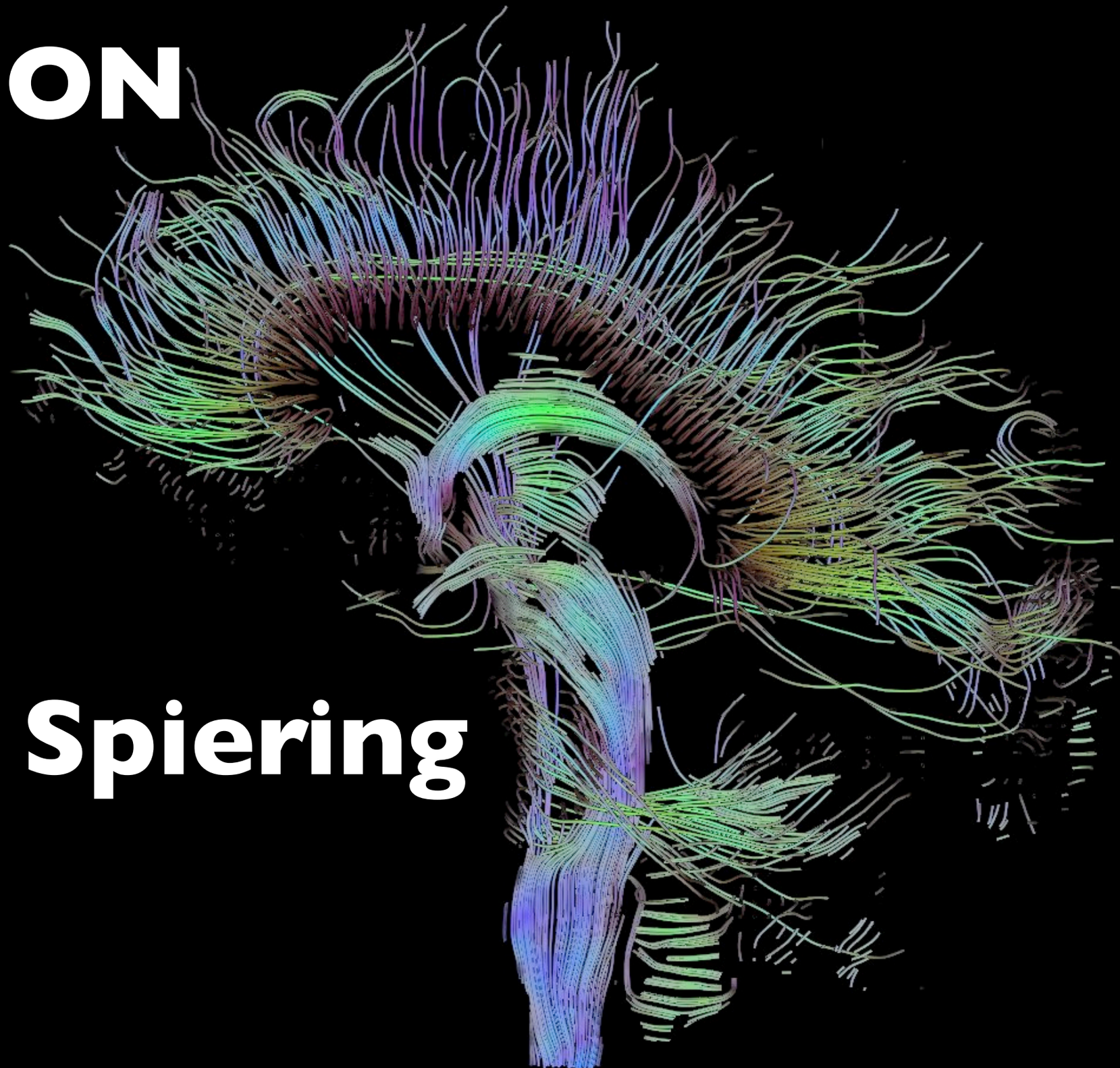
Building Better Models in Cognitive Neuroscience: APPLICATION



Dr. Brian J. Spiering

Review

- Better models help solve better problems
- Why?
- Ideals
- Modeling

HOW DOES PROCEDURAL EXPERTISE DEVELOP?

1)Idea

2)Inception

3)Instantiations

Previous Notions

"It has been widely held that although memory traces are at first formed in the cerebral cortex, they are finally reduced or transferred by long practice to subcortical levels" (p. 466)

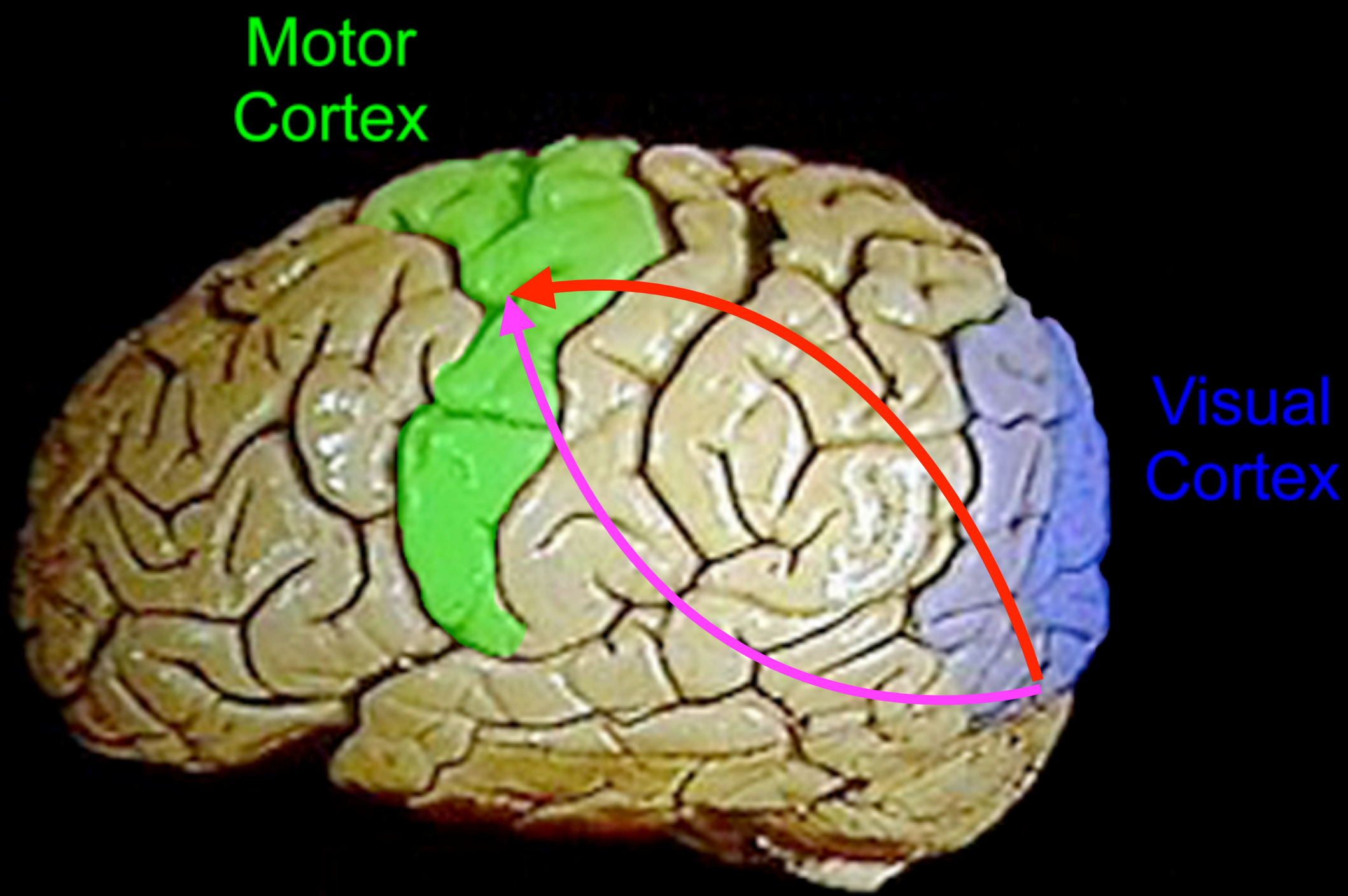
Karl Lashley (1950)
In search of the engram

Previous Notions

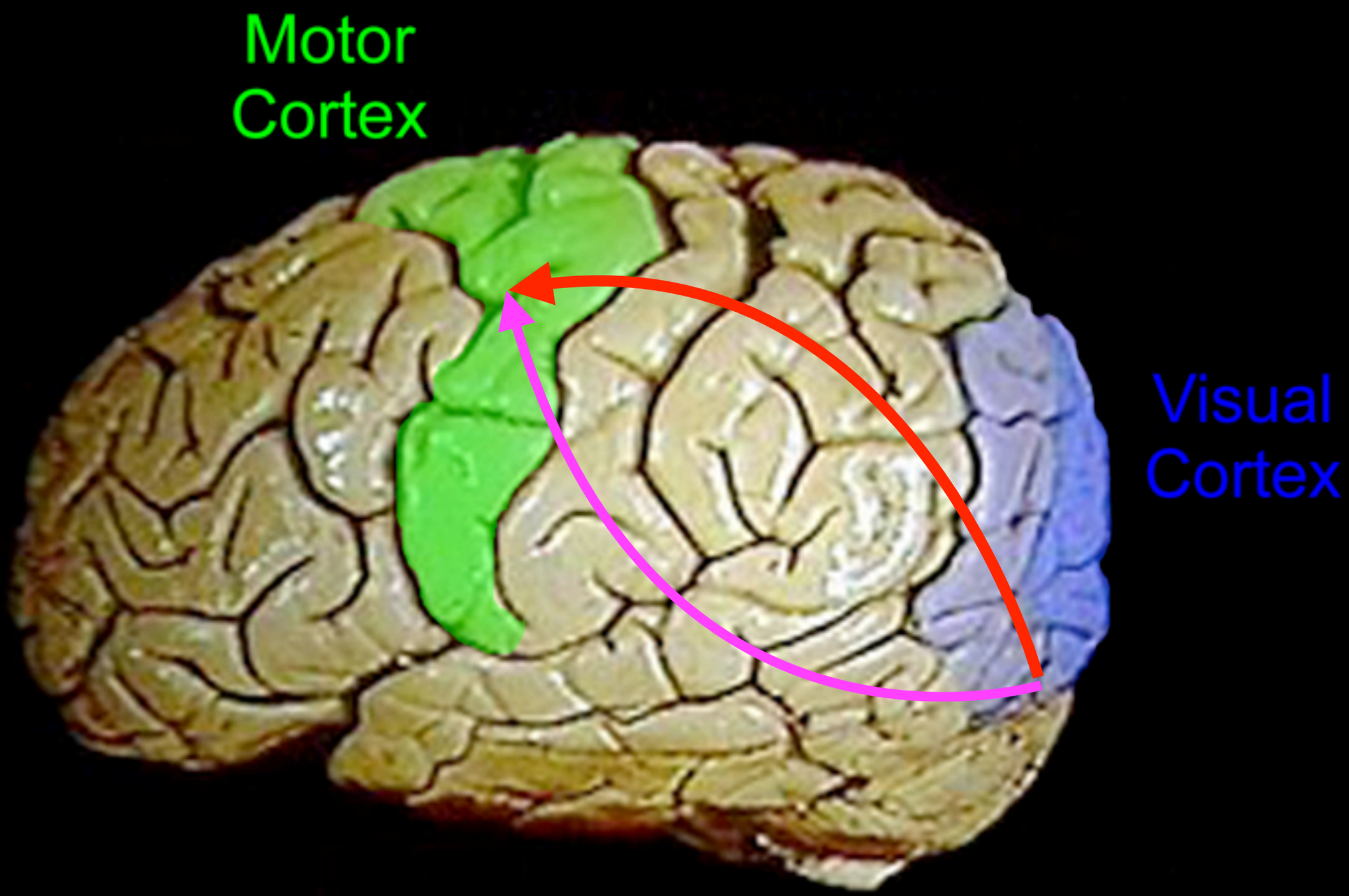
"Routine, automatic, or overlearned behavioral sequences, however complex, do not engage the PFC and may be entirely organized in subcortical structures" (p. 323)

Joaquin Fuster (2001)
The prefrontal cortex – an update

Previous Notions



An Contrarian Model of Procedural Expertise



Procedural ***learning*** is striatum ***dependent***.

Procedural ***expertise*** is striatum ***independent.***

SPEED Model

(Subcortical Pathways Enable Expertise Development)

INCEPTION

F. Greg Ashby

John Ennis

SCHEMATIC OVERVIEW

SPEED Model

Response

↑

A-B difference

Premotor Area
(Cortex)

Sensory
Association
Cortex

A

B

Thalamus

A

B

Globus Pallidus

A

B

Striatum

A

B

SPEED Model: Single Subcortical

A Response

Premotor Area
(Cortex)

A

A

Thalamus

A

Globus Pallidus

Sensory
Association
Cortex

Excitatory

Inhibitory

A

Striatum

SPEED Model: Subcortical

Response

A-B difference

Premotor Area (Cortex)

A

B

Sensory Association Cortex

Thalamus

A

B

Striatum

A

B

Globus Pallidus

A

B

SPEED Model: Subcortical Learning

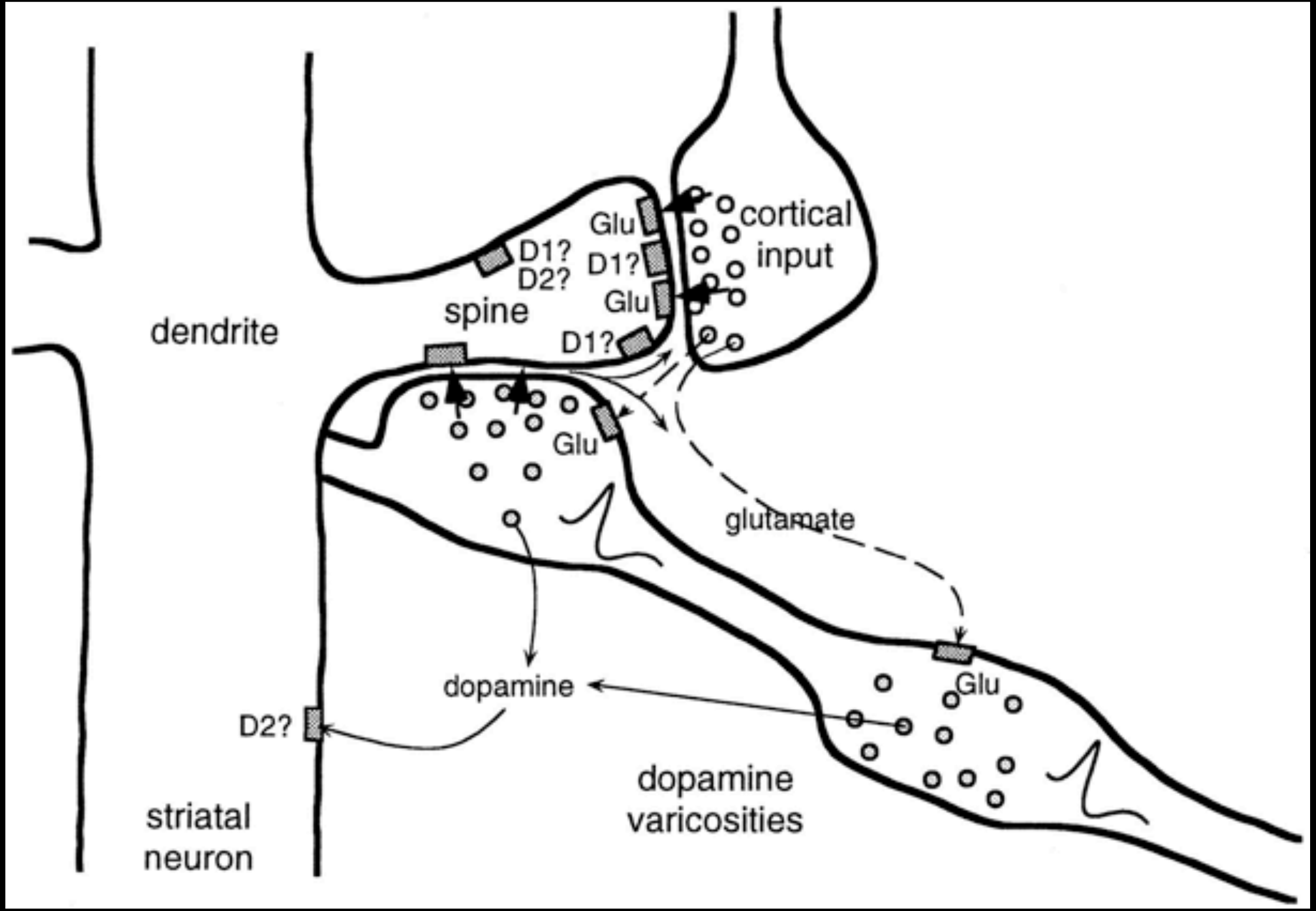
Excitatory ———

Dopamine · · · · · · · · · · · ·

Sensory Association Cortex

SNpc

Striatum


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

SPEED Model: Subcortical

Response

A-B difference

Premotor Area (Cortex)

A

B

Sensory Association Cortex

A

Thalamus

B

A

Striatum

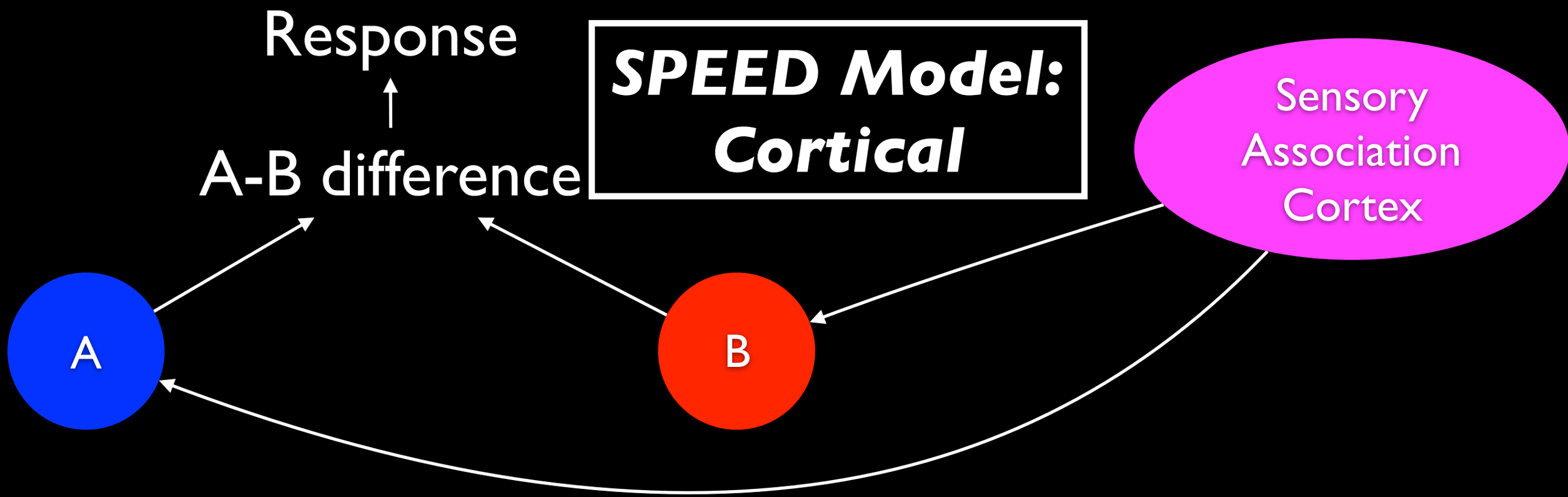
B

A

Globus Pallidus

B

SPEED Model: Cortical



SPEED Model: Cortical Learning

Response

A-B difference

Sensory Association Cortex

A

B

Premotor Area (Cortex)

A

B

Thalamus

A

B

Globus Pallidus

A

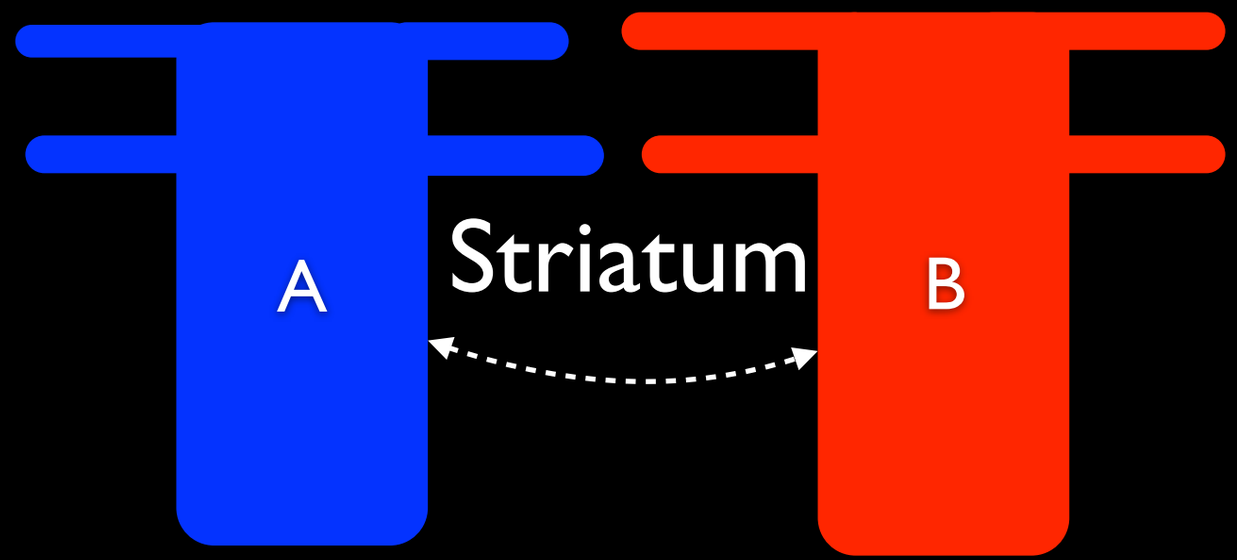
Striatum

B

ACTIVATION EQUATIONS

Sensory
Association
Cortex

$$I_K(t) = \frac{1}{\alpha} e^{-\frac{d(K,stimulus)^2}{2\alpha^2}}$$



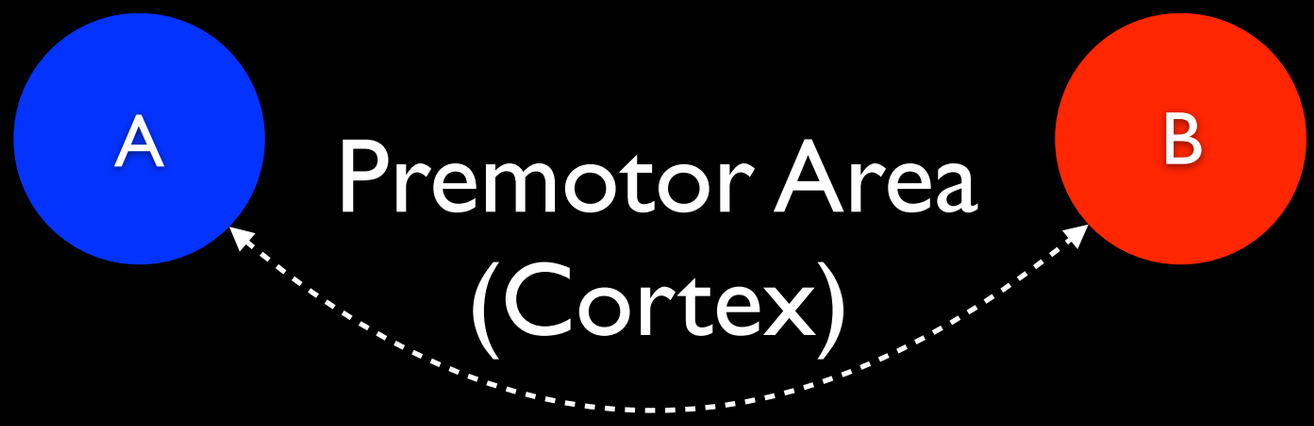
$$\frac{dS_J(t)}{dt} = \left[\sum_K w_{K,J}(n) I_K(t) \right] [1 - S_J(t)]$$

$$- \beta_S S_M(t) - \gamma_S [S_J(t) - S_{base}] + \sigma_S \varepsilon(t) S_J(t) [1 - S_J(t)]$$

A Globus Pallidus B

$$\frac{dG_J(t)}{dt} = -\alpha_G S_J(t) G_J(t) - \beta_G [G_J(t) - G_{base}]$$

$$\frac{dT_J(t)}{dt} = -\alpha_T G_J(t) T_J(t) - \beta_T [T_J(t) - T_{base}]$$



$$\frac{dE_J(t)}{dt} = \left[\alpha_E T_J(t) + \sum_K \nu_{K,J}(n) I_K(t) \right] [1 - E_J(t)]$$

$$- \beta_E E_K(t) - \gamma_E [E_J(t) - E_{base}] + \sigma_E \varepsilon(t) E_J(t) [1 - E_J(t)],$$

Response

↑

A-B difference

$$\Delta_{A,B}(t) = \int [E_A(t) - E_B(t)]dt.$$

SPEED Model

Response

↑

A-B difference

Premotor Area
(Cortex)

Sensory
Association
Cortex

A

B

Thalamus

A

B

Globus Pallidus

A

B

Striatum

A

B

LEARNING

Sensory Association Cortex

A

Premotor Area (Cortex)

SPEED Model: 1st Trial

A

Thalamus

A

Globus Pallidus

A

Striatum

Sensory Association Cortex

A

Premotor Area (Cortex)

SPEED Model: Early Learning

A

Thalamus

A

Globus Pallidus

A

Striatum

Sensory Association Cortex

A

Premotor Area (Cortex)

SPEED Model: Middle Learning

A

Thalamus

A

Globus Pallidus

A

Striatum

Sensory Association Cortex

A

Premotor Area (Cortex)

SPEED Model: Mature Performance

A

Thalamus

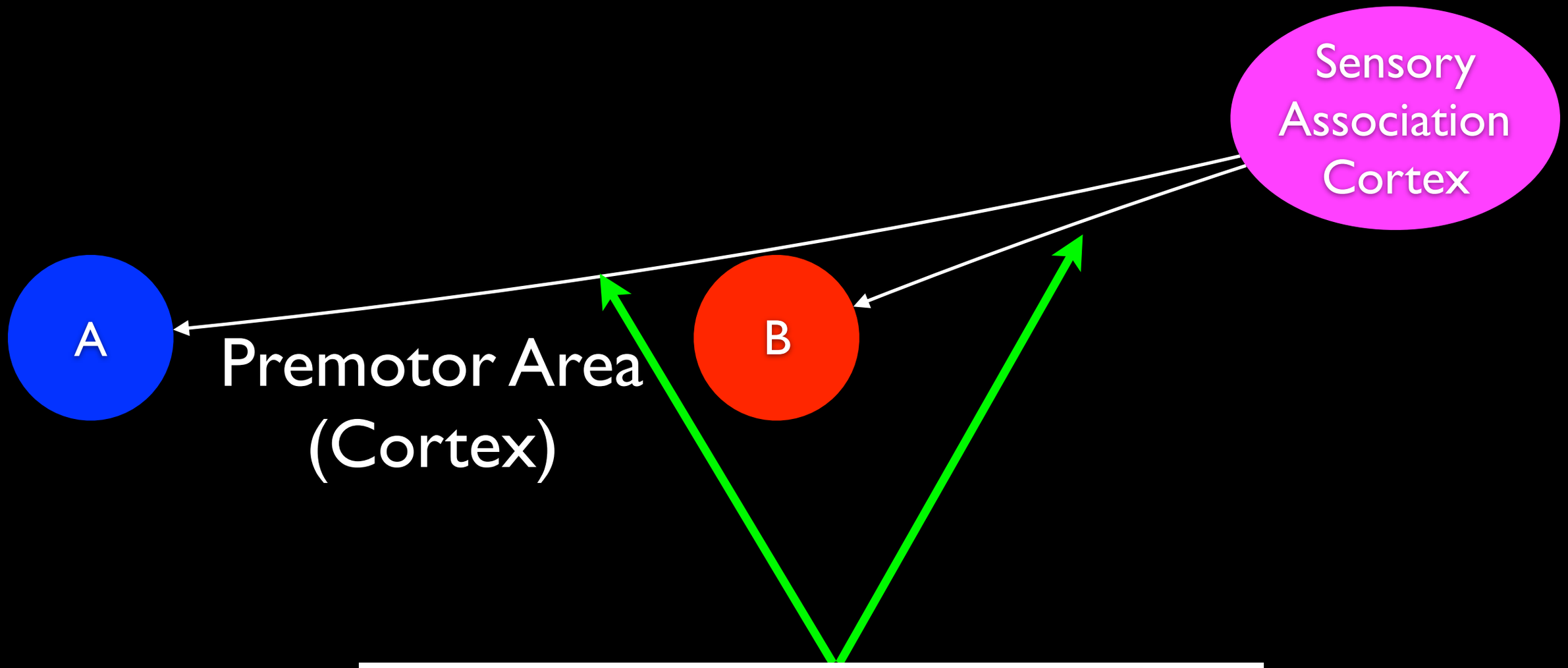
A

Globus Pallidus

A

Striatum

LEARNING EQUATIONS



$$v_{K,J}(n+1) = v_{K,J}(n) + \alpha_v \sum_t I_k(t) \left[\sum_t E_J(t) - \theta_{NMDA} \right]^+$$

$$\times [1 - v_{K,J}(n)] - \beta_v \sum_t I_k(t) \left[\theta_{NMDA} - \sum_t E_J(t) \right]^+ v_{K,J}(n),$$

2-Factor Learning

$$w_{K,J}(n+1) = w_{K,J}(n)$$

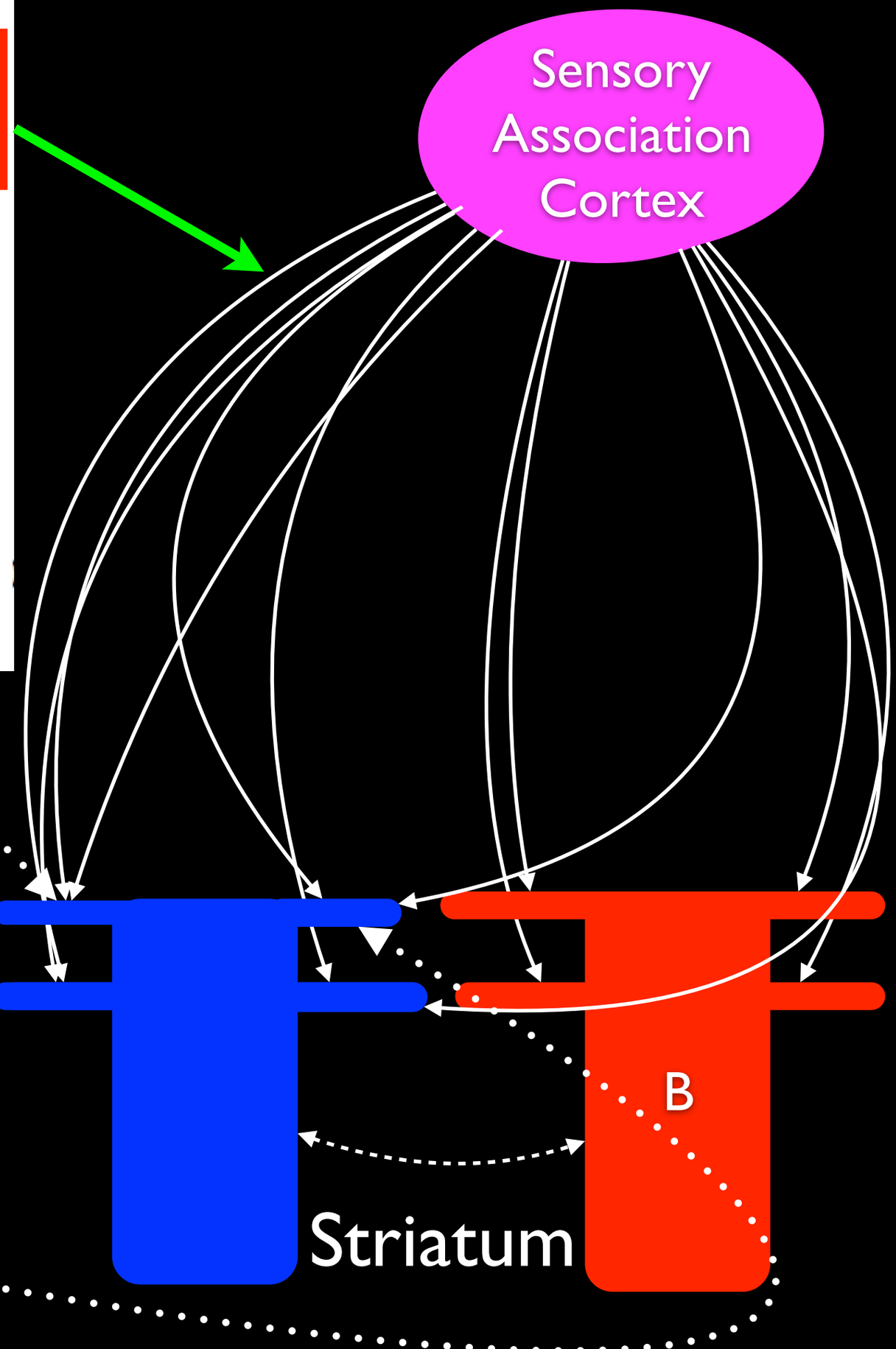
$$+ \alpha_w \sum_t I_K(t) \left[\sum_t S_J(t) - \theta_{NMDA} \right]^+ [D(n) - D_{base}]^+ [1 - w_{K,J}(n)]$$

$$- \beta_w \sum_t I_K(t) \left[\sum_t S_J(t) - \theta_{NMDA} \right]^+ [D_{base} - D(n)]^+ w_{K,J}(n)$$

$$- \gamma_w \sum_t I_K(t) \left[\theta_{NMDA} - \sum_t S_J(t) \right]^+ w_{K,J}(n)$$

$$- \phi_w \left(1 - \frac{1 - [D(n) - D_{base}]^+}{1 - D_{base}} \right) w_{K,J}(n),$$

3-Factor Learning



Dopamine Release

Correct Trial

$$D(n) = D_{base} + [1 - P(C)](1 - D_{base})$$

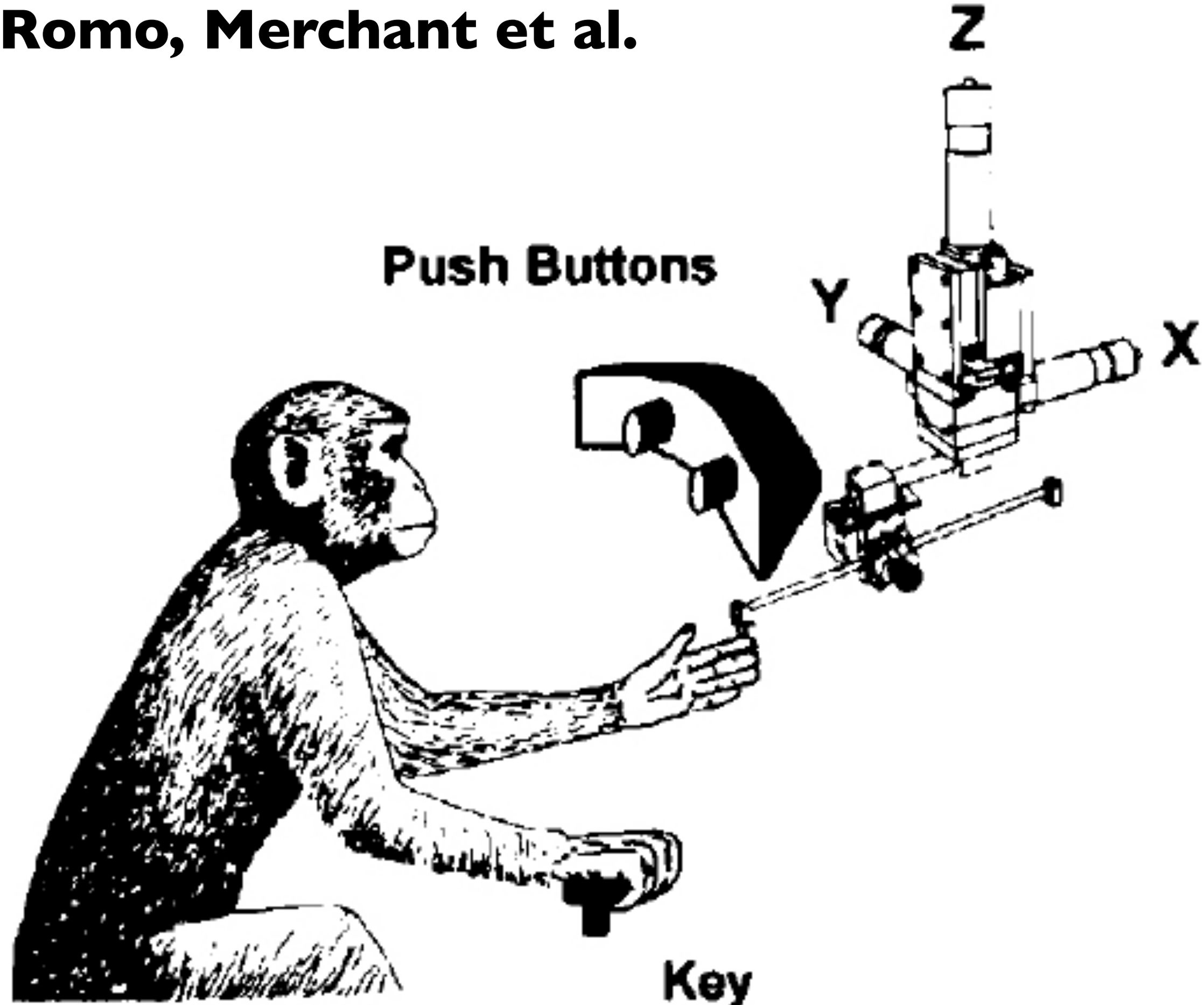
Incorrect Trial

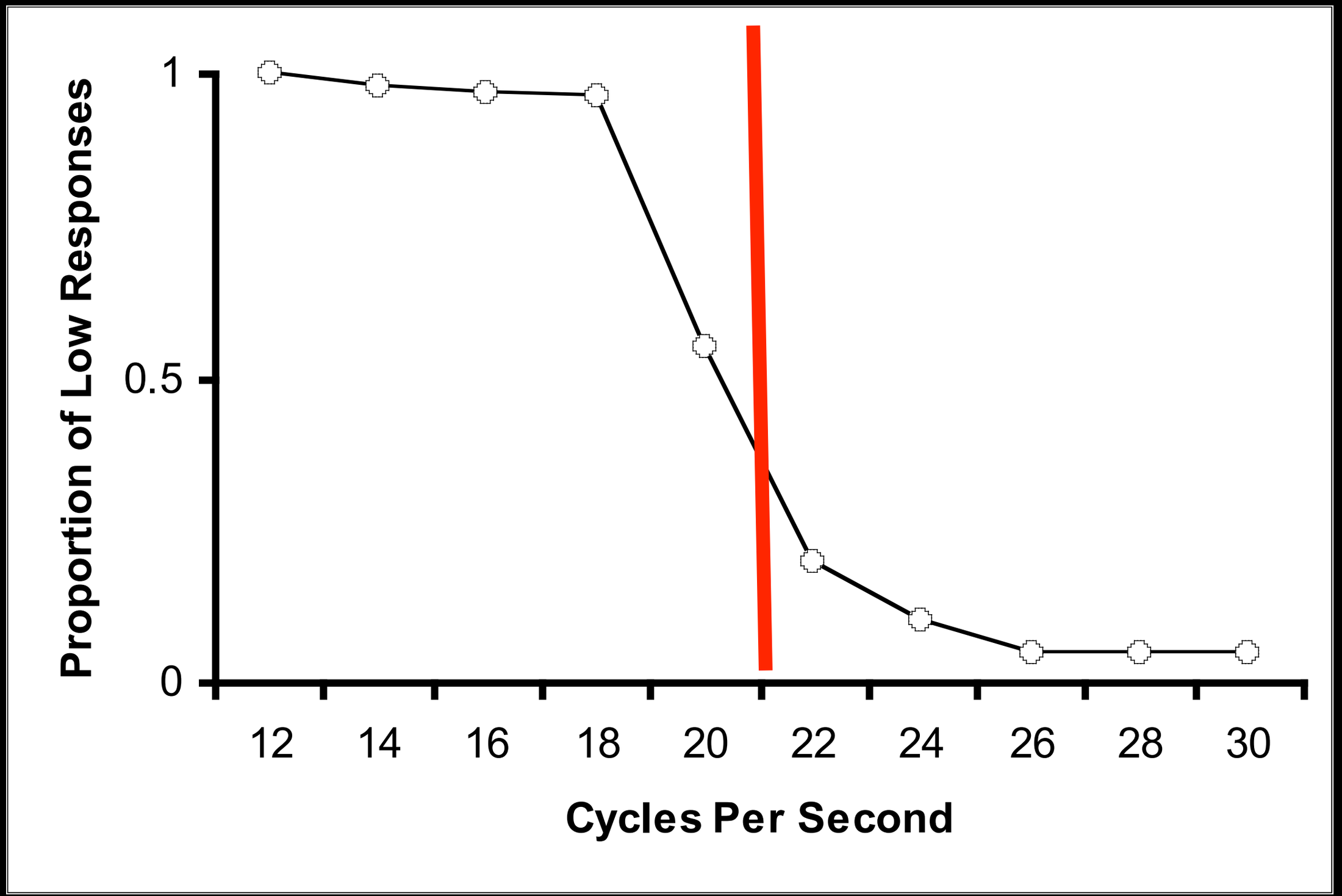
$$D(n) = D_{base} - P(C)D_{base},$$

Break

INSTANTIATIONS

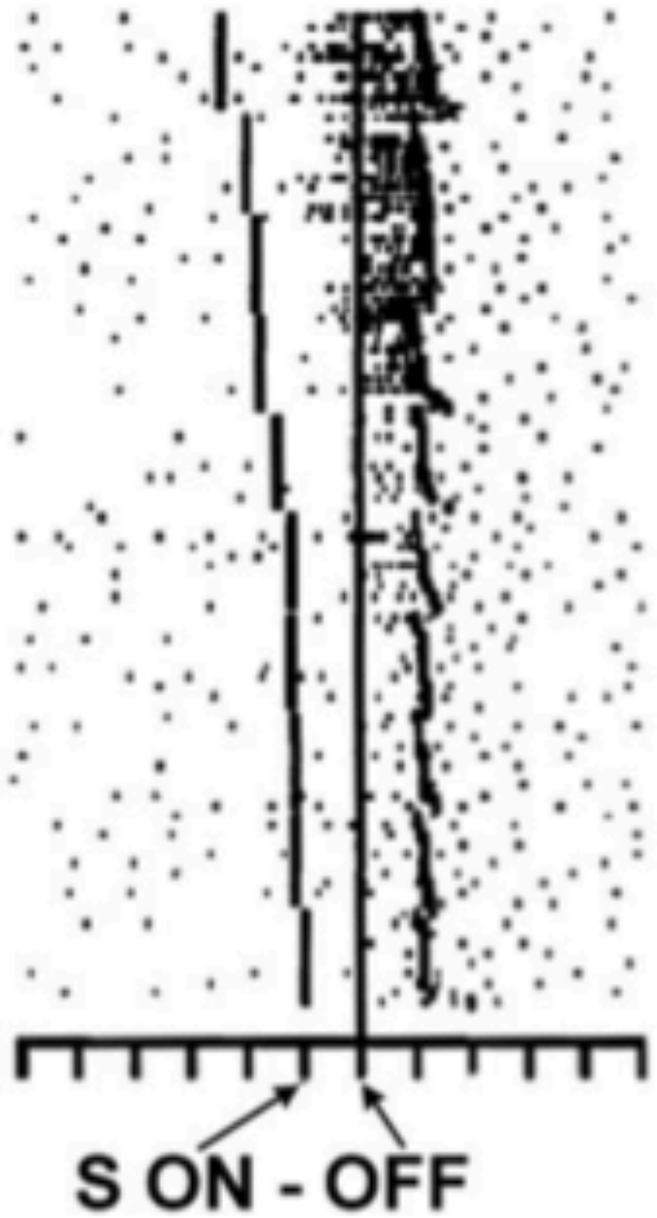
Romo, Merchant et al.



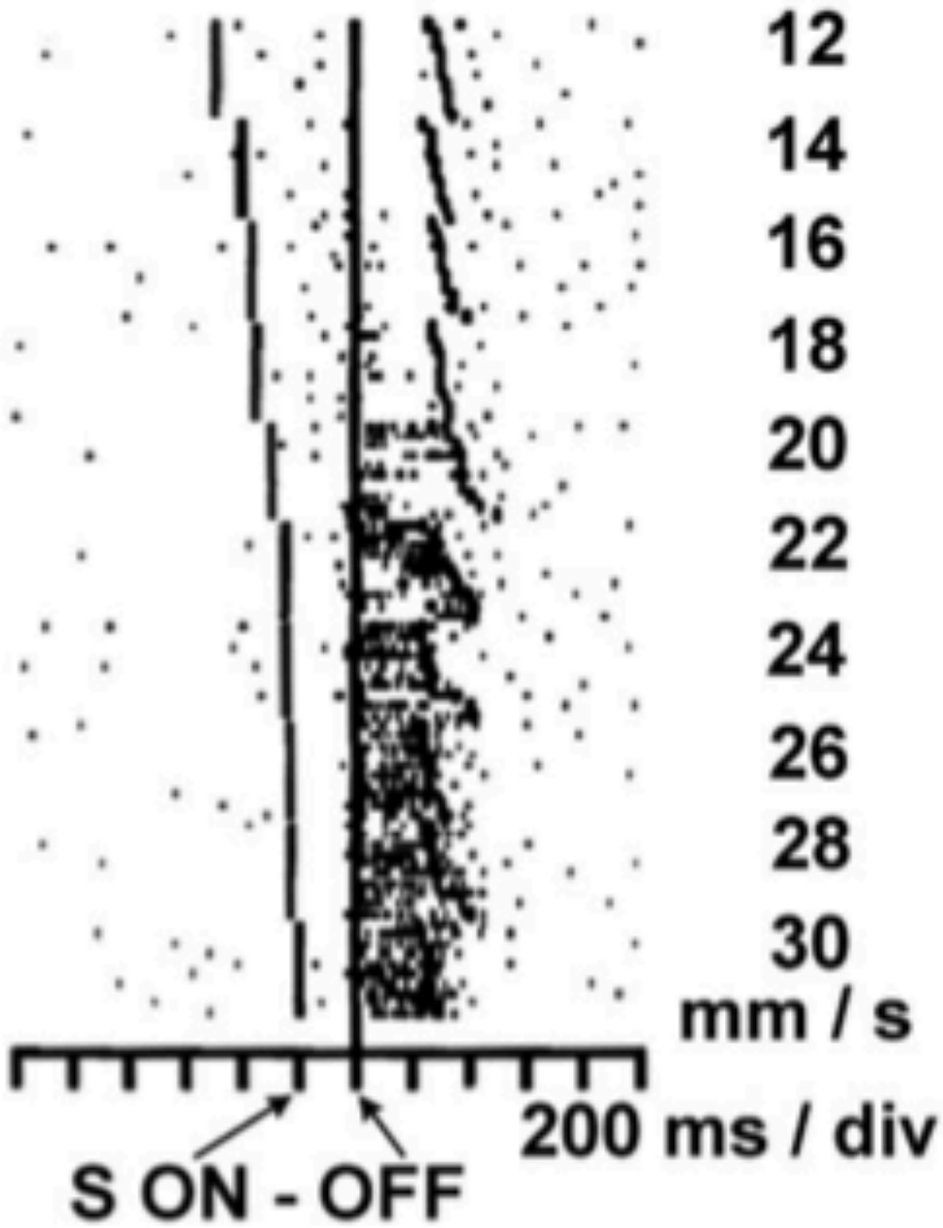

Proportion of Low Responses
1
0.5
0
12
14
16
18
20
22
24
26
28
30
Cycles Per Second

Single Cell Responses -- Left Putamen

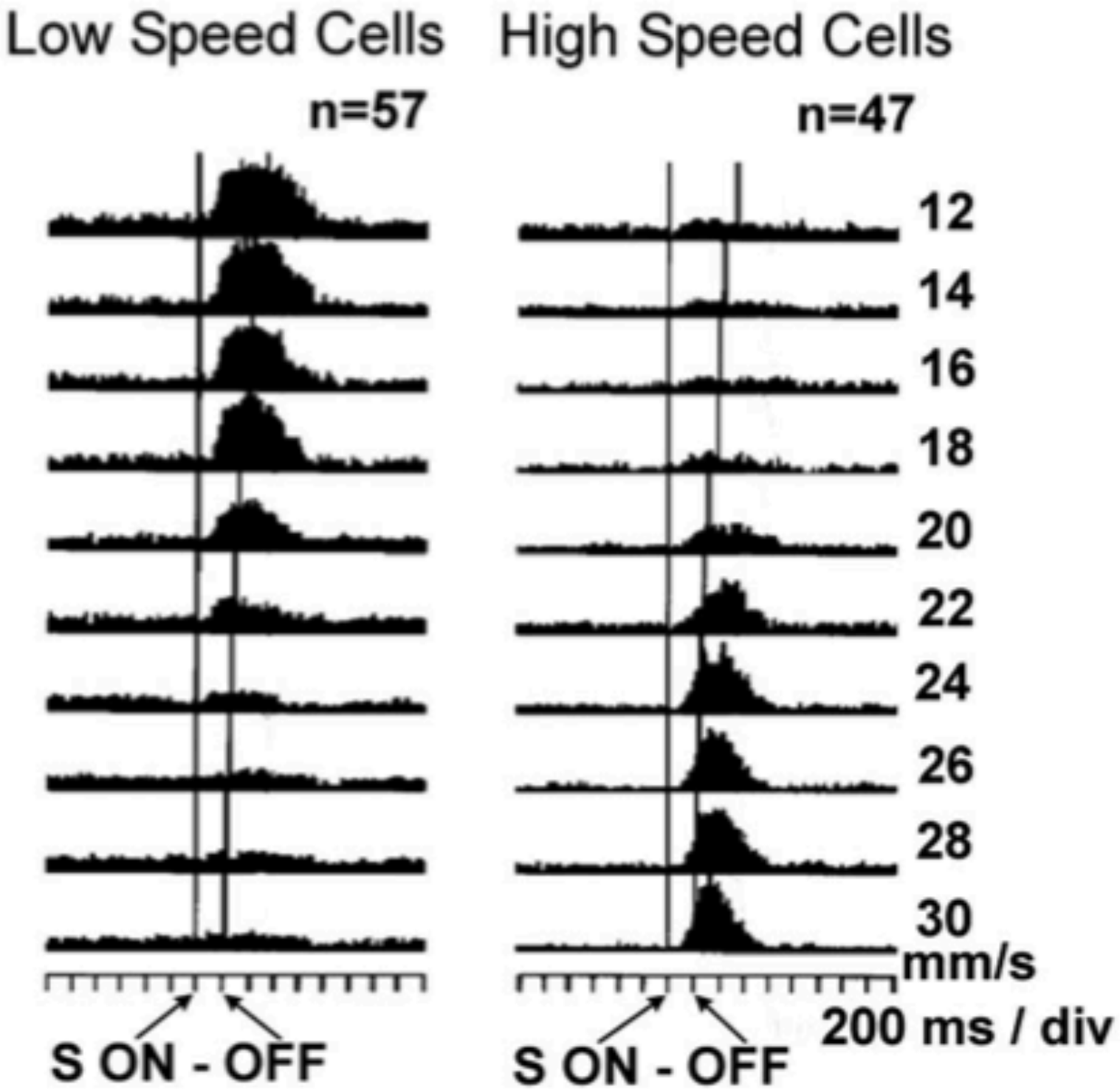
Low Speed Cell

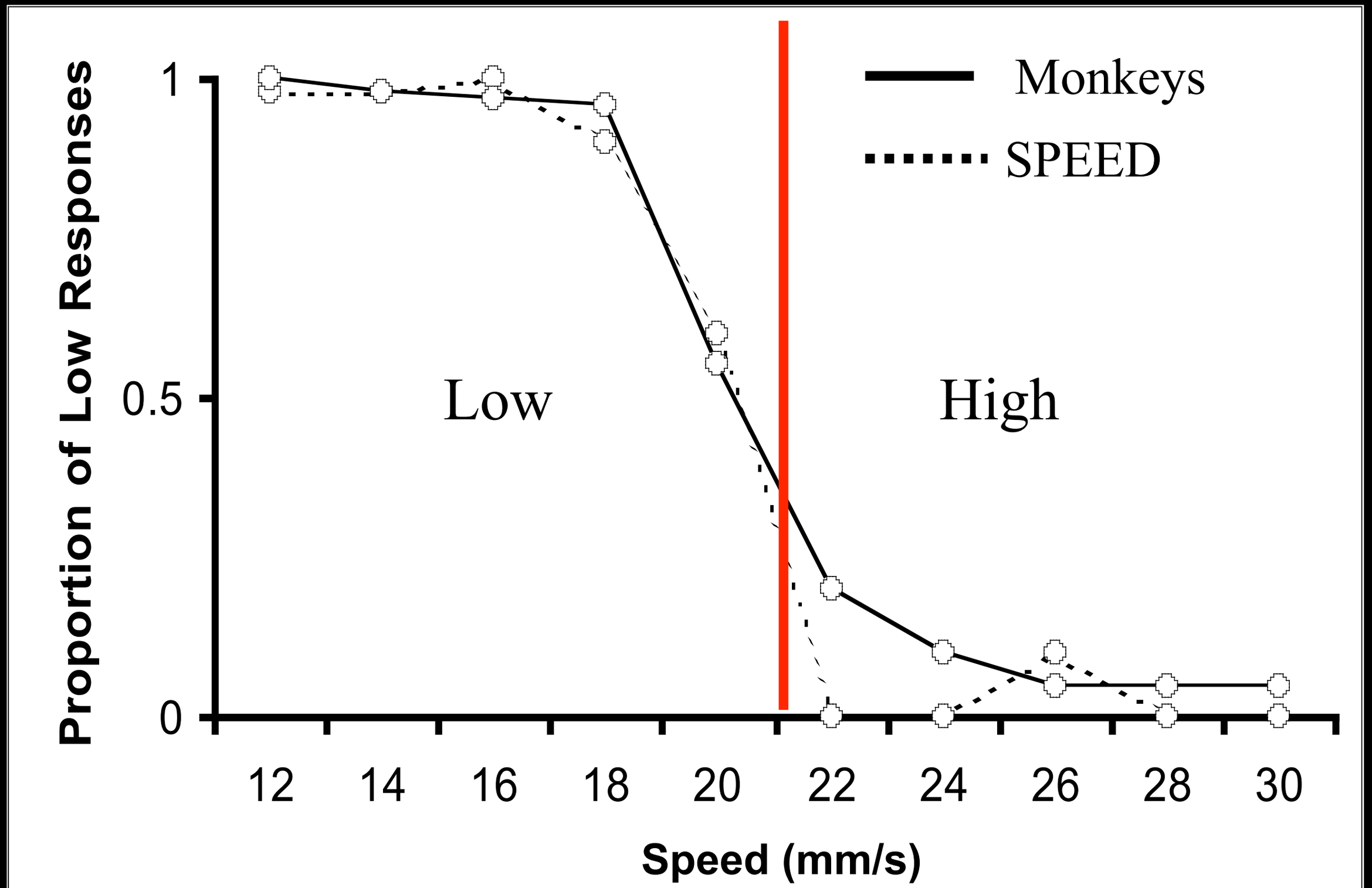


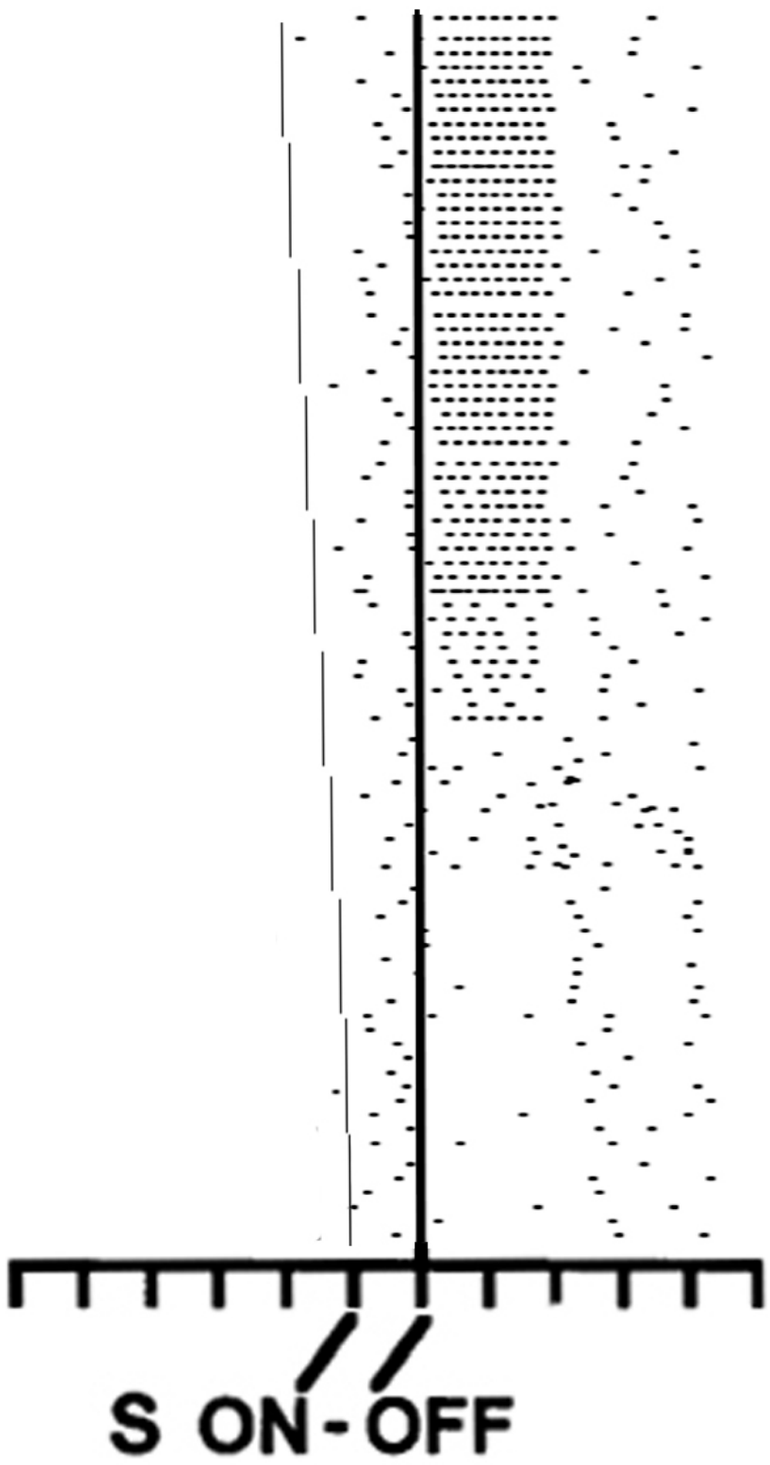
High Speed Cell

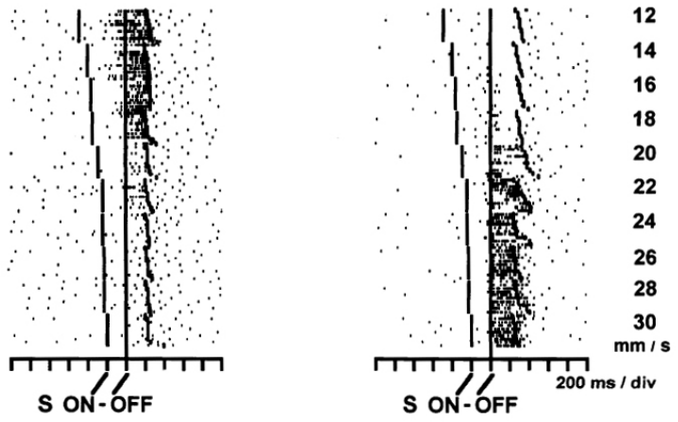


Population Responses -- Premotor Cortex

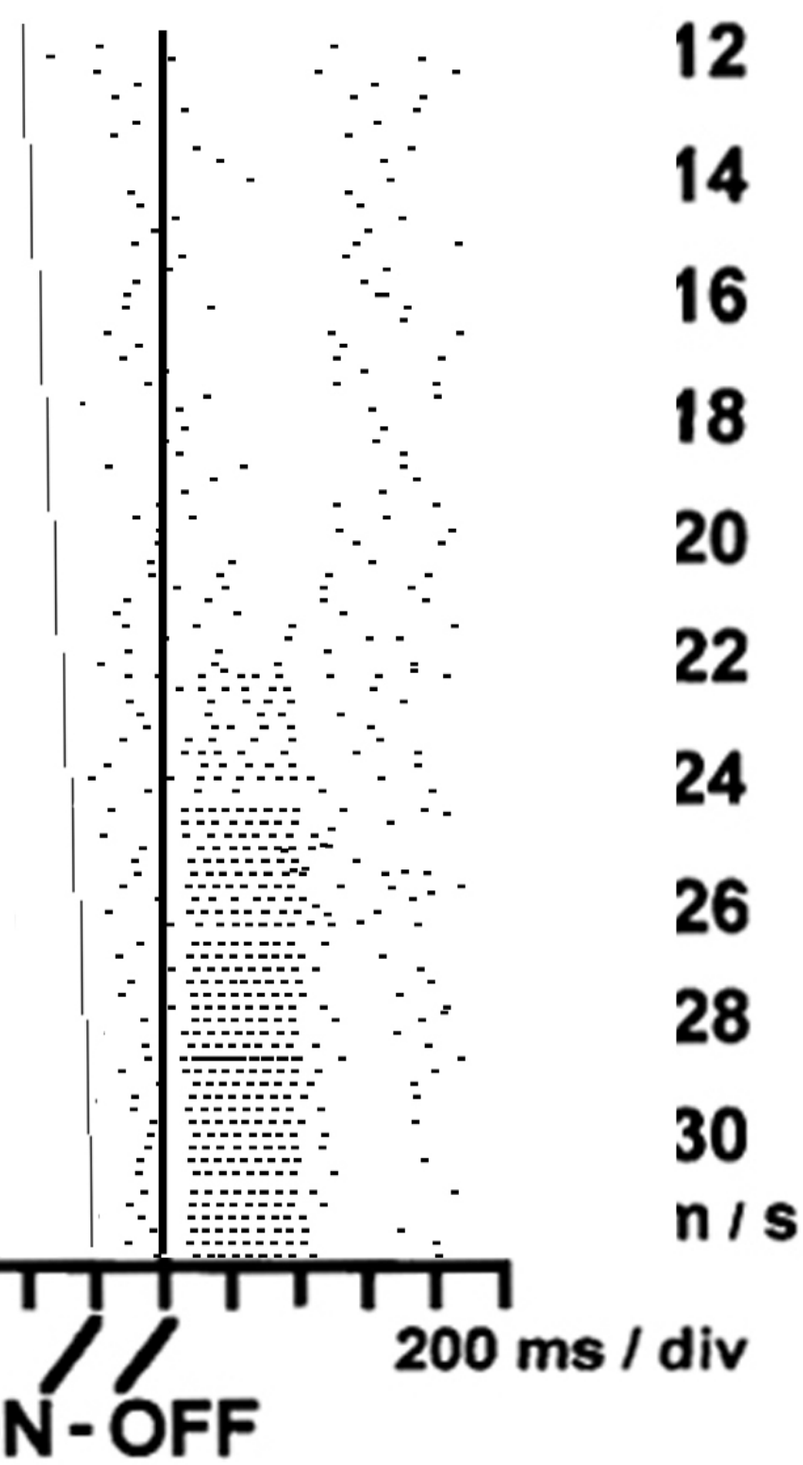



Monkeys
SPEED
Low
High
Proportion of Low Responses
1
0.5
0
12
14
16
18
20
22
24
26
28
30
Speed (mm/s)

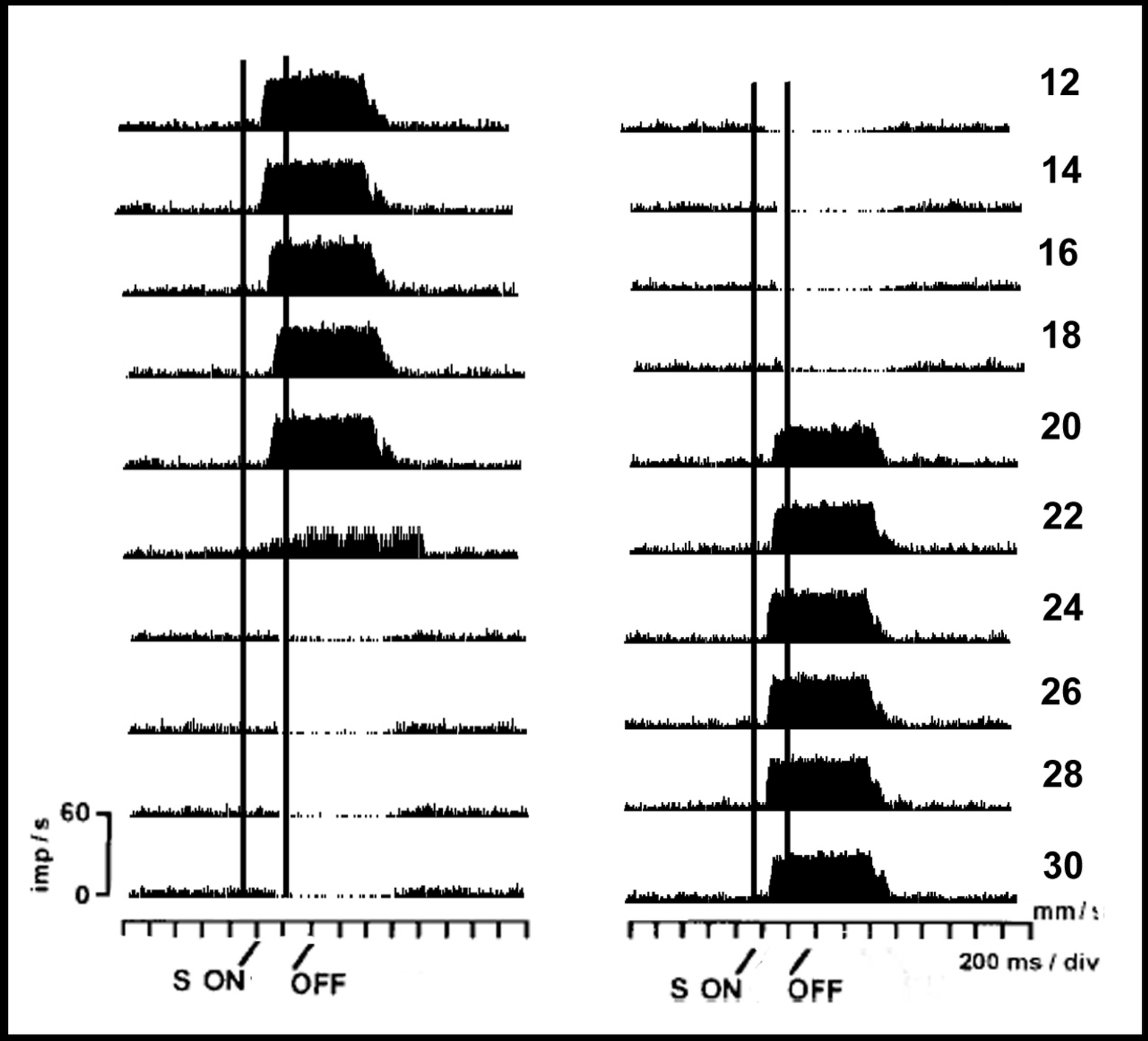




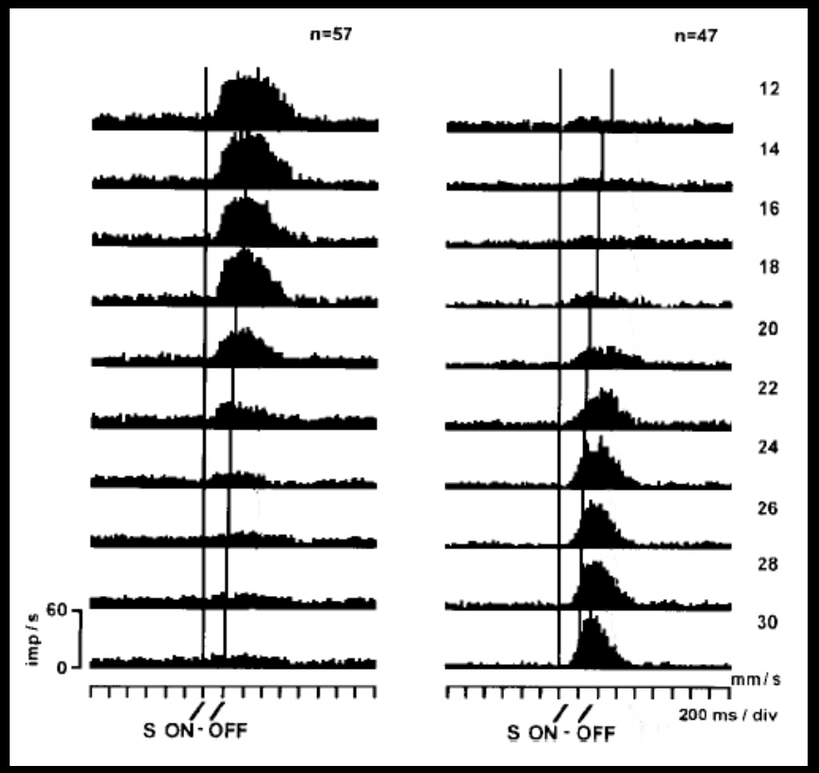
Merchant et al. (1997)



SPEED



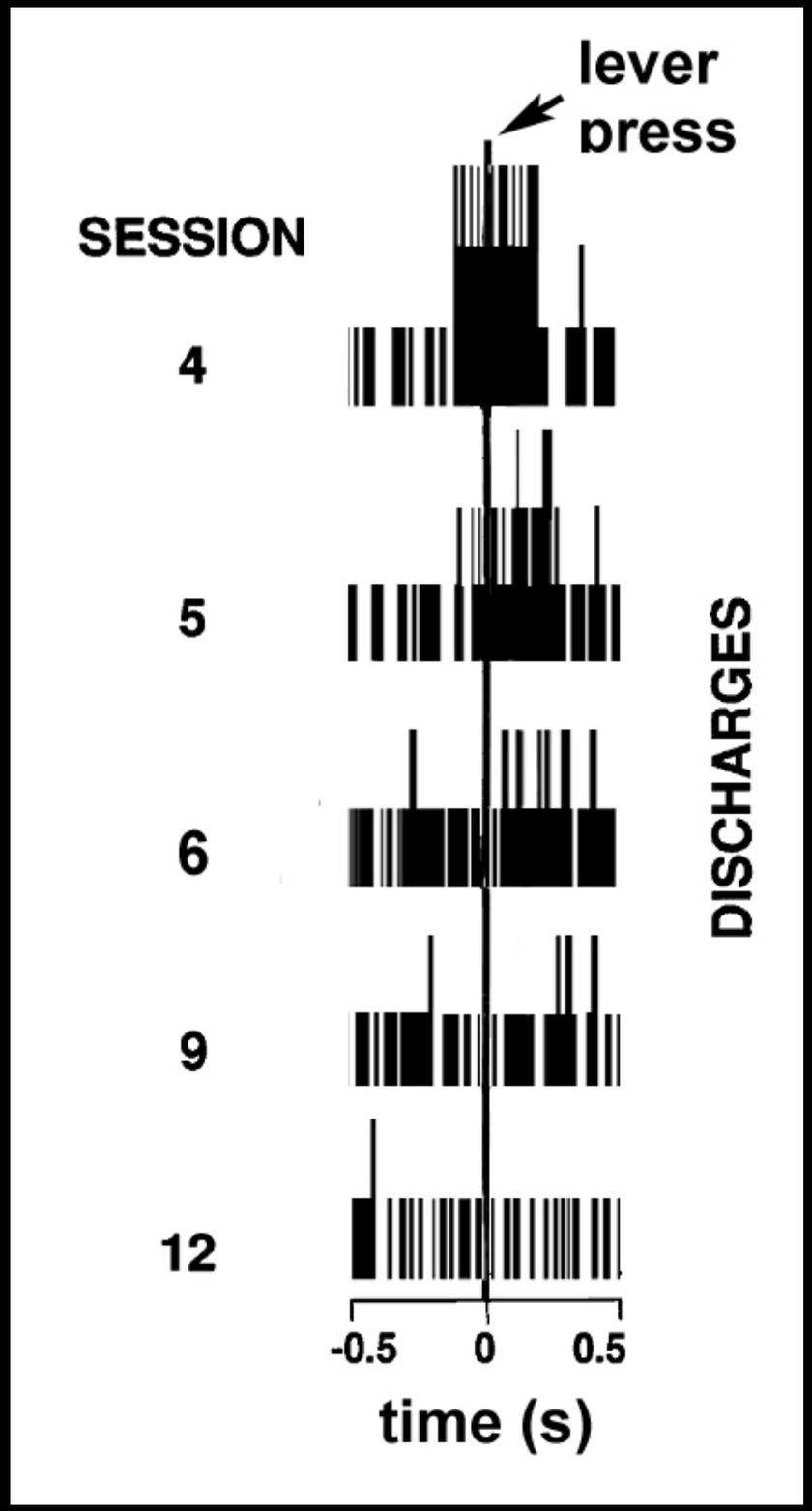
SPEED



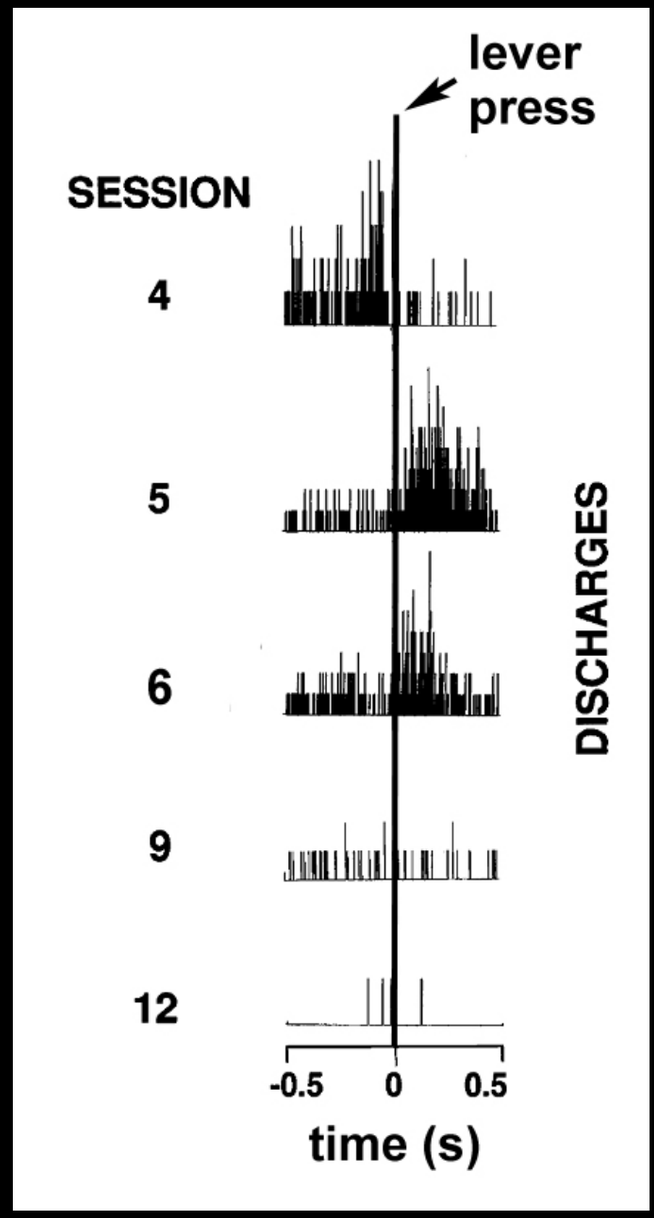
Romo et al., 1997

Carelli, Wolske, & West (1997)


lever
press
SESSION
4
DISCHARGES
-0.5
0
0.5
time (s)

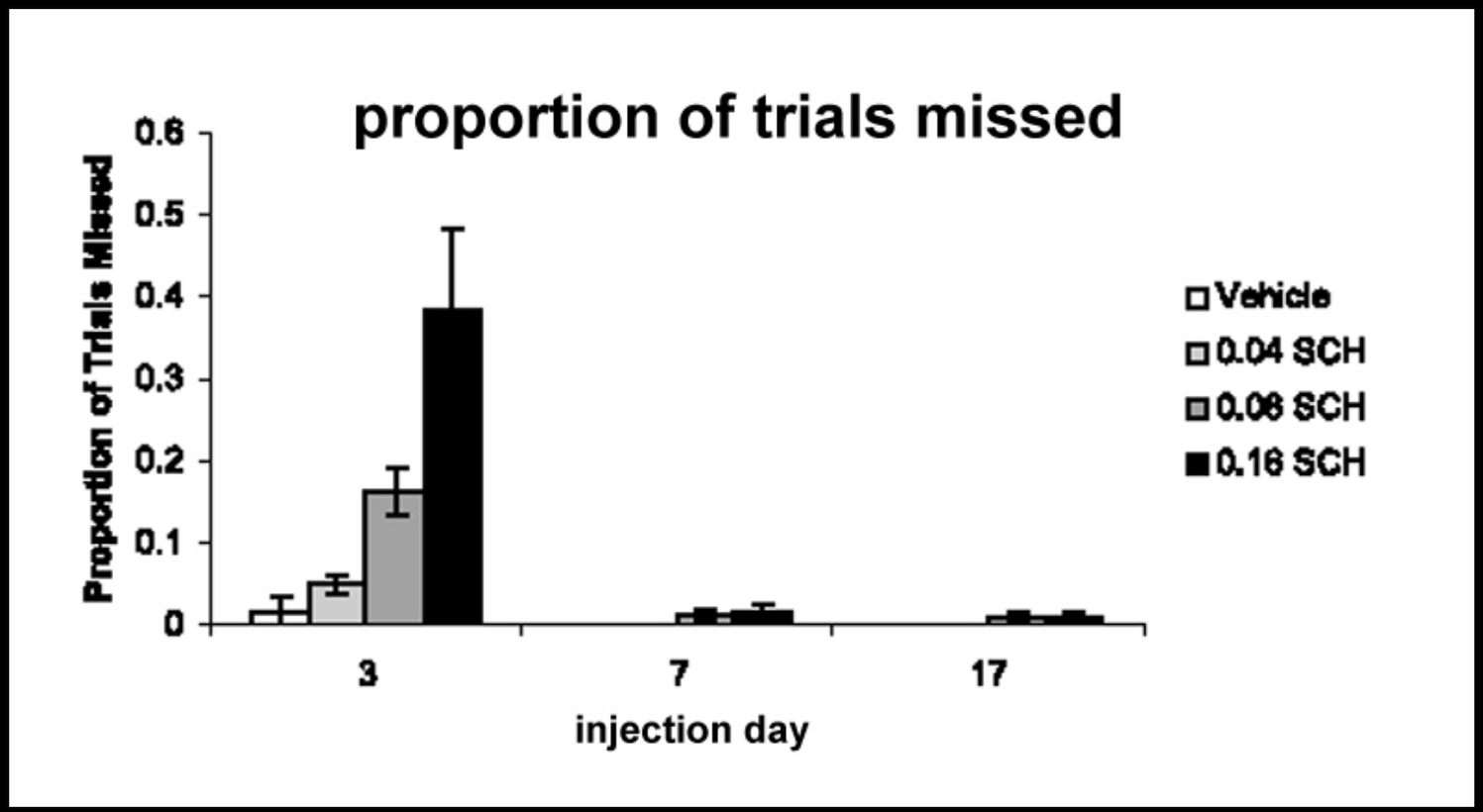


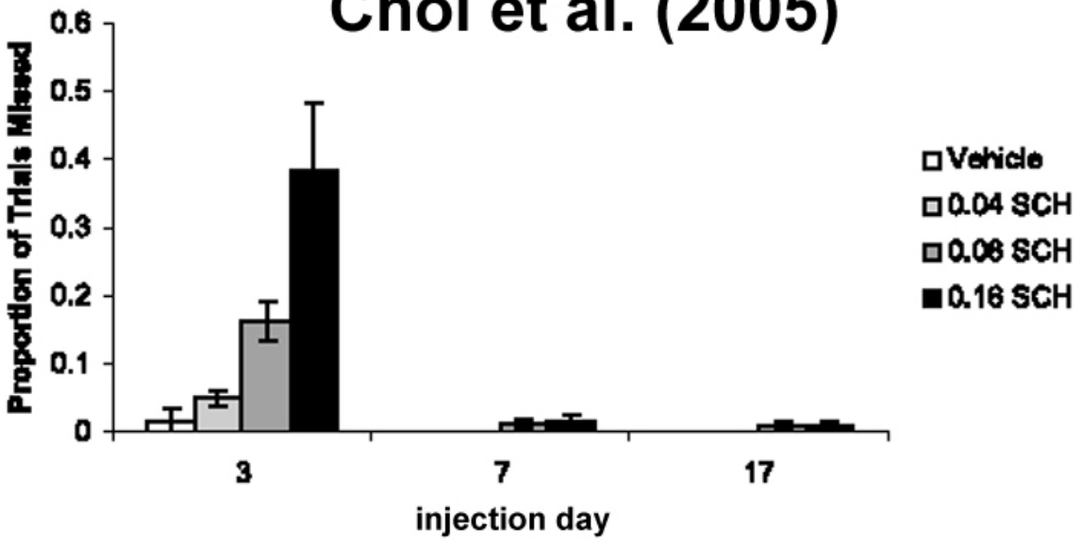
SPEED



Carelli et al., 1997

Choi, Balsam, & Horvitz (2005)

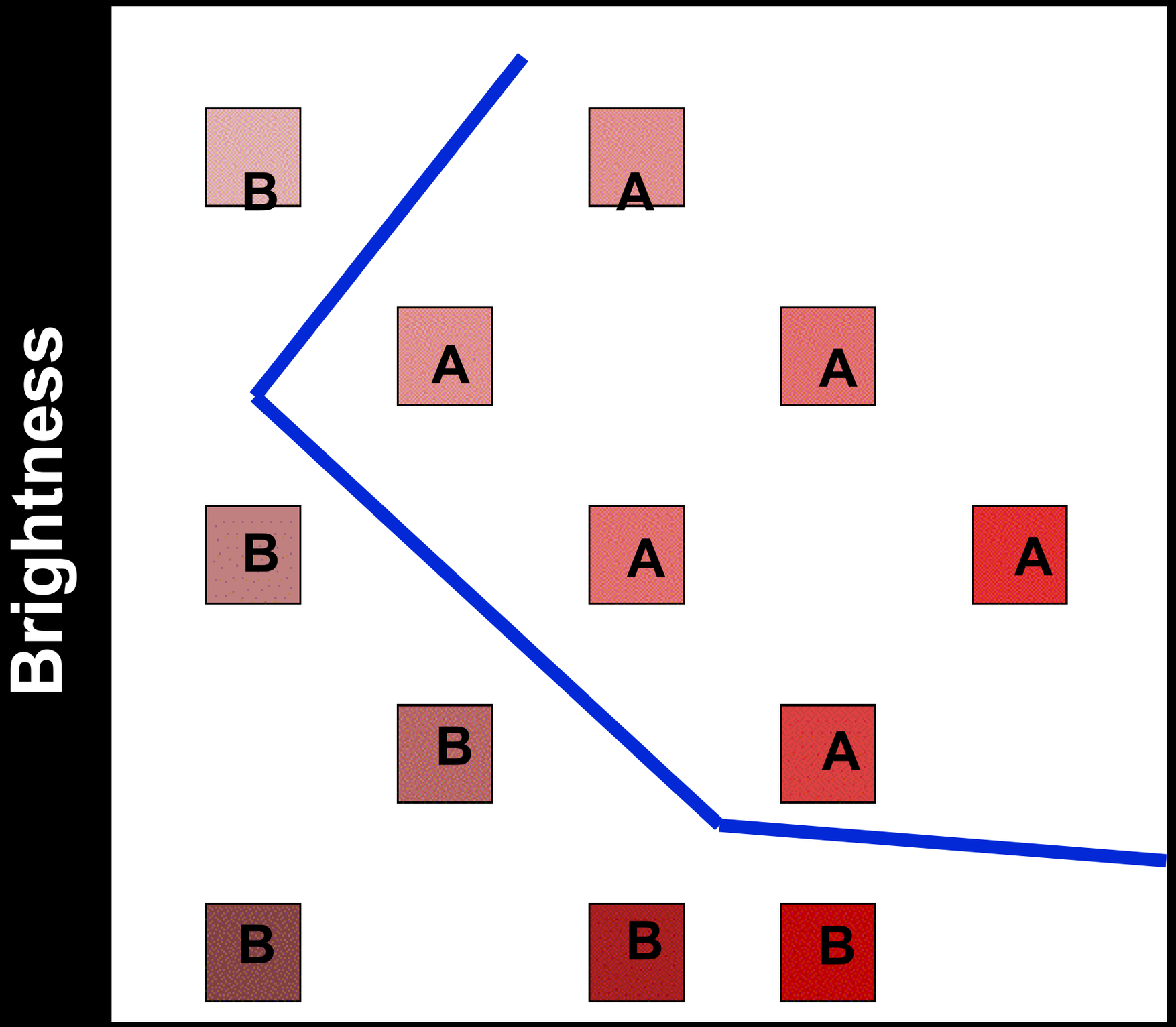

proportion of trials missed
Proportion of Trials Missed
0.6
0.5
0.4
0.3
0.2
0.1
0
3
7
17
injection day
Vehicle
0.04 SCH
0.08 SCH
0.16 SCH


Choi et al. (2005)
Proportion of Trials Missed
0.6
0.5
0.4
0.3
0.2
0.1
0
3
7
17
injection day
Vehicle
0.04 SCH
0.08 SCH
0.16 SCH

Proportion of Trials Missed
0.6
0.5
0.4
0.3
0.2
0.1
0
3
7
17
Injection Day
Vehicle
0.04 SCH
0.08 SCH
0.16 SCH

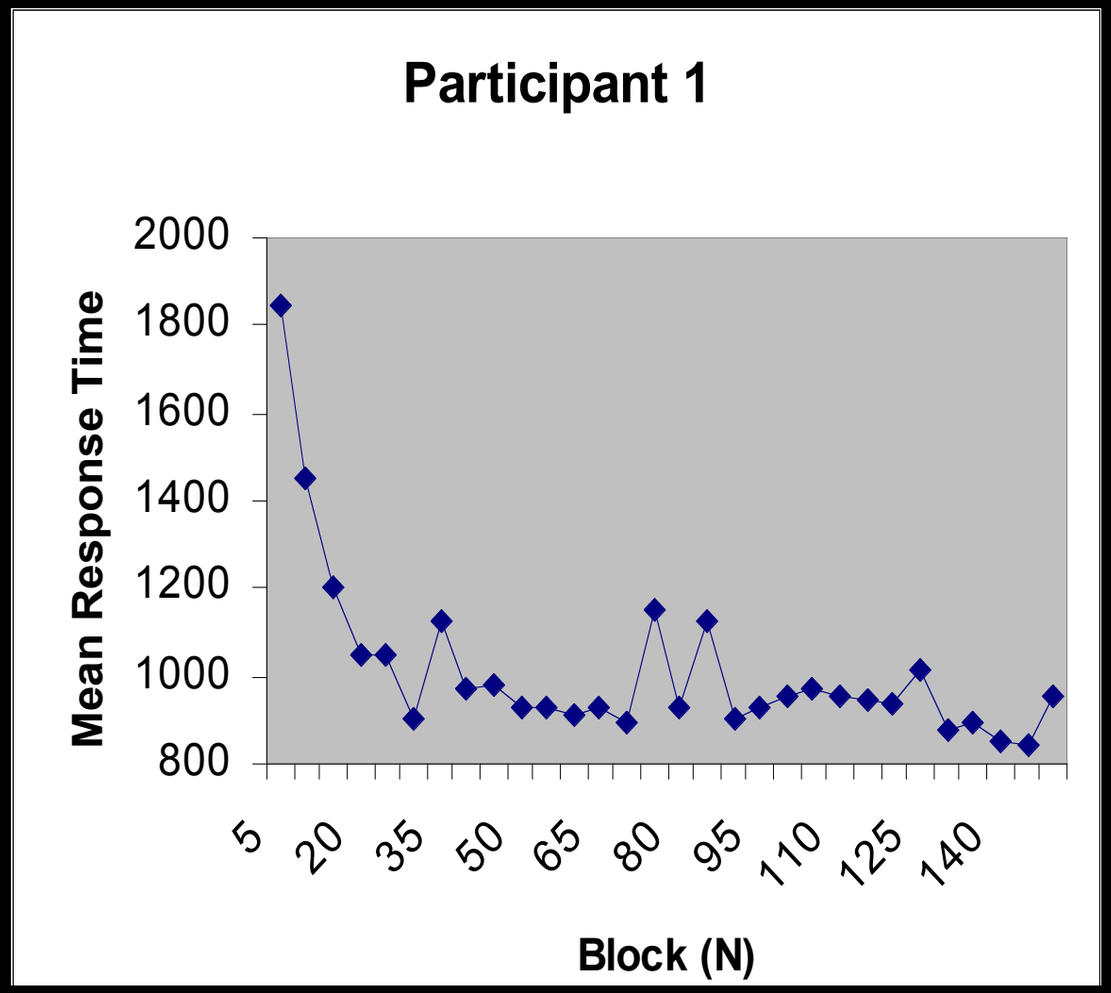
SPEED

Nosofsky & Palmeri (1997)

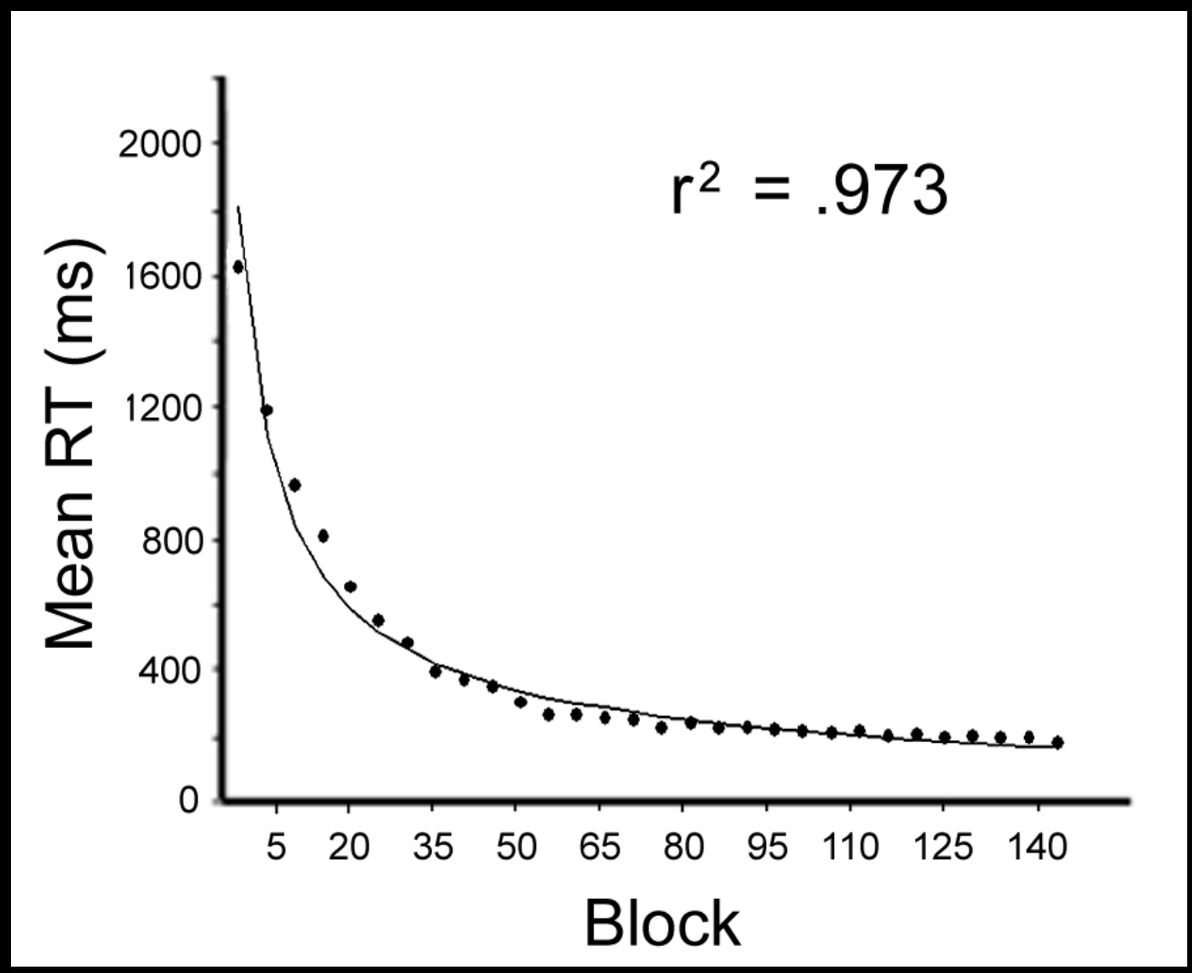


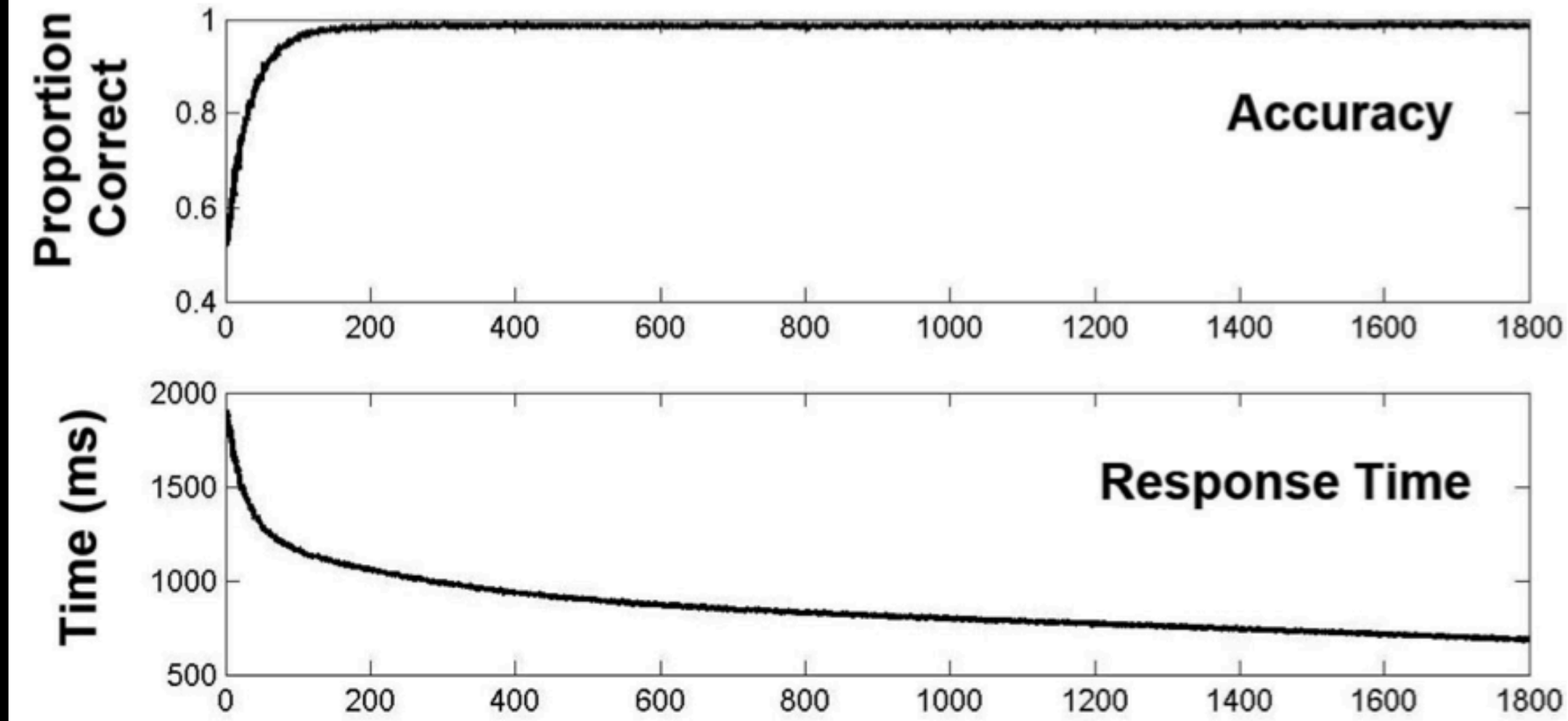
Saturation

Nosofsky & Palmeri (1997)



SPEED




Proportion Correct
1
0.8
0.6
0.4
Accuracy
0
200
400
600
800
1000
1200
1400
1600
1800
Time (ms)
2000
1500
1000
500
Response Time
0
200
400
600
800
1000
1200
1400
1600
1800

SPEED

UPDATES

Behavior Research Methods
2008, 40 (3), 713-721
doi: 10.3758/BRM.40.3.713

Fitting computational models to fMRI data

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University of California, Santa Barbara, California

NeuroImage 56 (2011) 1791–1802

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

Cortical and striatal contributions to automaticity in information-integration categorization

Jennifer G. Waldschmidt, F. Gregory Ashby *

University of California, Santa Barbara, USA

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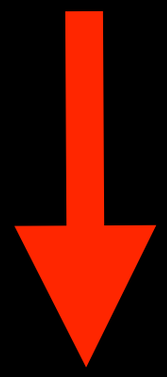
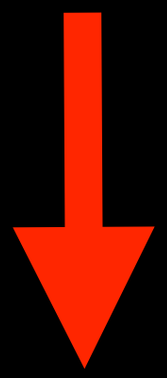
bspiering@gmail.com


THANK
YOU

Input

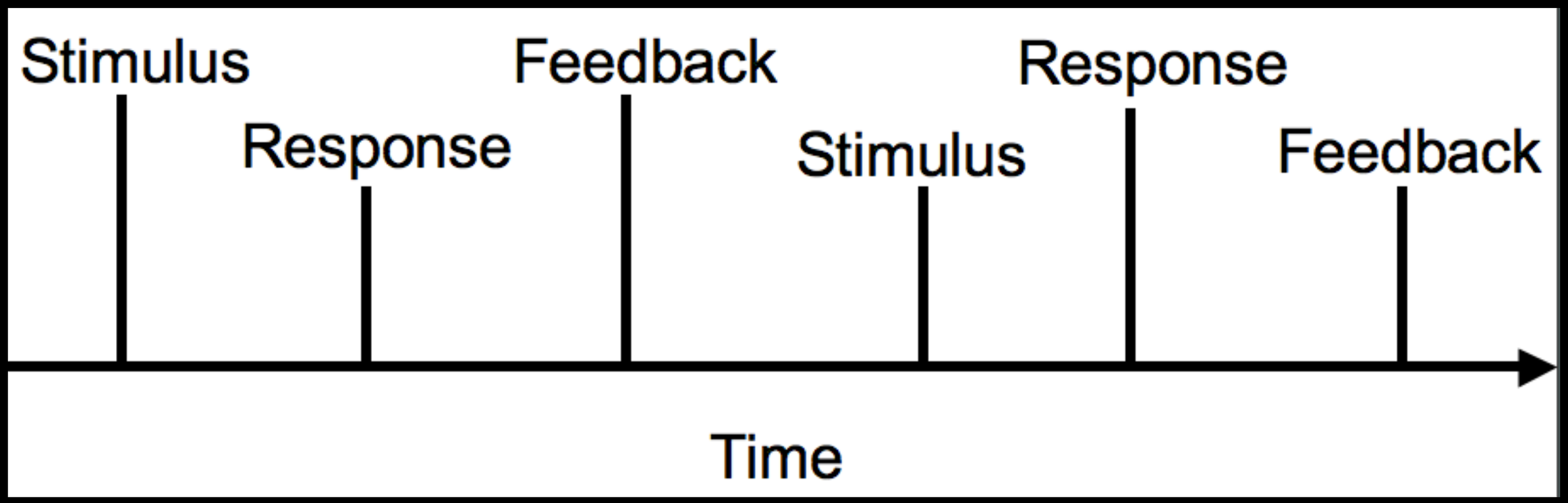


Black Box

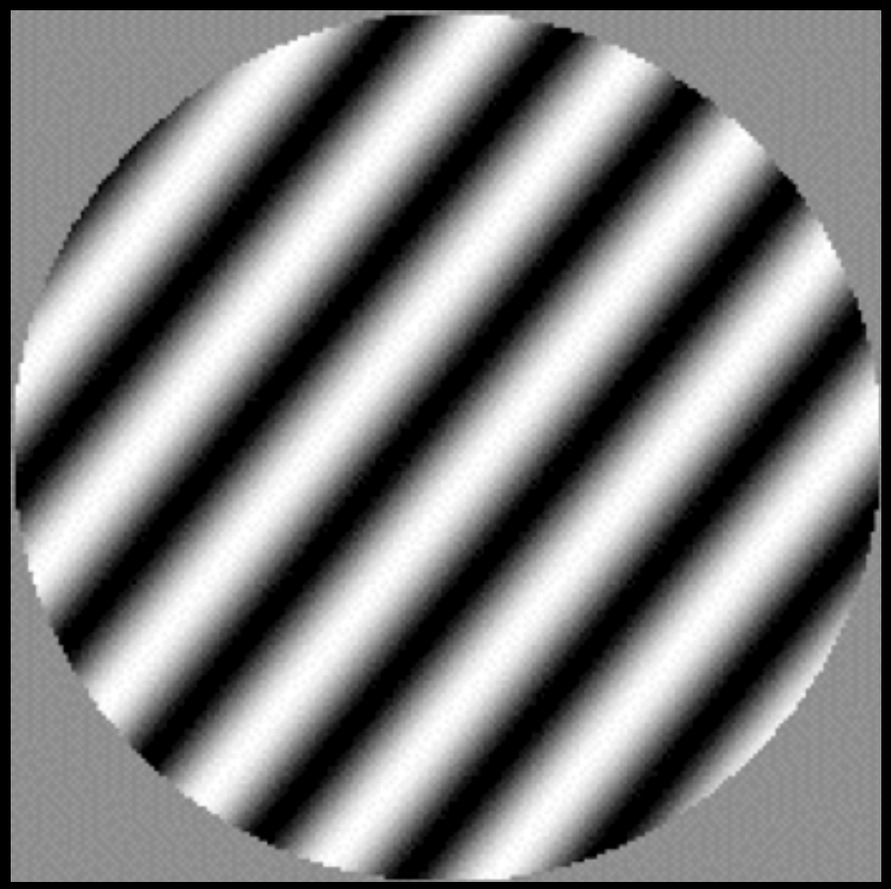


Output

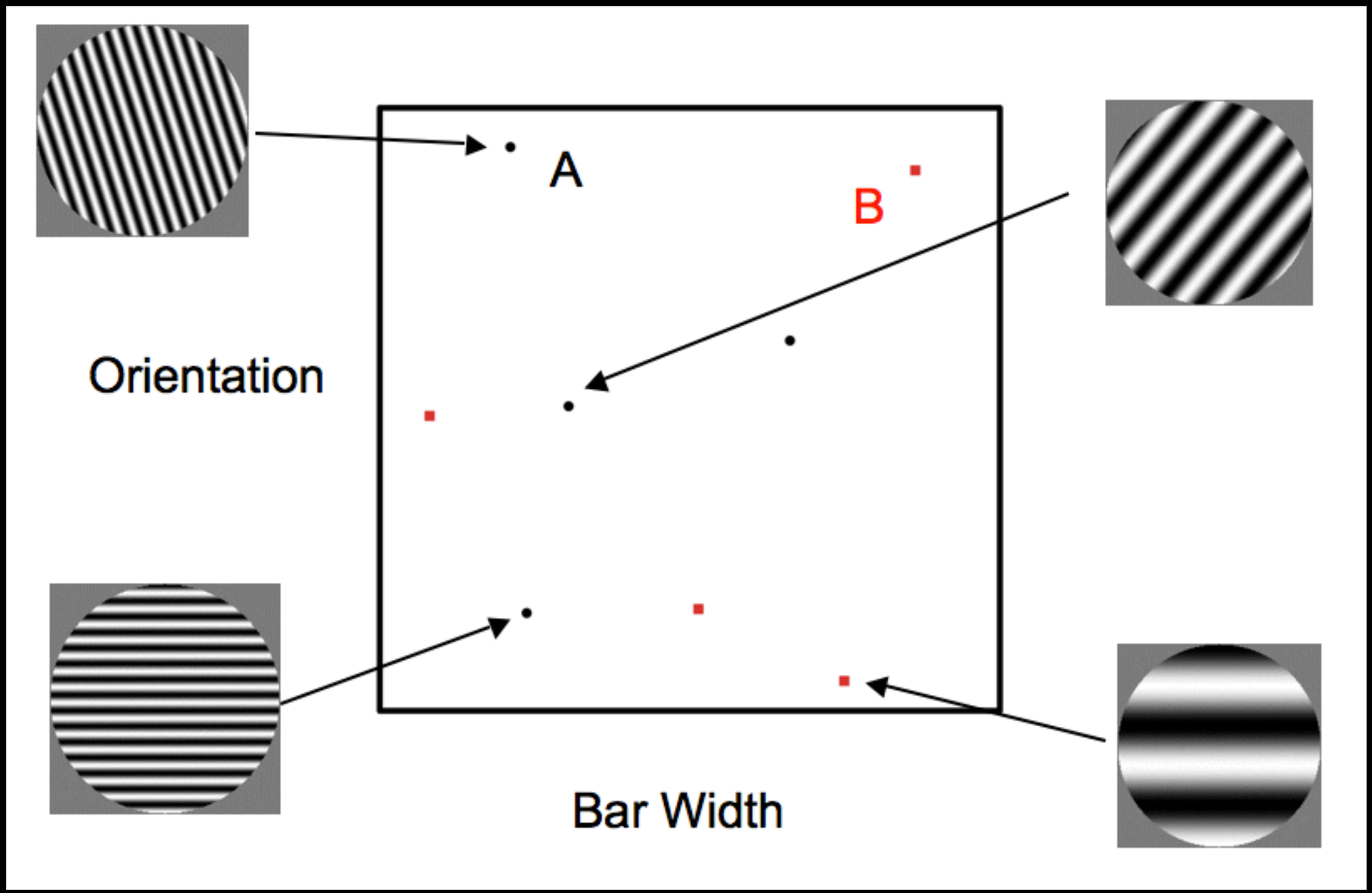
Category Learning Task



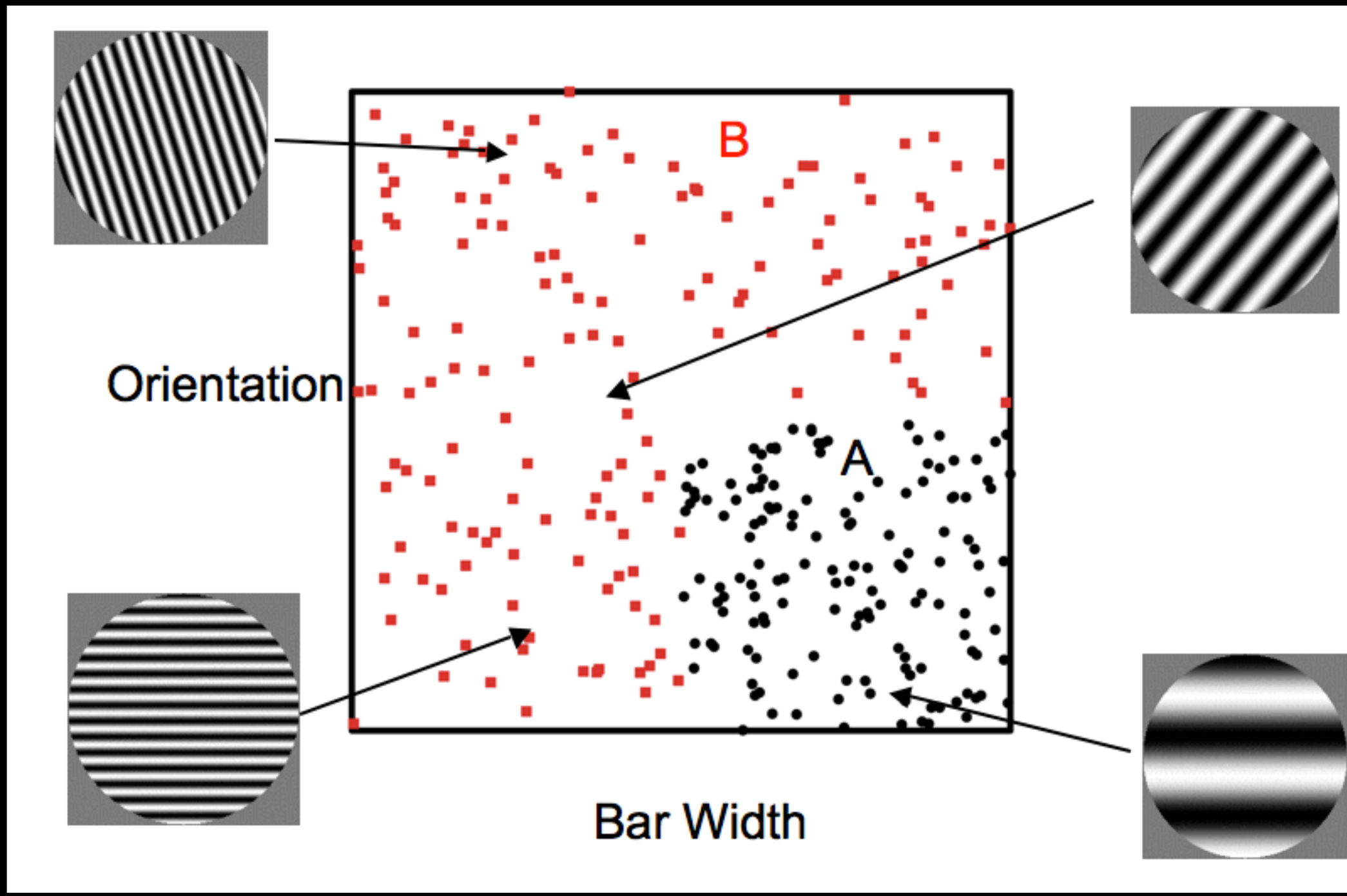
Category Learning Stimuli



Unstructured Categorization



Rule-Based Categorization



Information-Integration Categorization