Symbol Fun: ACT-R's Brain Changes with Practice

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ACT-R 5.0

Intentional Module
(not identified)

Declarative Module
(Temporal/Hippocampus)

Goal Buffer
(DLPFC)

Retrieval Buffer
(VLPFC)

Productions
(Basal Ganglia)

Matching (Striatum)

Selection (Pallidum)

Execution (Thalamus)

Visual Buffer
(Parietal)

Manual Buffer
(Motor)

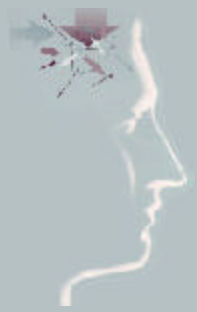
Visual Module
(Occiptal/etc)

Manual Module
(Motor/Cerebellum)

Environment

Brain Imaging to Track ACT-R Modules

1. Functional Magnetic Resonance Imaging (fMRI) tracks the brain's metabolic expenditures. It allows relatively high spatial resolution but poor temporal resolution. Good for tracking ACT-R components
2. Event-Related potentials (ERP) track the indicating brain's electrical activity. They offer poor spatial resolution but high temporal resolution and are relatively non-intrusive. Good for tracking ACT-R dynamics (maybe). With the localization provided by fMRI they offer the promise of tracking the detail of brain function.
3. I will show some results from an fMRI study of college students solving problems in a new algebra. We are now collecting data on children (11-14 years) learning high-school algebra



Symbolic Reasoning Experiment
Based on Blessing & Anderson (1996)

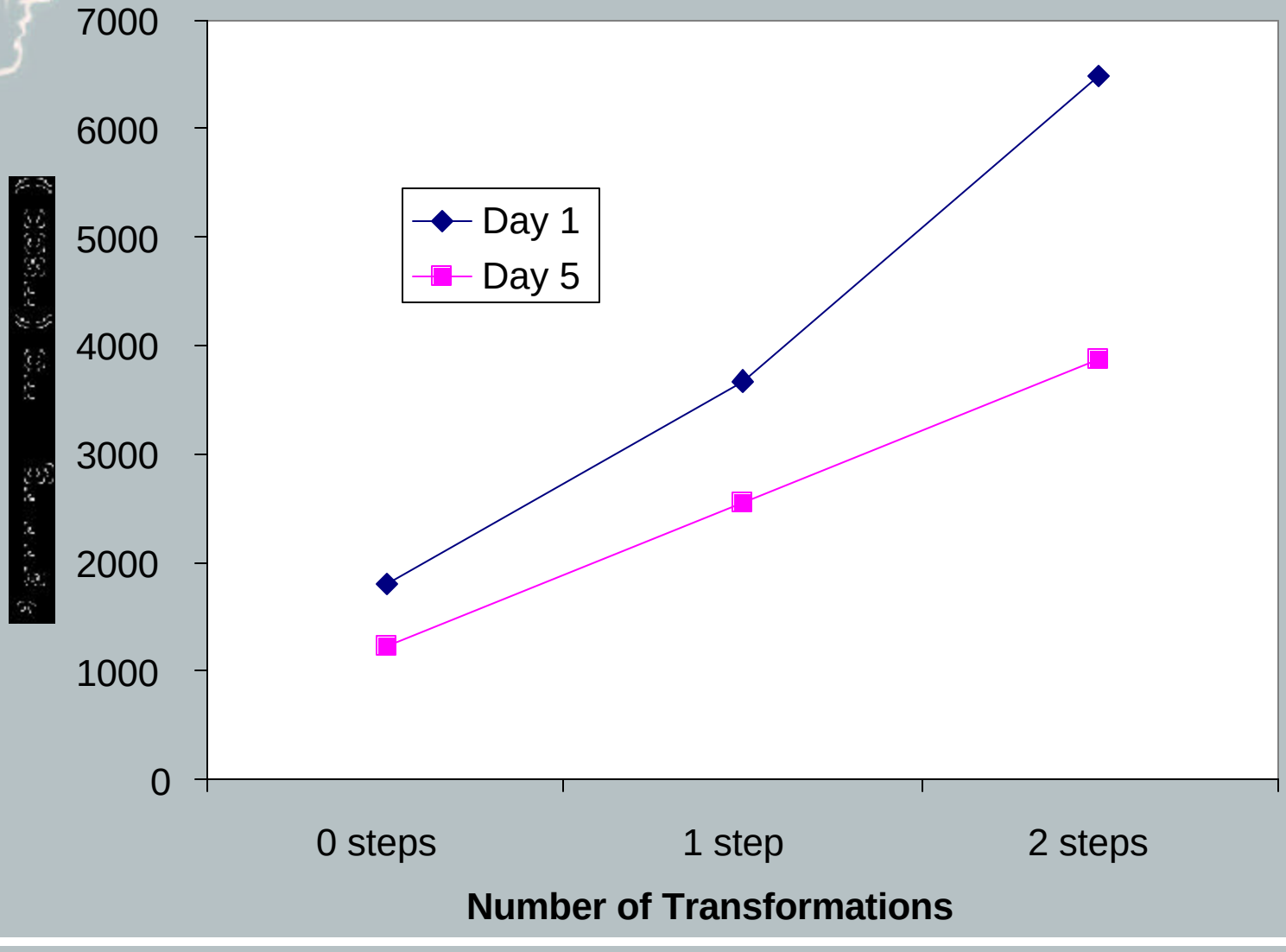
Example of equations:

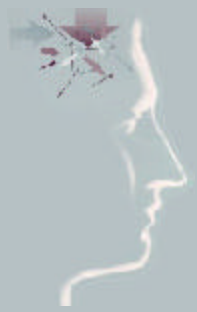
step	equation	answer
0 step	**P** <-> ¬4 ¬5	**P** <-> ¬4 ¬5
1 step	¬**P** <-> ¬4 ¬5	**P** <-> ¬4 ¬5
2 step	¬**P** ¬4 <-> ¬5	**P** <-> ¬5 ¬4

Subject types answer by pressing thumb and then key the 4 terms in the answer as fast as they can.

Practice Task 5 days; imaged on 1st and 5th day

Decrease Produced by ACT-R base-level Learning

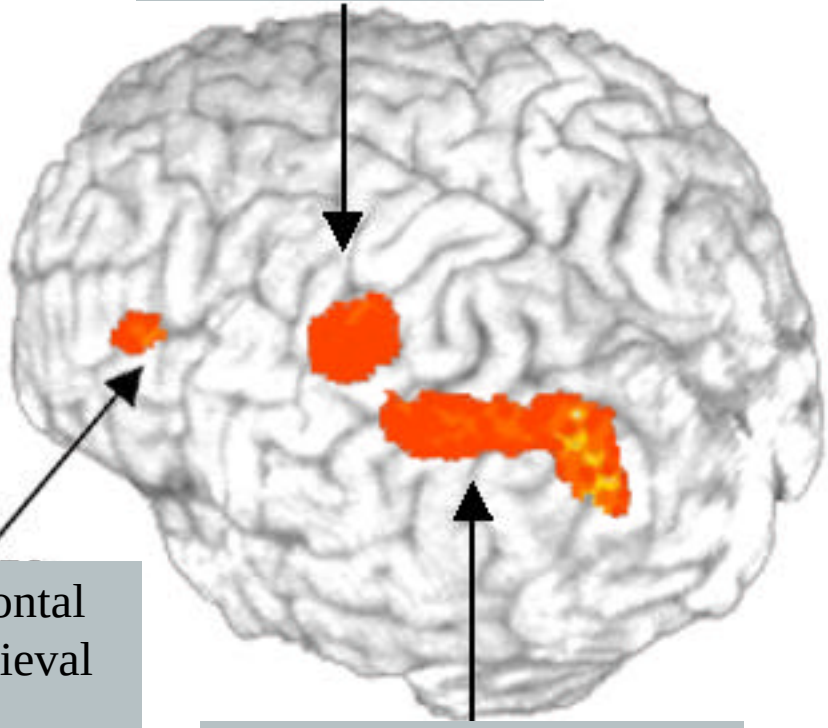




ACT-R Buffer Activity during Solution of 3 **P** <=> ✍3✍4

Motor – tracks manual execution

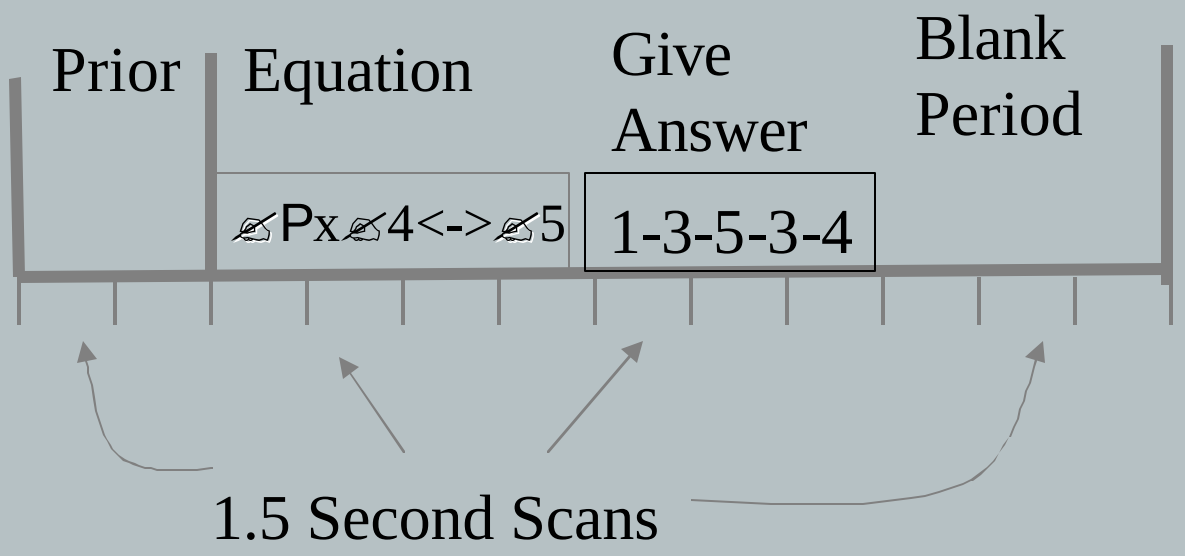
Basal Ganglia – tracks the learning of new rules



Ventrolateral Prefrontal Cortex – tracks retrieval of algebraic facts

Posterior Parietal— tracks transformations of equations

18 Second Structure of fMRI Trial



Basic proposal (Boyton, 1996; Dale & Buckner, 1997; Cohen, 1997) for the shape of fMRI response to an event t times units ago is:

$$B(t) \propto t^{a} e^{-t}$$

Observed fMRI response is integrated over time the buffer is active. Therefore

$$CB(t) = M \int_{0}^{t} i(x) B\left(\frac{t - x}{s}\right) dx$$

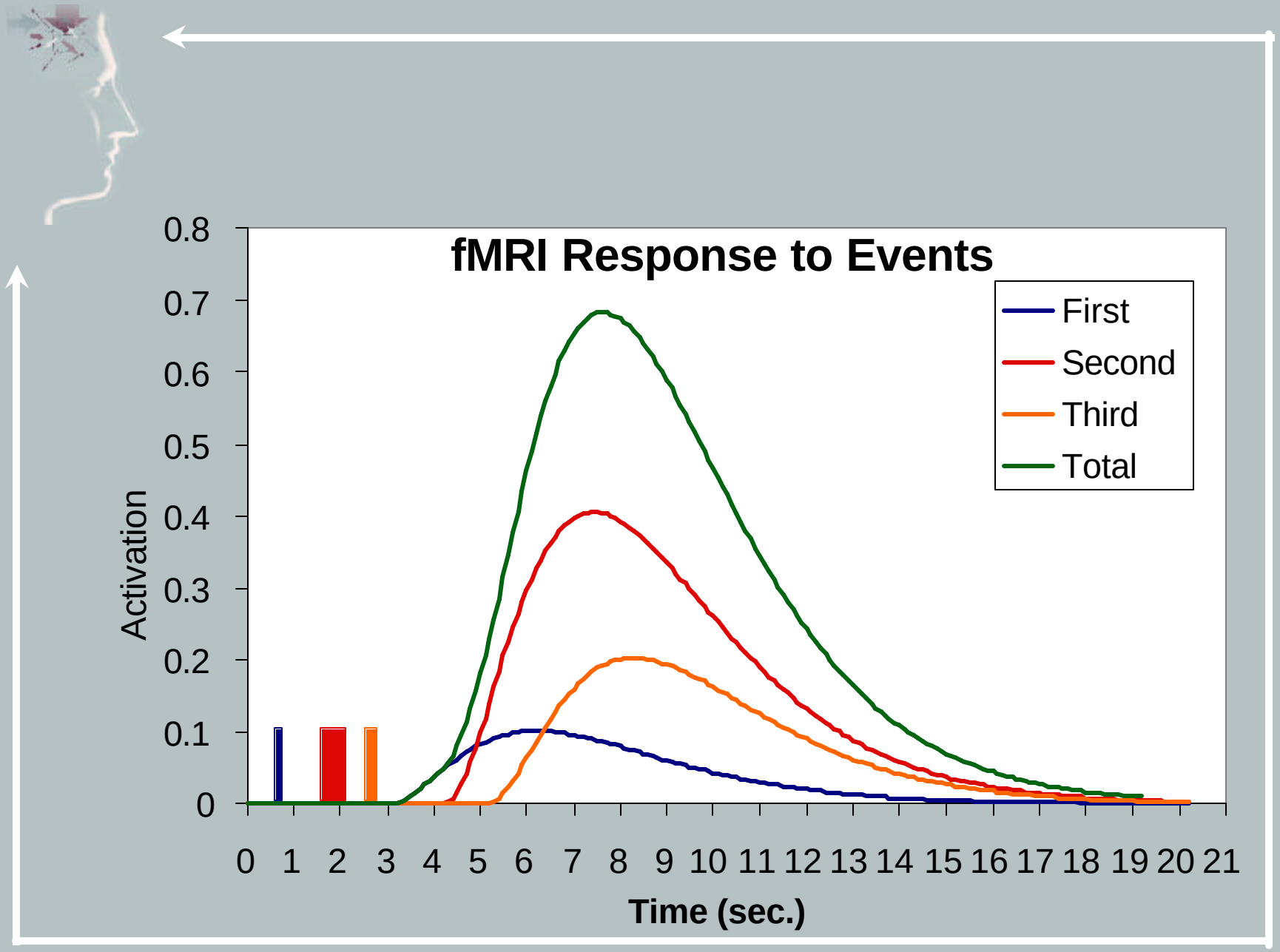
where

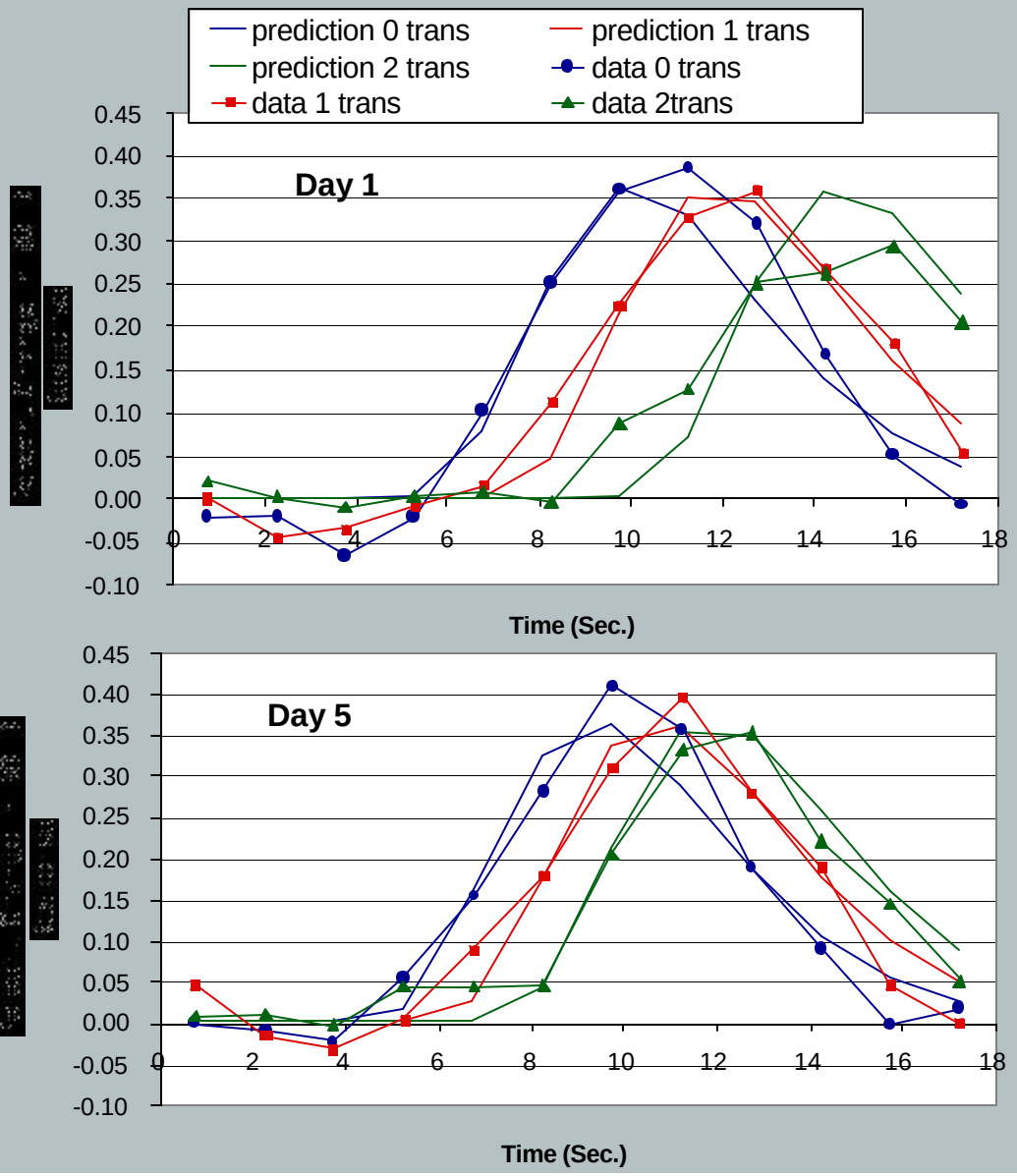
M = magnitude scale for response (varies with sensitivity of region)

s = latency scale (estimated value 1-2 sec.)

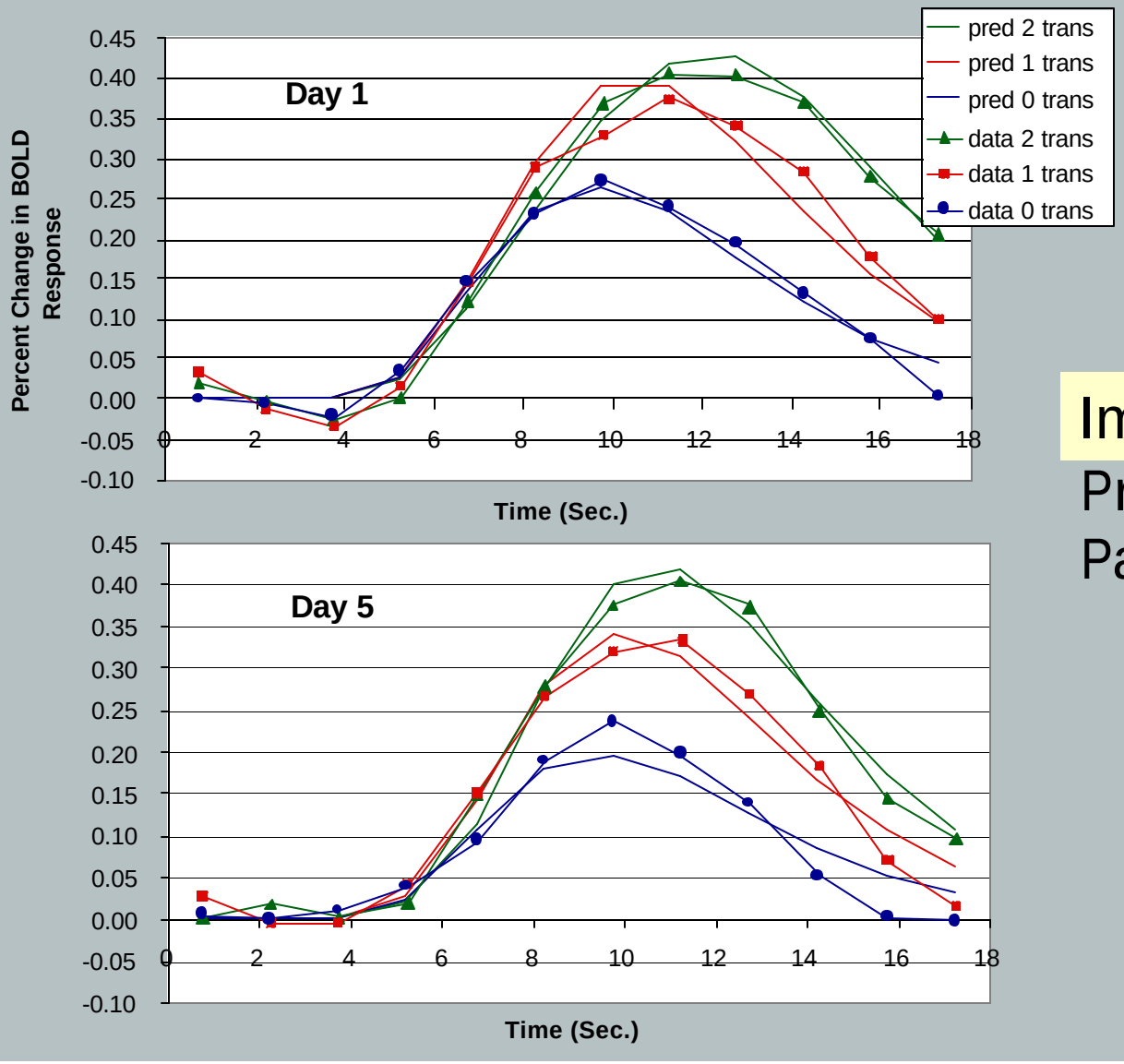
i(x) = 1 if buffer occupied at time x, 0 otherwise

a = exponent (estimated value 2-10)

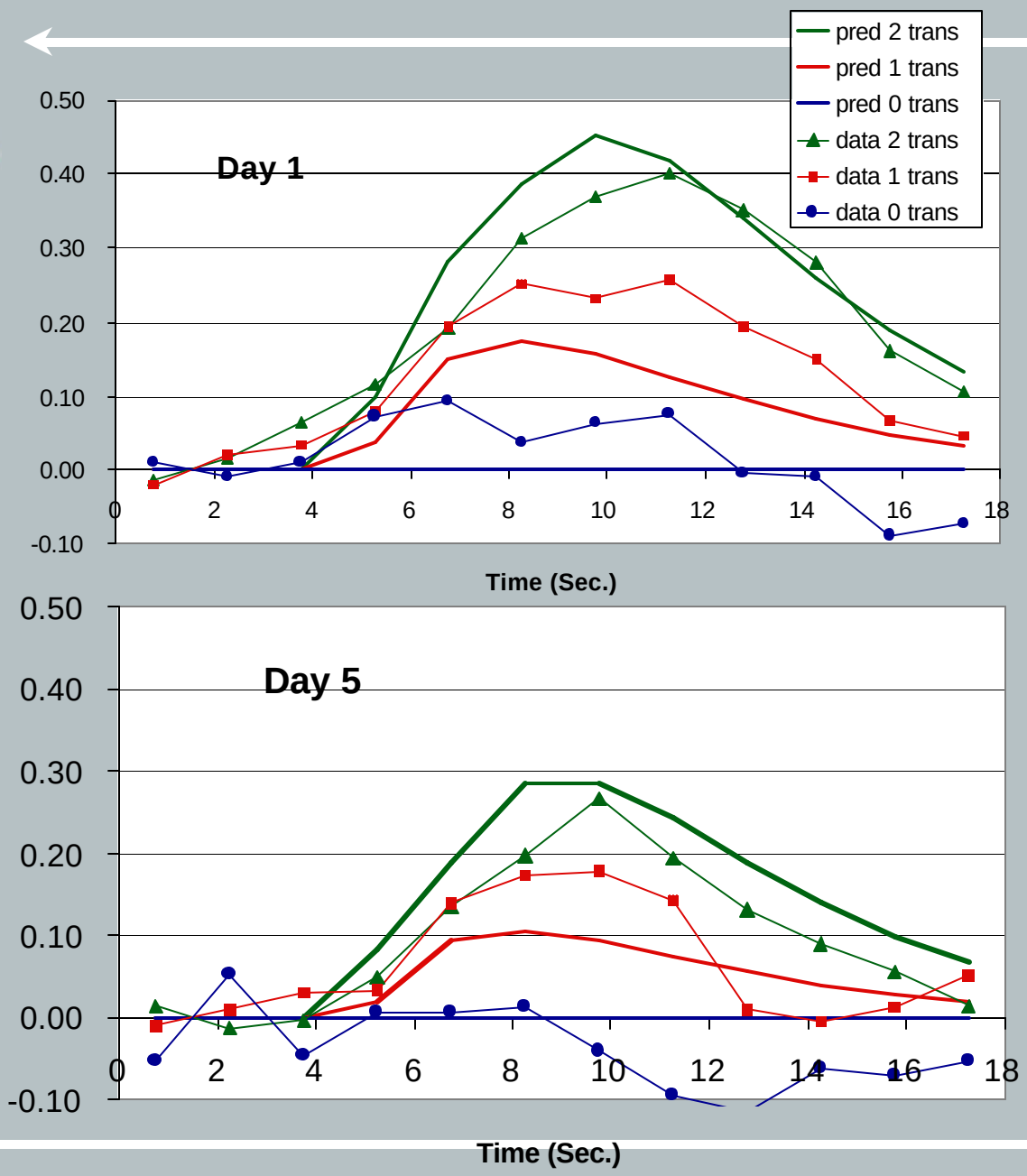

fMRI Response to Events
First
Second
Third
Total
Activation
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21
Time (sec.)



Manual Predicts Motor

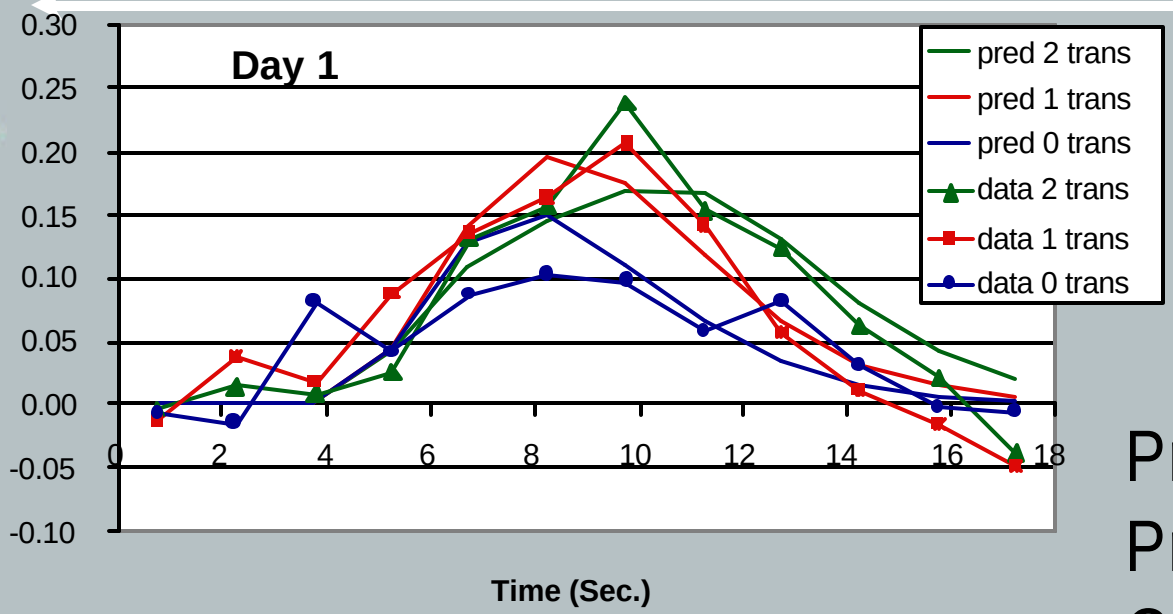


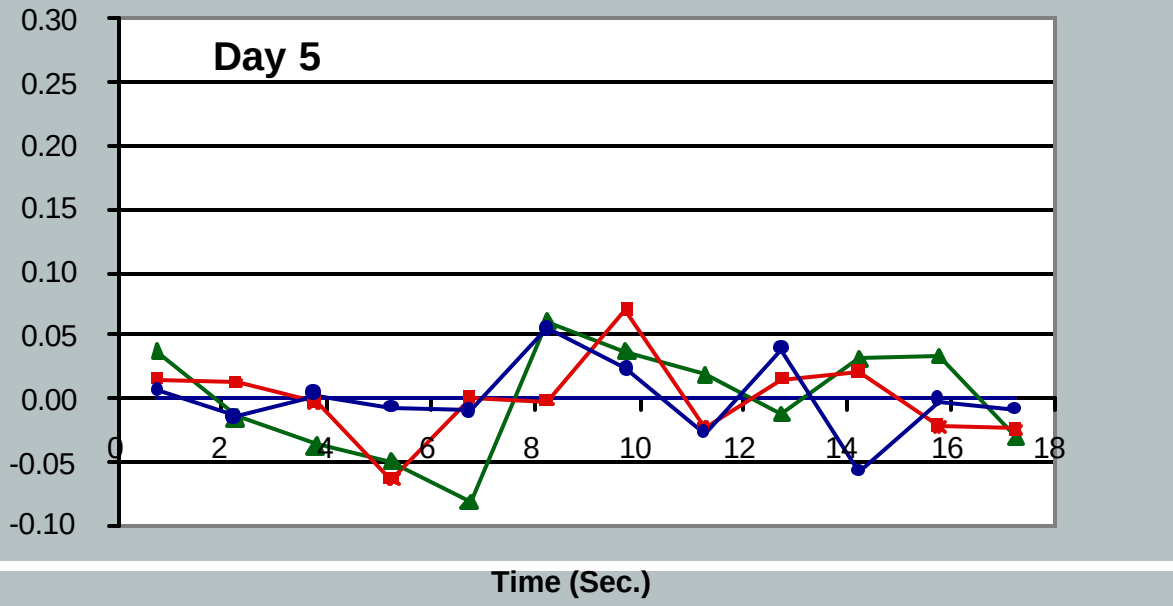
Imaginal Predicts Parietal



Retrieval Predicts VLPFC

$$B_i \; ? \; \ln(\; ? \; t_i^{\;?d}\;)$$





Productions Predict Caudate

Brain Imaging Separates Manual, Imaginal, Retrieval, and Procedural

1. Motor area tracks activity of manual buffer. The form of the BOLD function is not sensitive to cognitive complexity or practice.
2. Parietal area tracks mental the new imaginal buffer. The form of the BOLD function is sensitive to cognitive complexity but not practice.
3. Prefrontal area tracks activity of the retrieval buffer. The form of the BOLD function is sensitive to cognitive complexity and decreases with practice.
4. Caudate seems tracks firing of new productions. The BOLD function is only weakly sensitive to cognitive complexity and disappears with practice.