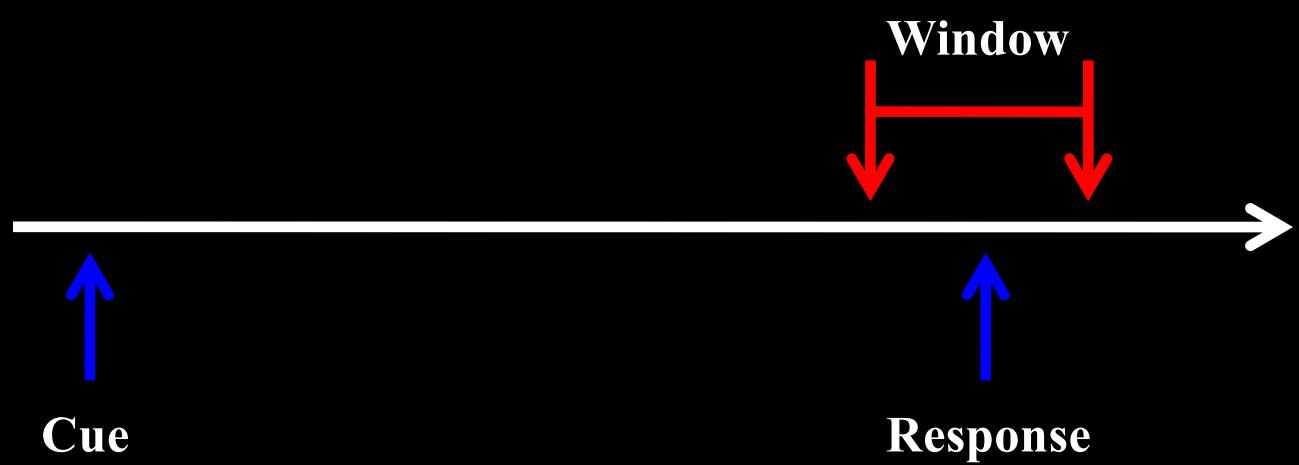
(Holroyd & Coles, 2002)

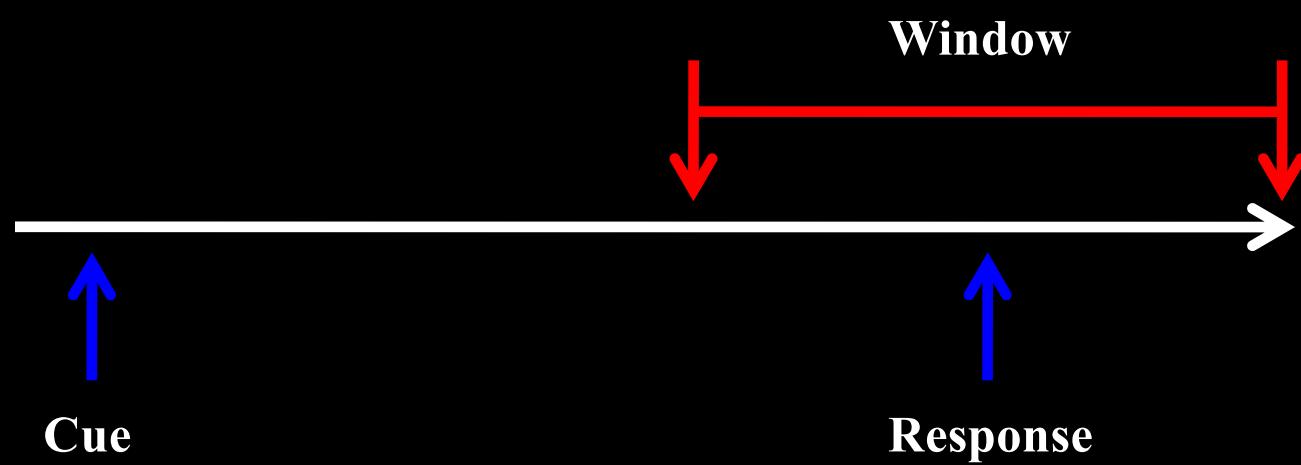


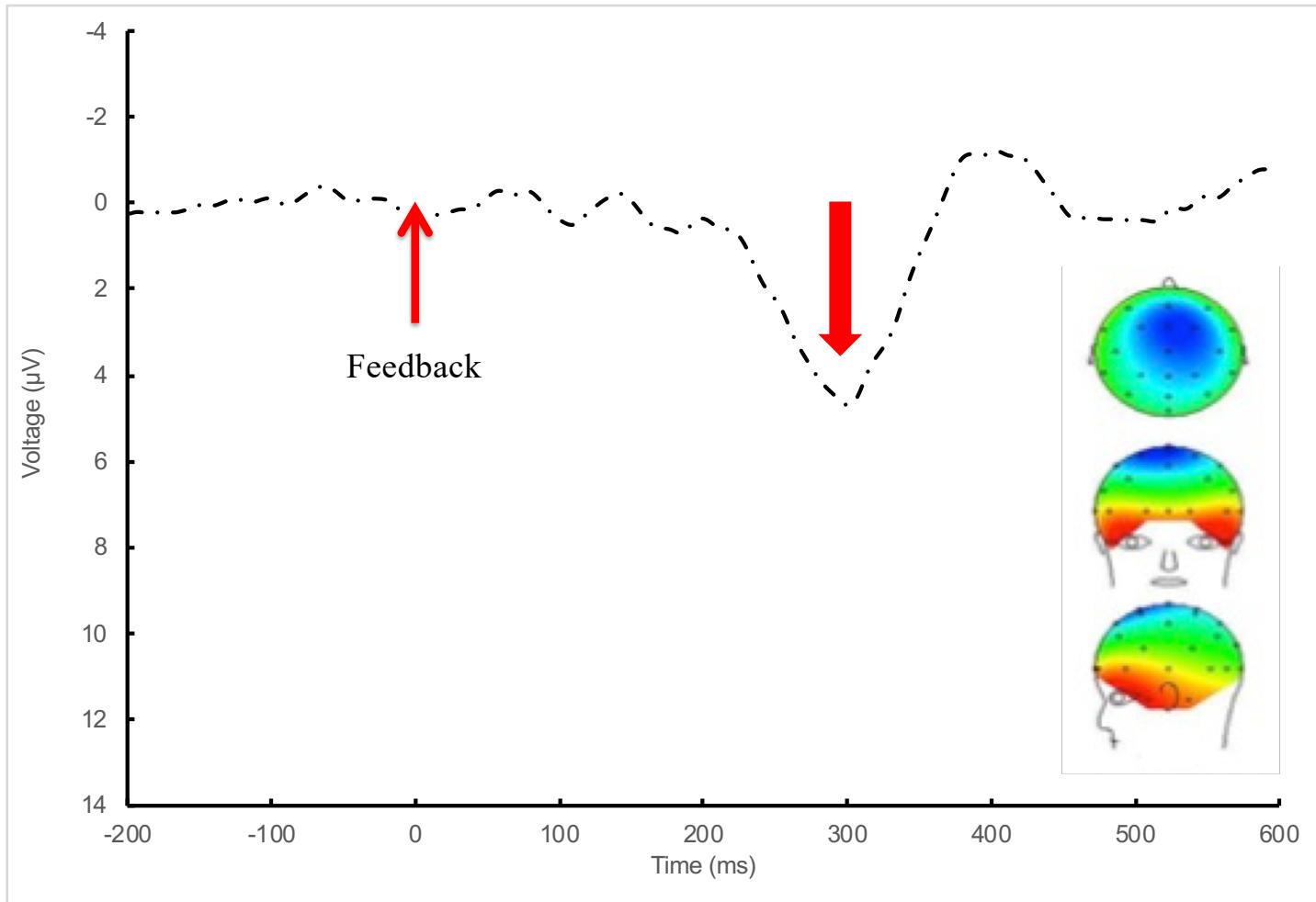
(Holroyd & Coles, 2002)

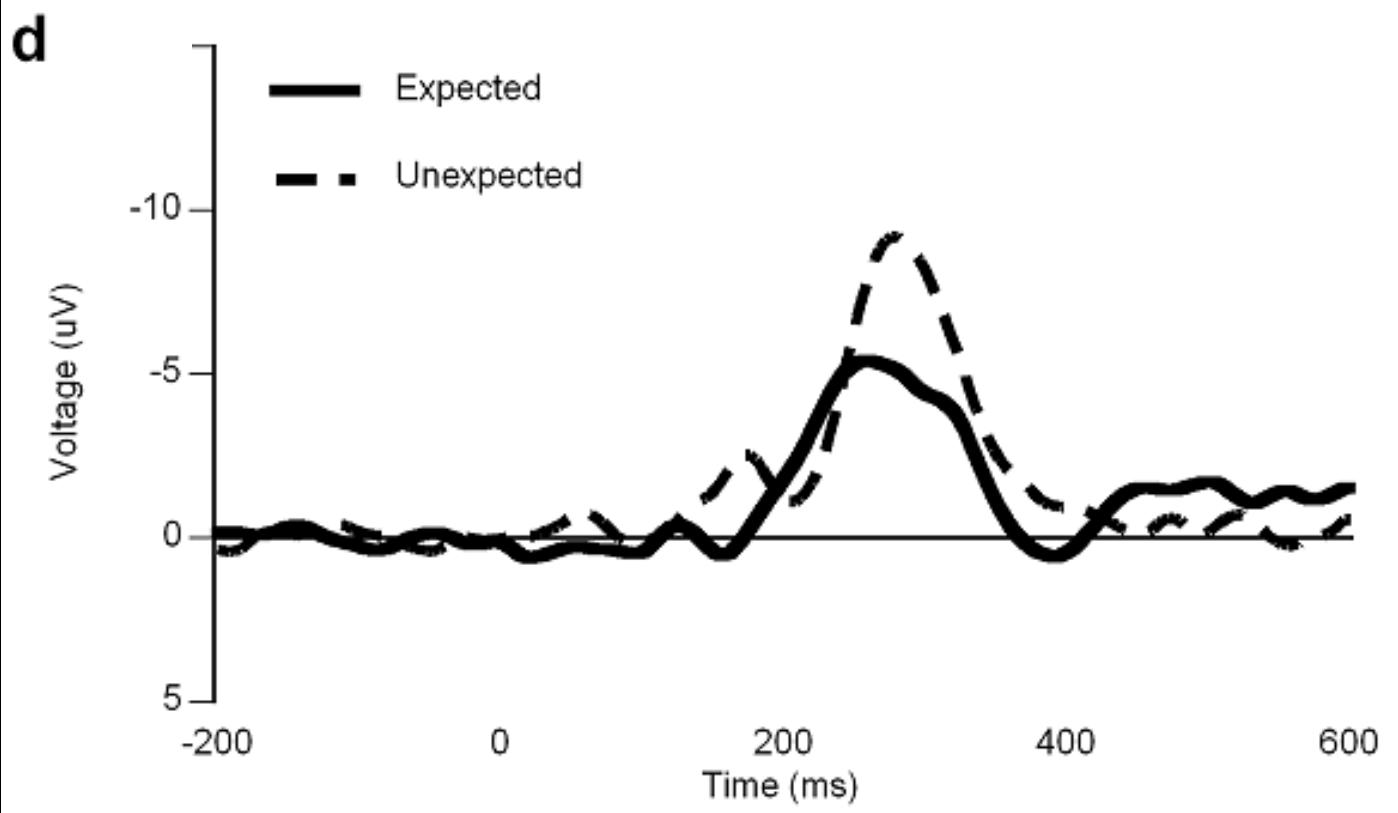
Chasing Theory











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Krigolson et al., 2009



Krigolson et al., 2009



A

Krigolson et al., 2009

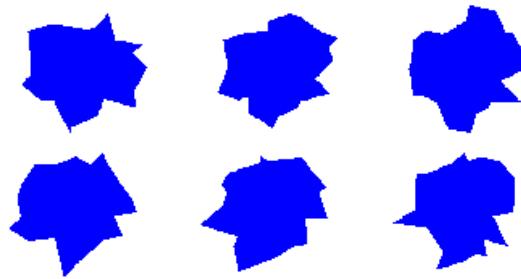
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Krigolson et al., 2009

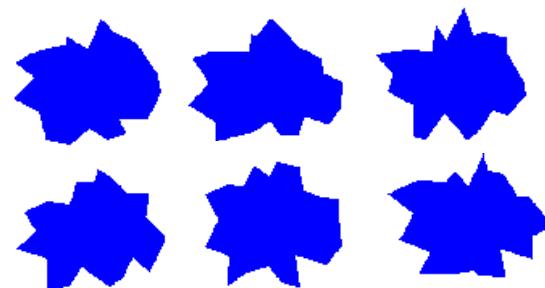
Correct!

Krigolson et al., 2009

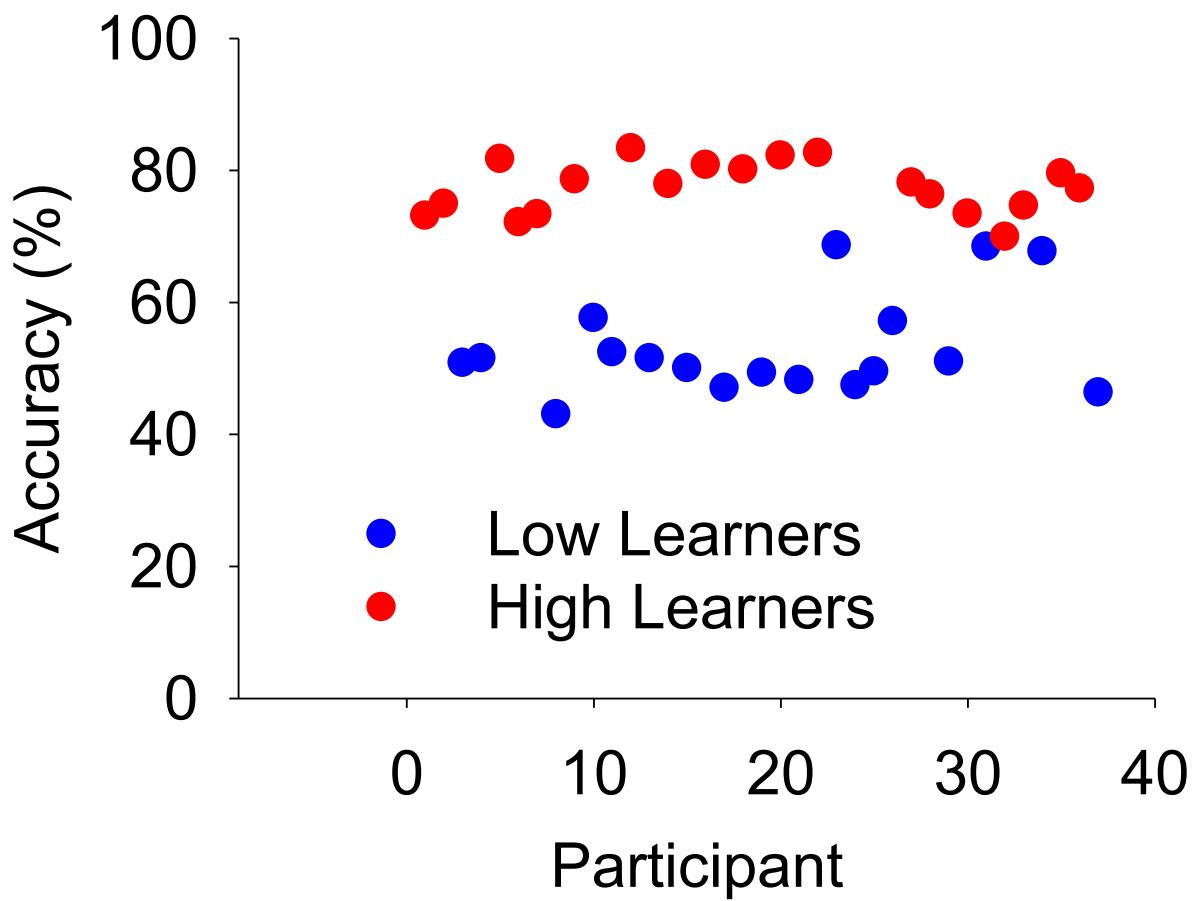
A Family Blobs



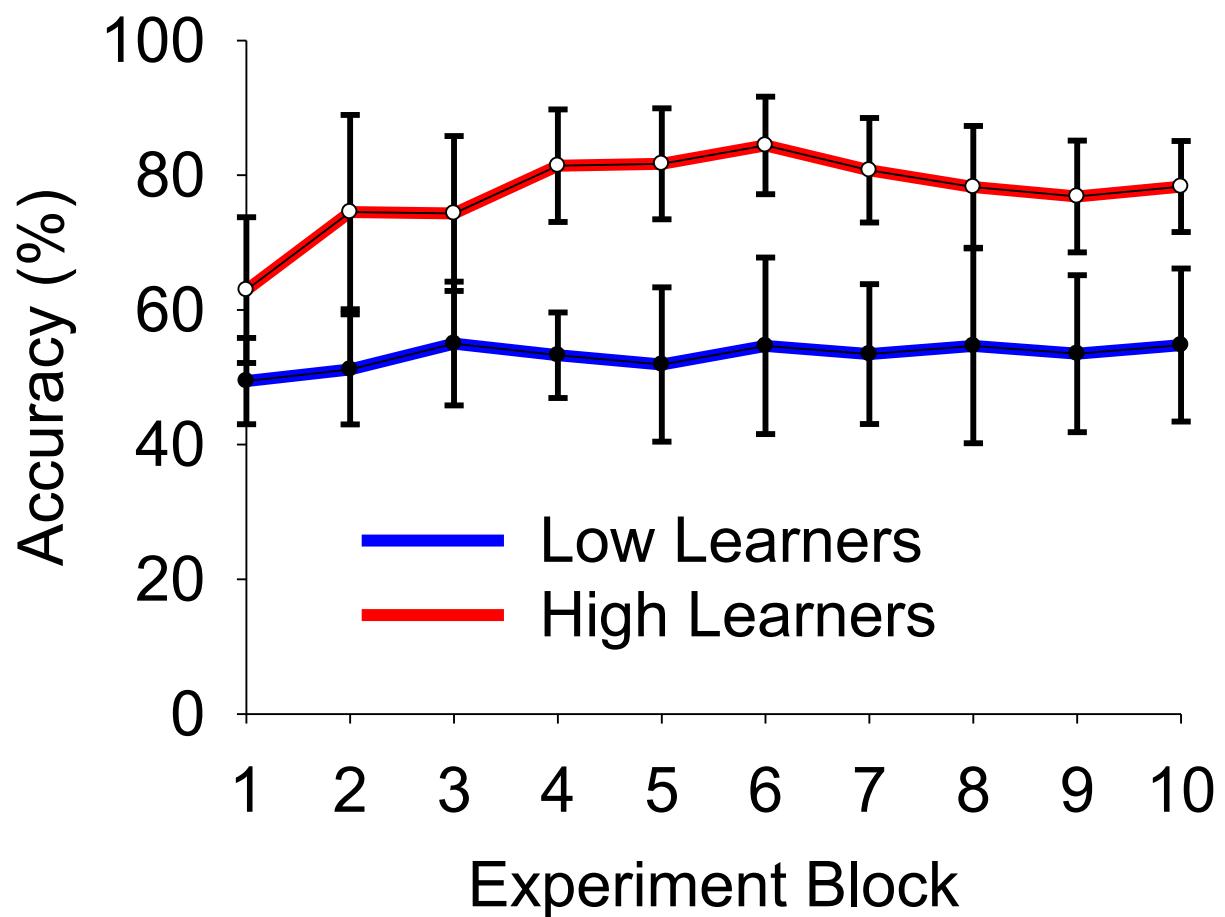
B Family Blobs

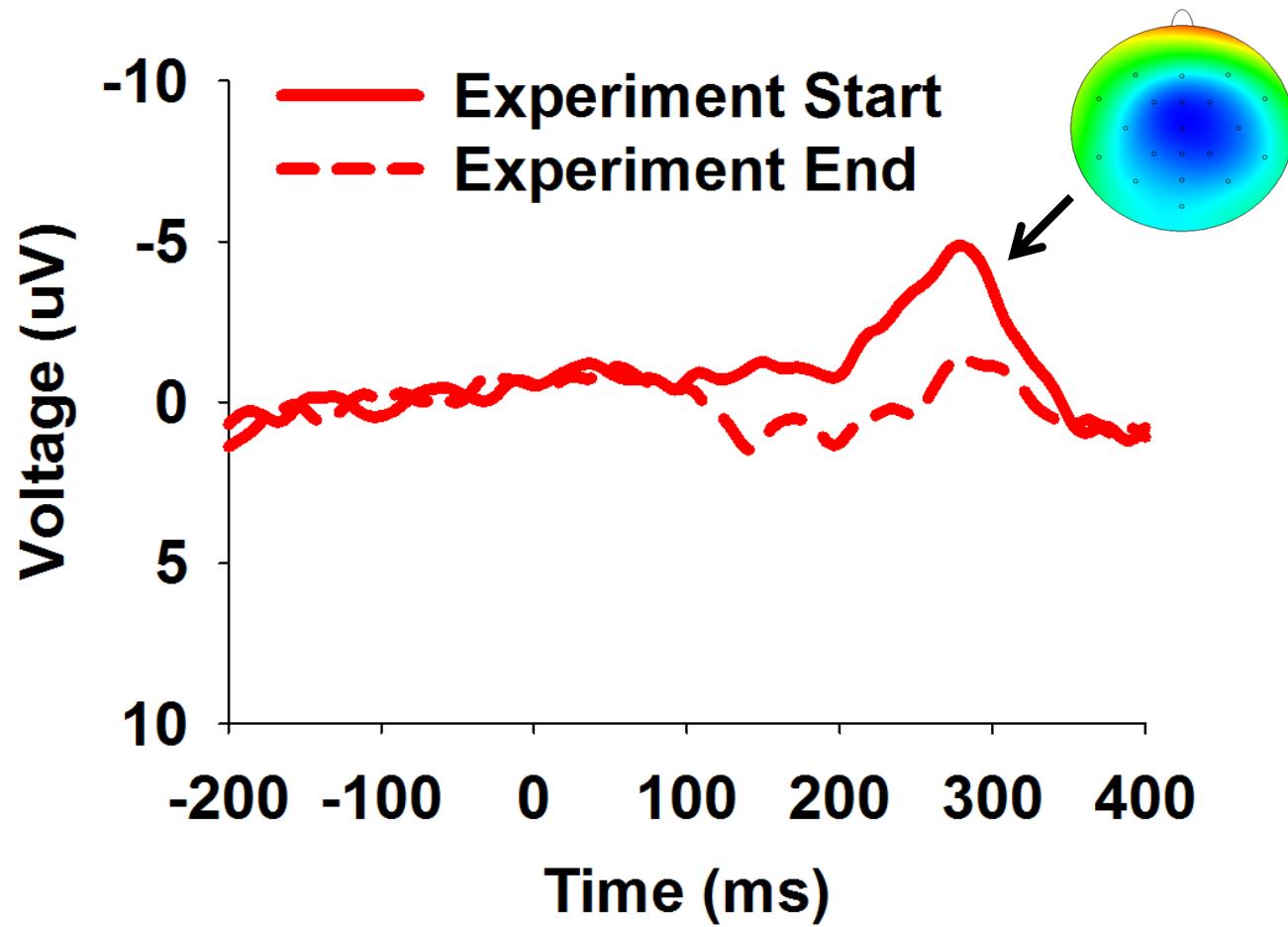


Krigolson et al., 2009



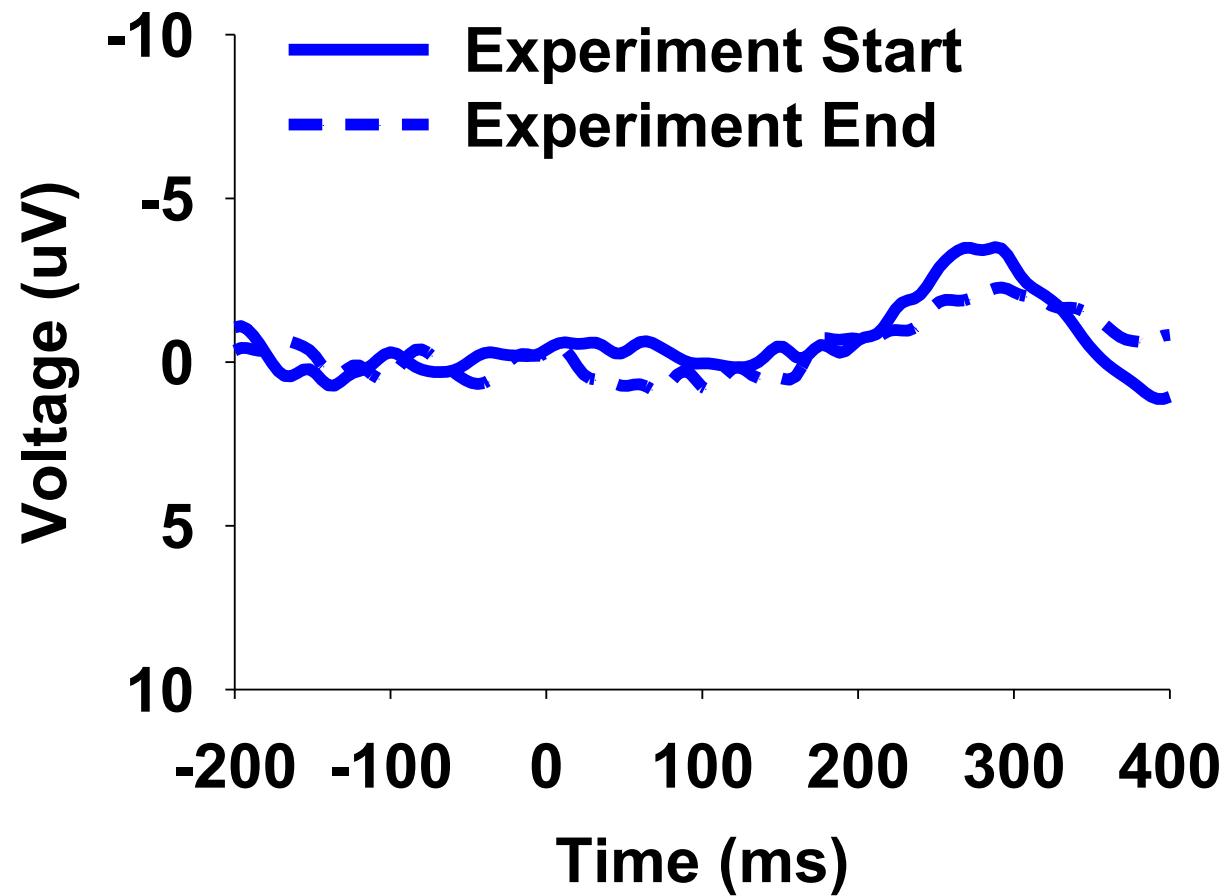
Krigolson et al., 2009





High Learners

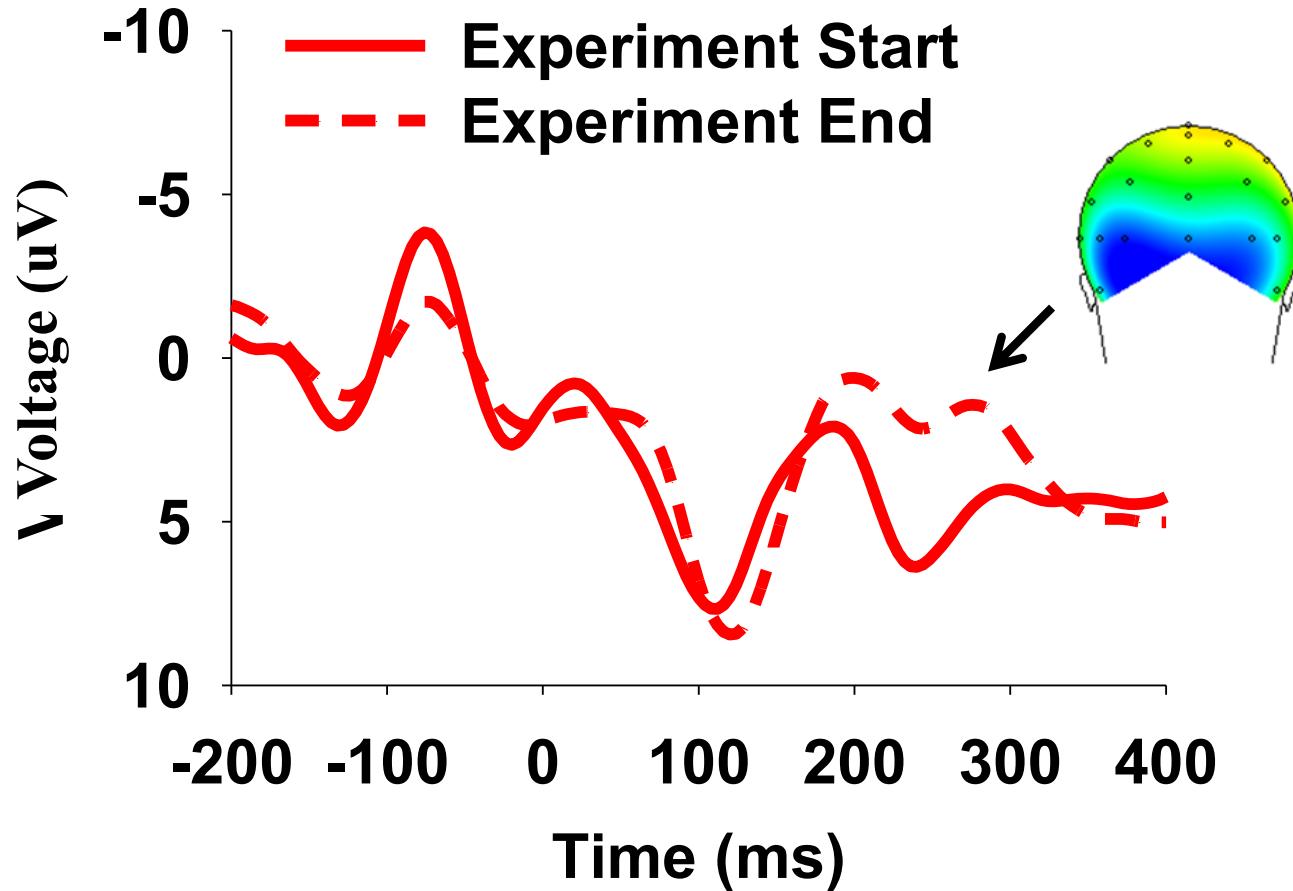
Krigolson et al., 2009



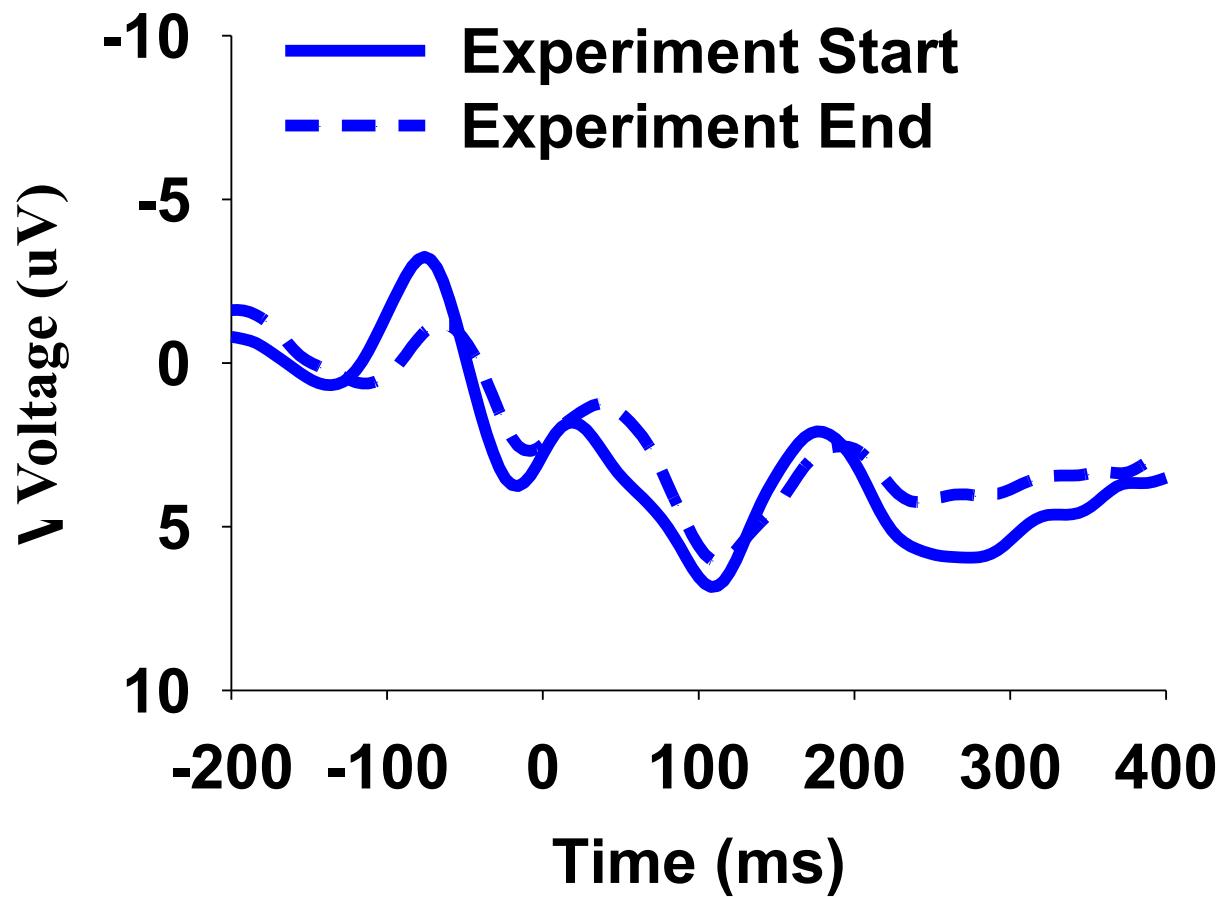
Low Learners

Krigolson et al., 2009





High Learners

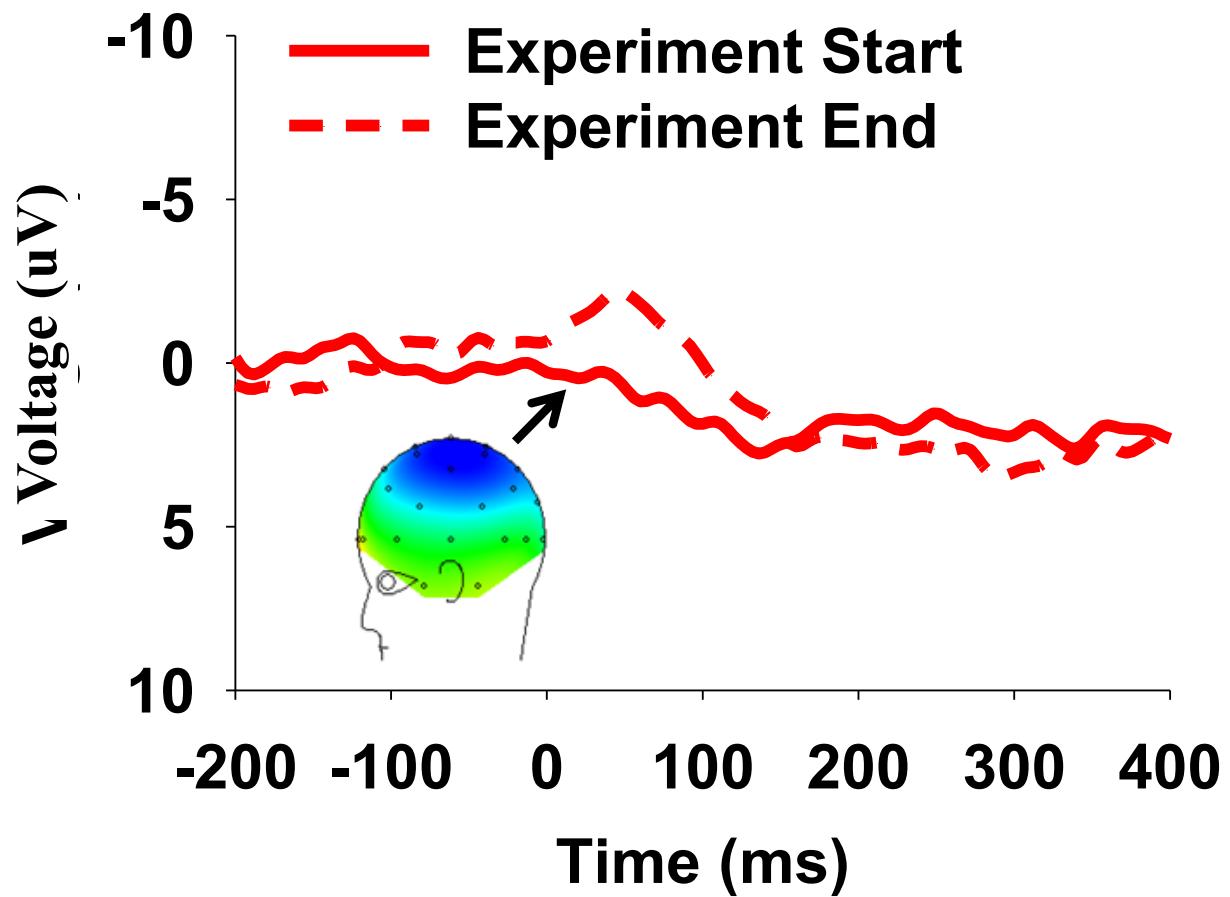


Low Learners

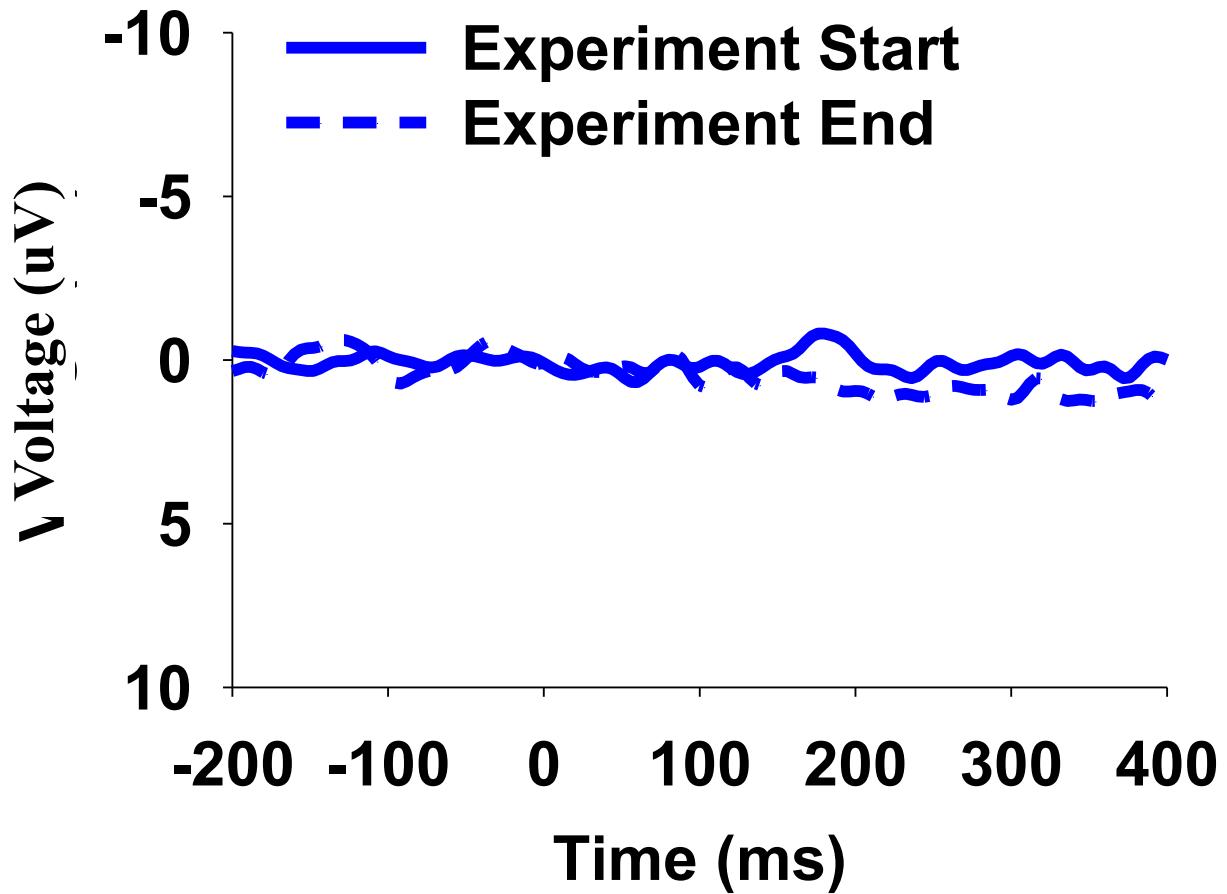


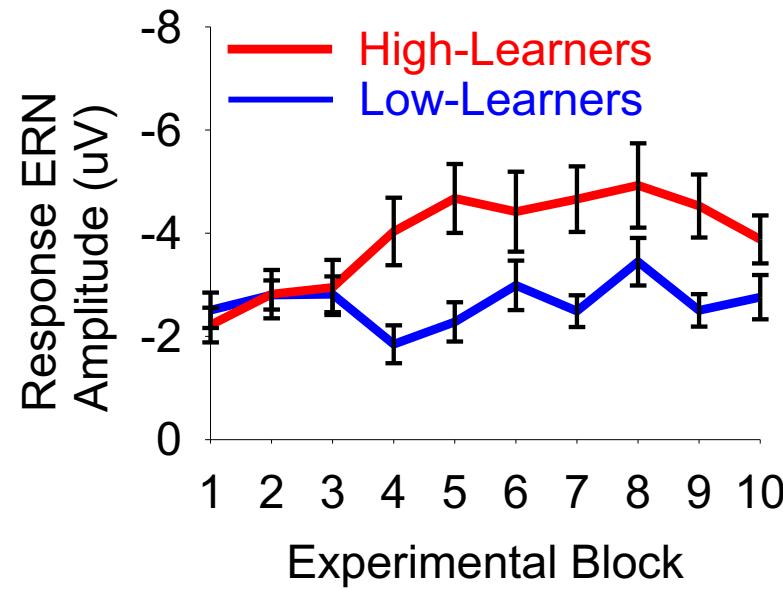
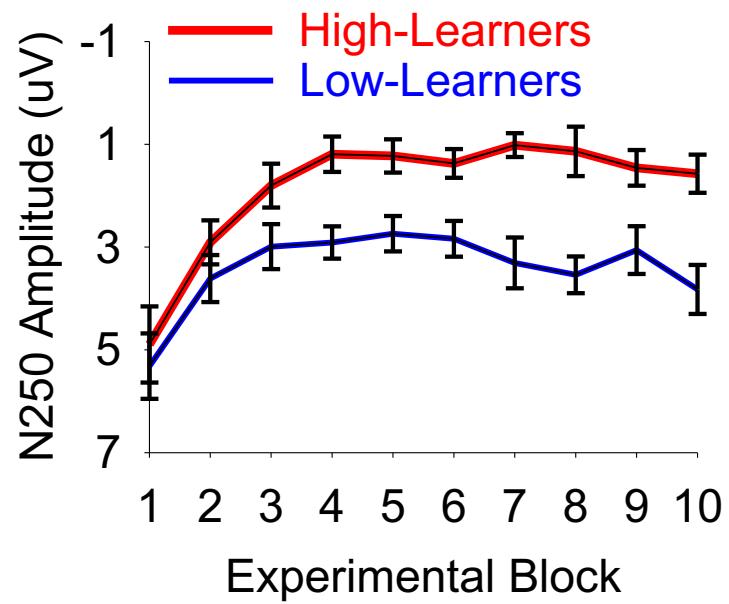
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High Learners

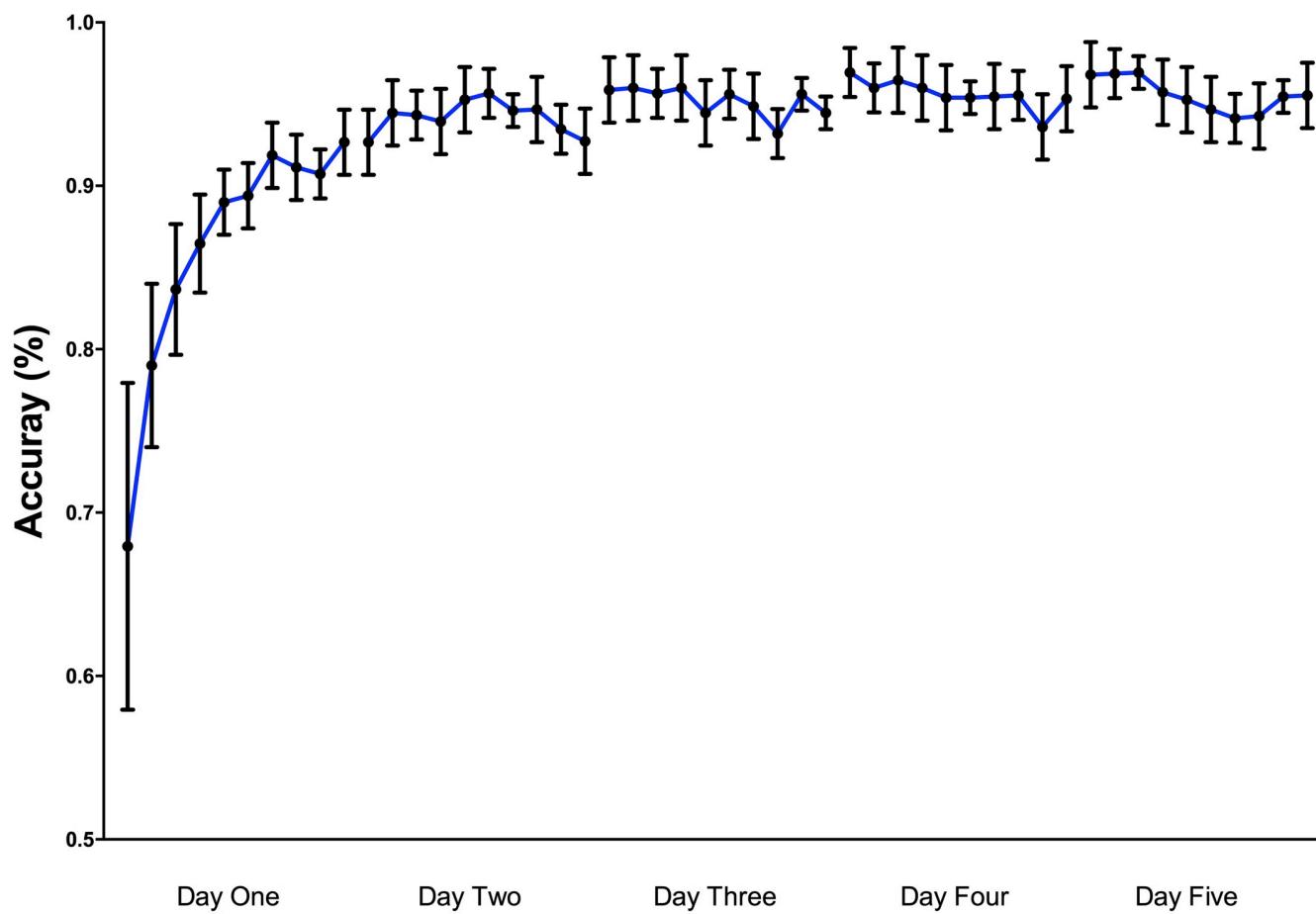


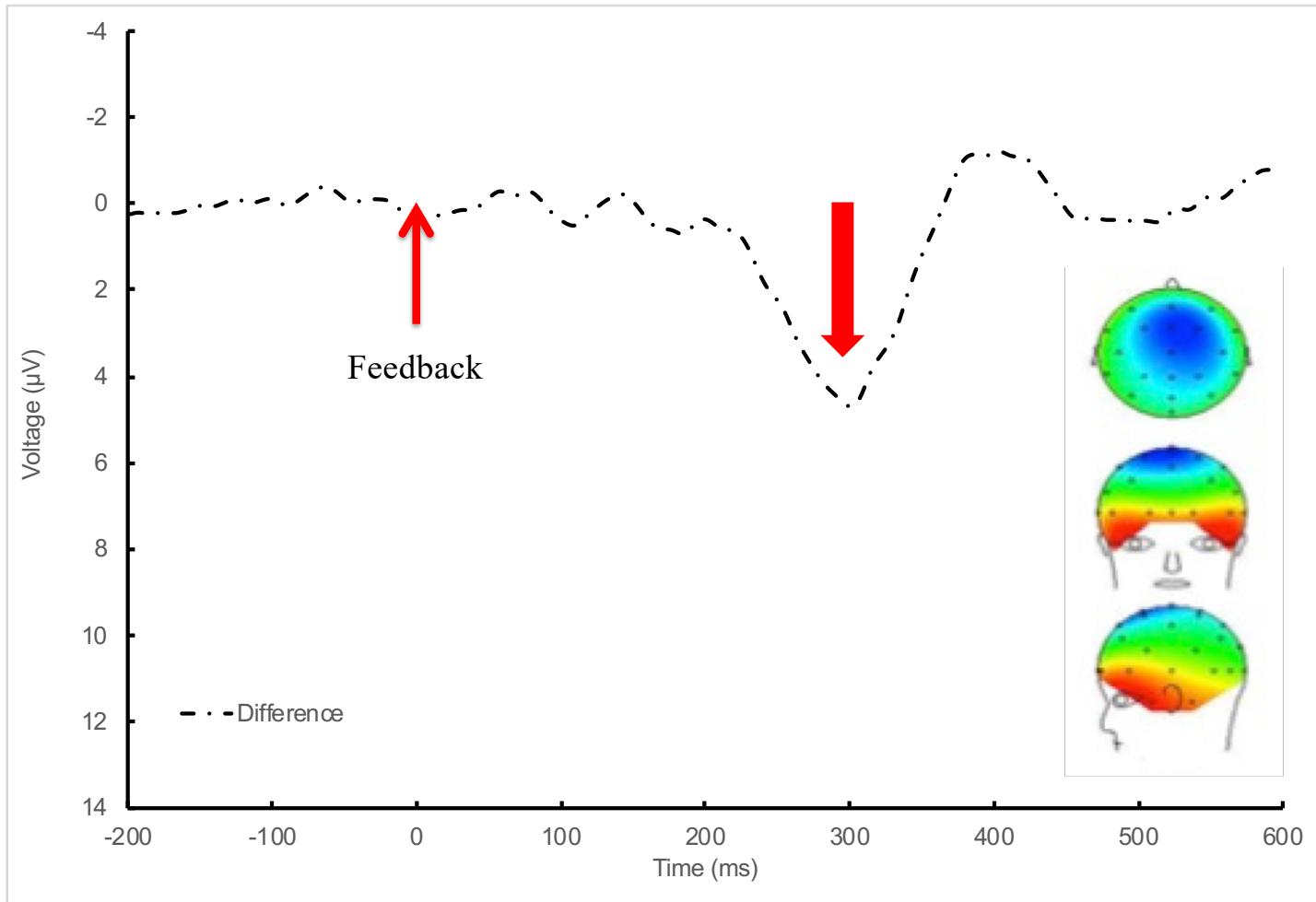


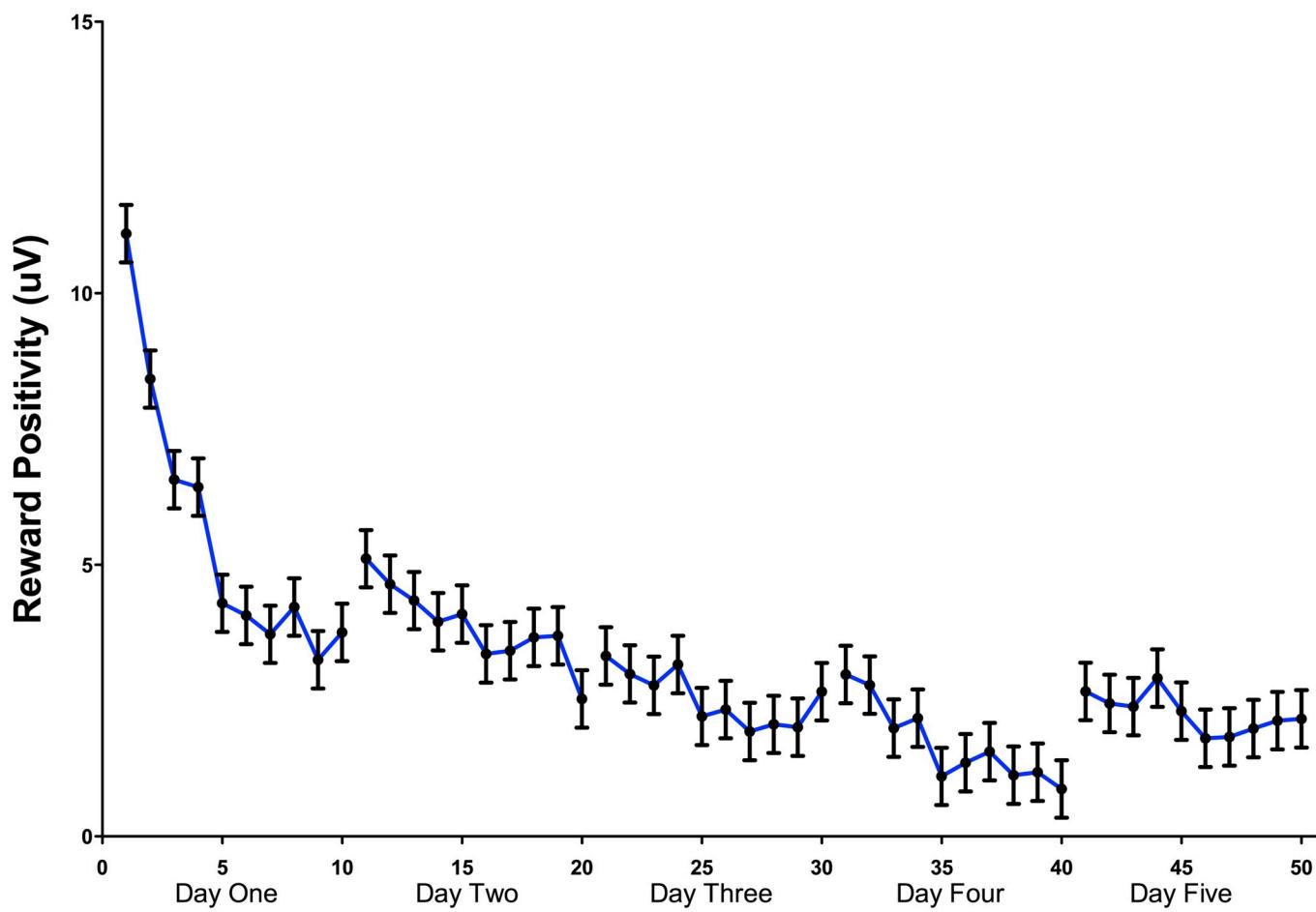
More Blobs

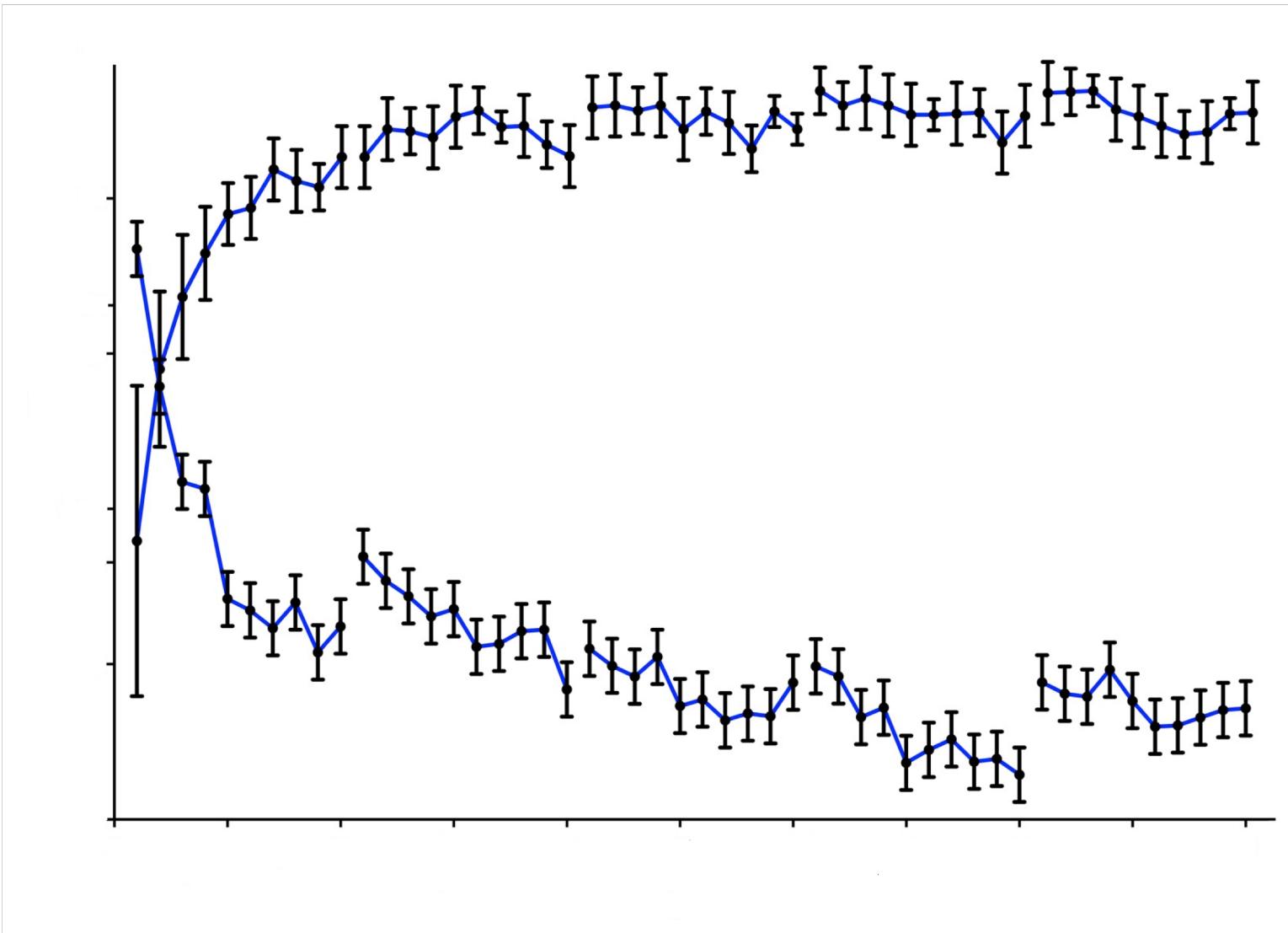


A



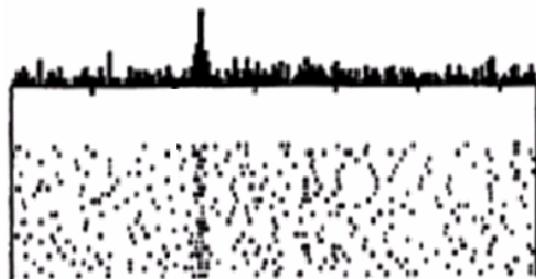






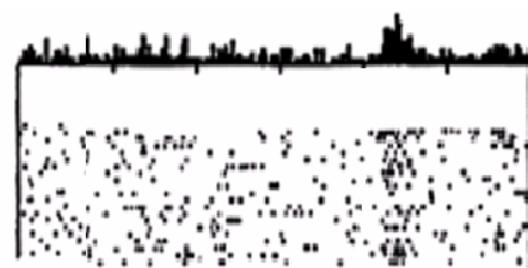
Propagation of Prediction Errors

Cue Rew



After Learning

Cue Rew

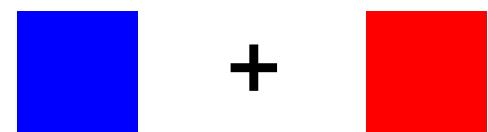


Before Learning

Schultz et al., 1997

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Krigolson et al., 2014



Krigolson et al., 2014



Krigolson et al., 2014

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Krigolson et al., 2014

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Krigolson et al., 2014

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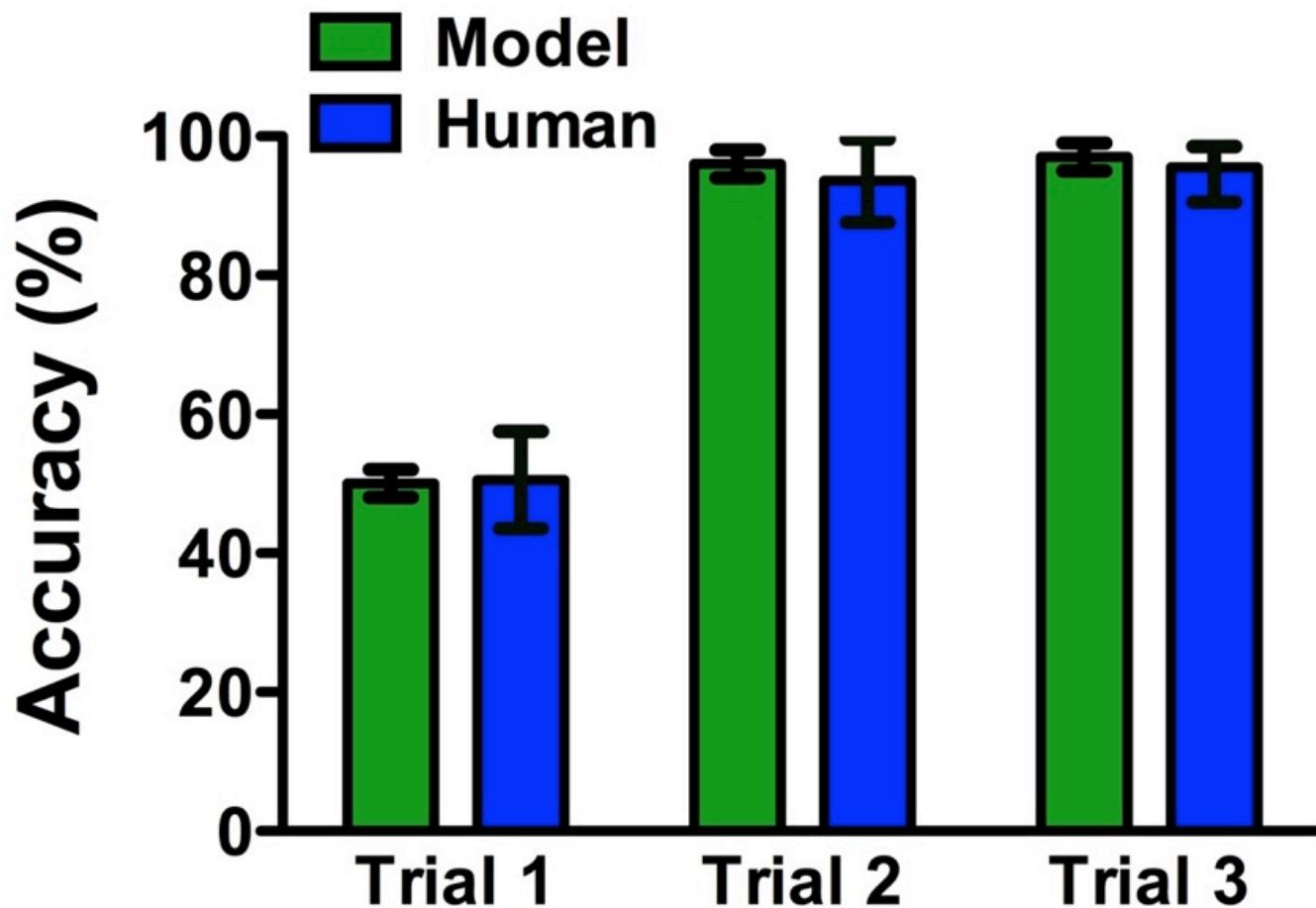
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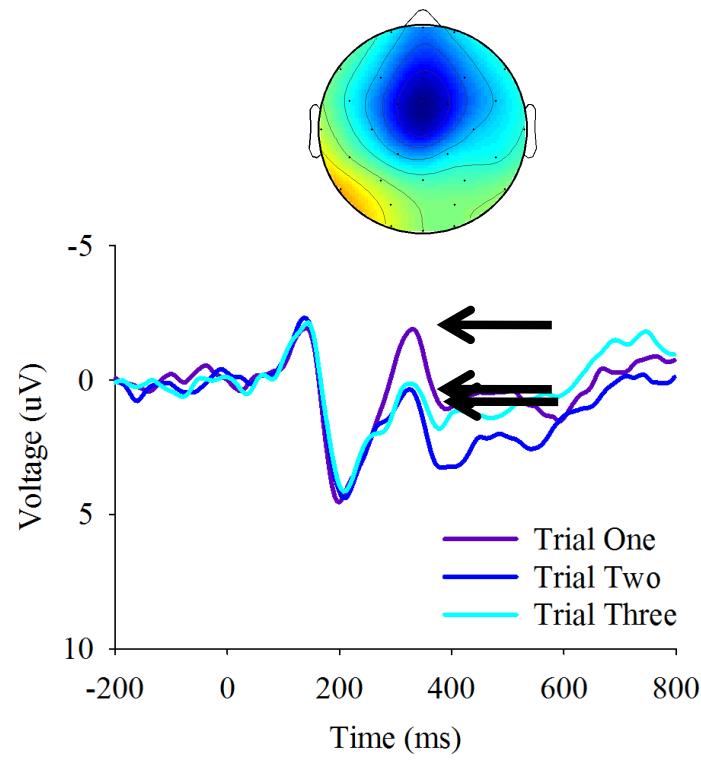
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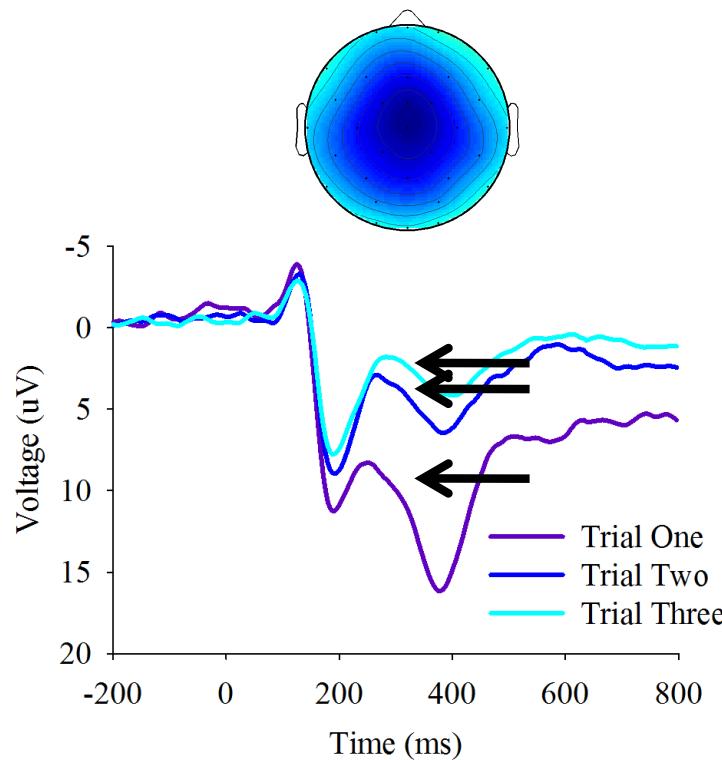
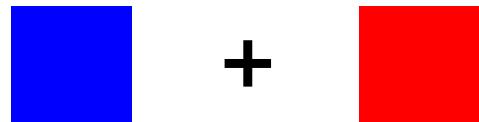
Krigolson et al., 2014



Krigolson et al., 2014



Stimulus Averaged
ERP Waveforms

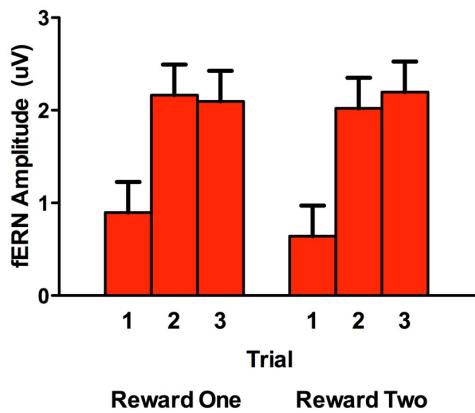


Feedback Averaged
ERP Waveforms

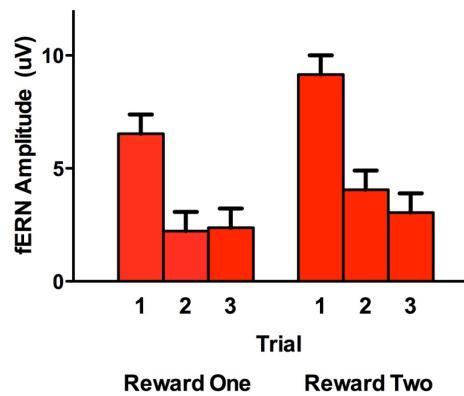
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Krigolson et al., 2014

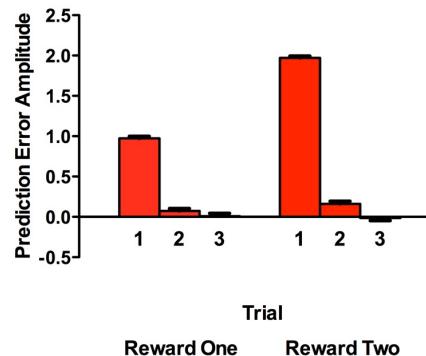
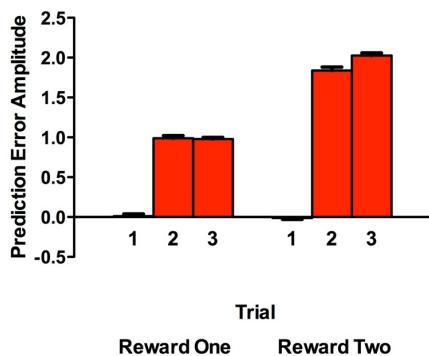
Choice Presentation



Reward Delivery



DATA



MODEL

Krigolson et al., 2014