Topics:

1. Basics of eye movements
2. The eye plant and the brainstem nuclei
3. The superior colliculus
4. Visual inputs for saccade generation
5. Cortical structures involved in saccadic eye-movement control
6. The effects of paired electrical and visual stimulation
7. The effects of lesions on eye movement
8. Pharmacological studies

5. Cortical areas involved in saccadic eye-movement control

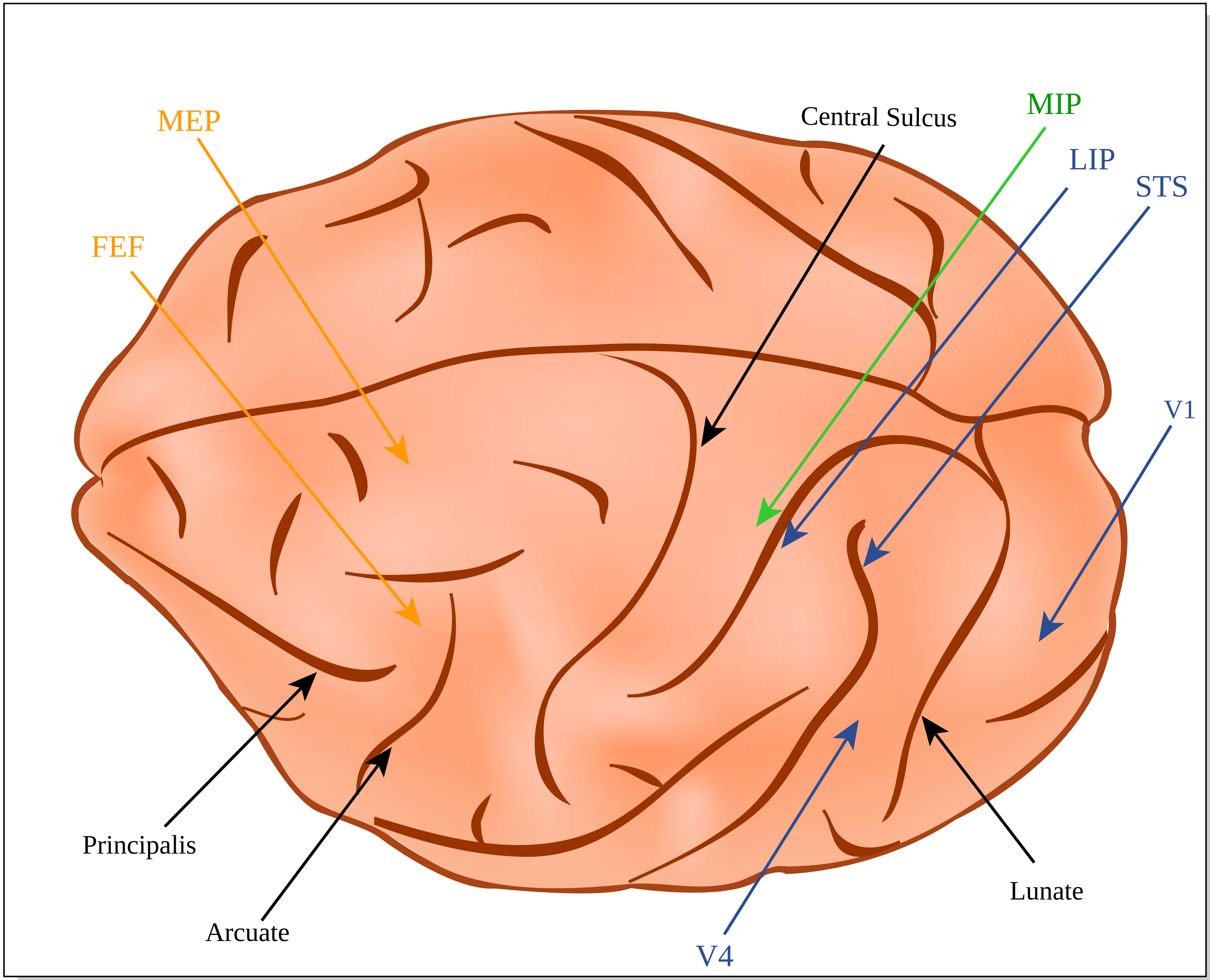
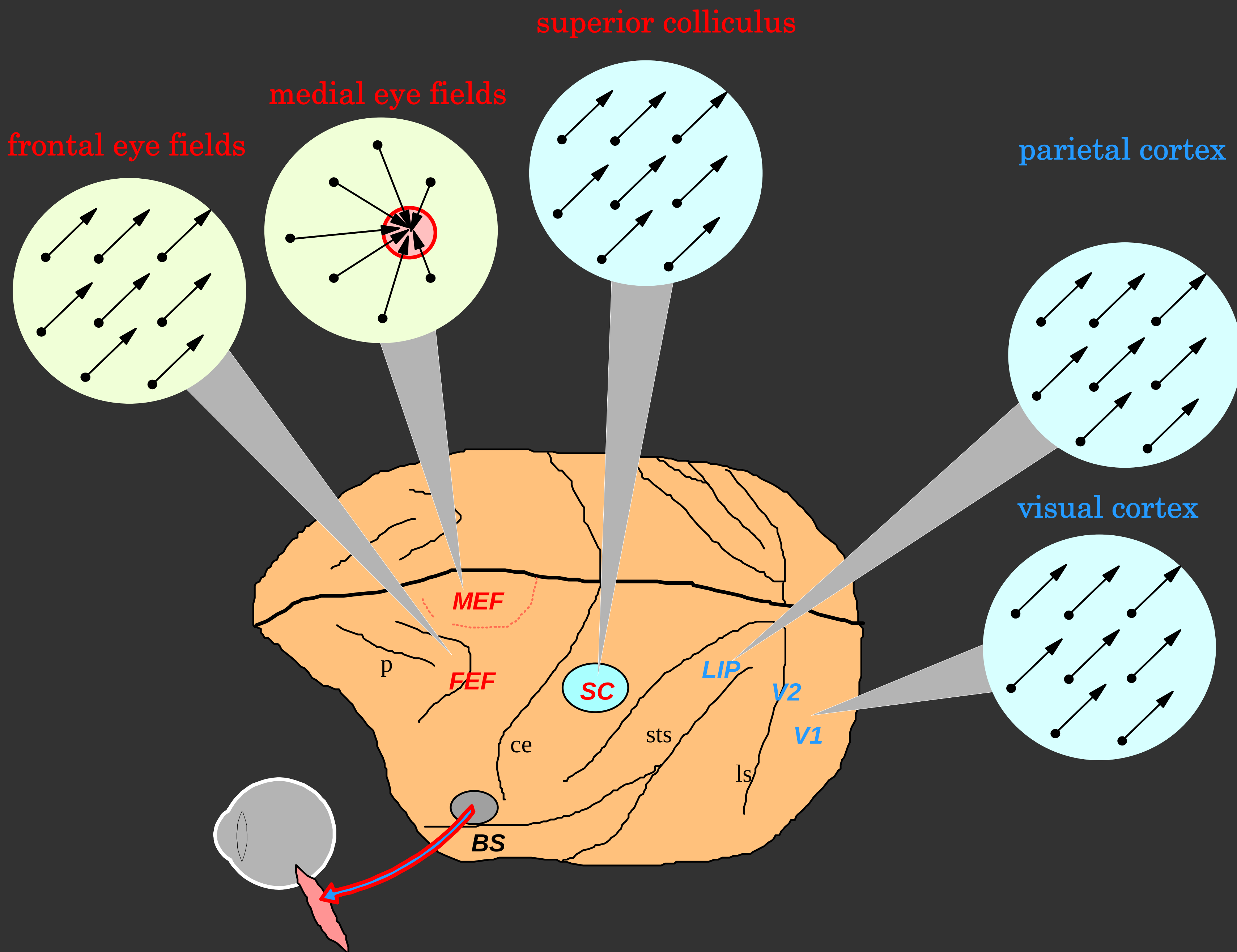
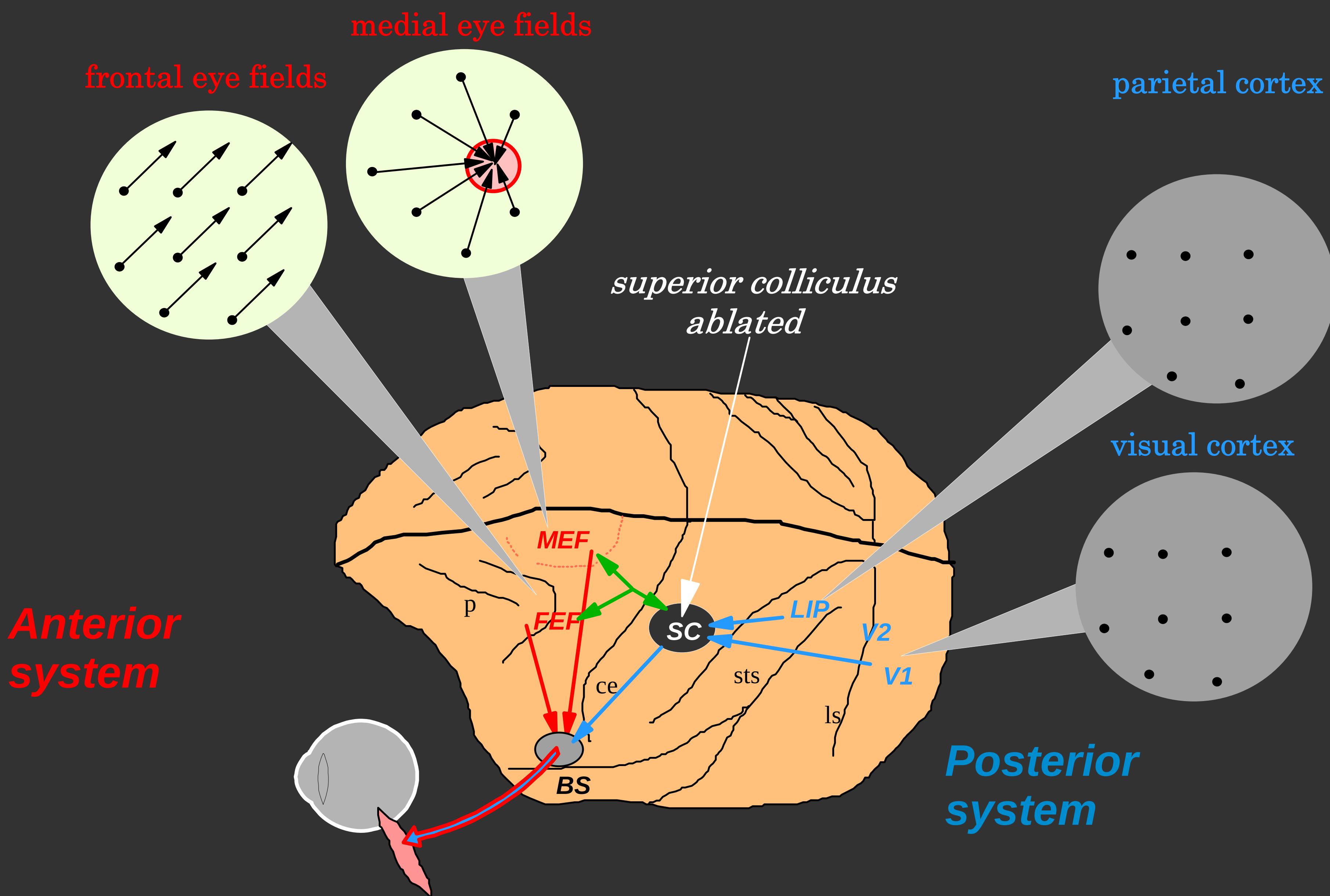


Image by MIT OpenCourseWare.

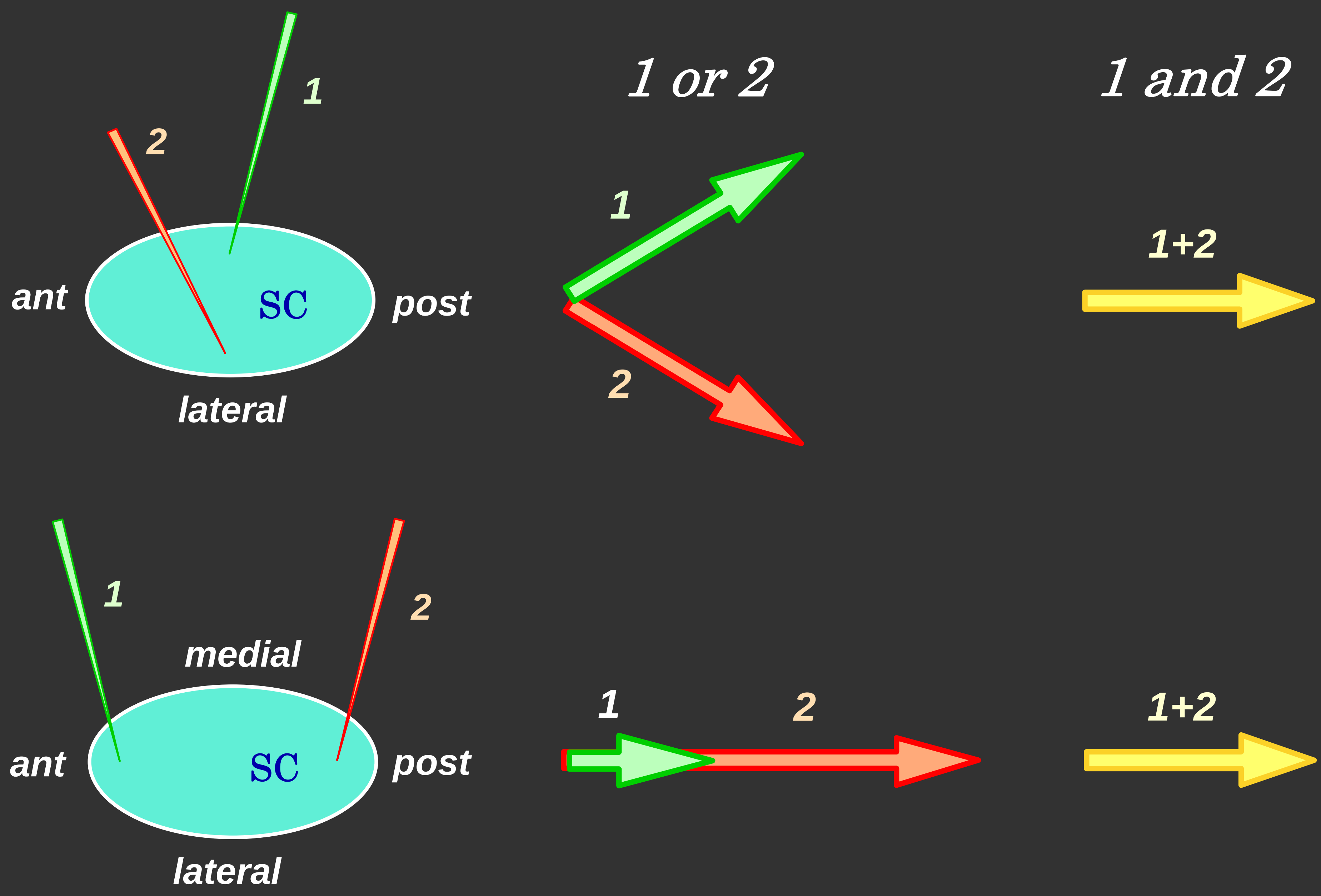


superior colliculus
medial eye fields
frontal eye fields
parietal cortex
visual cortex
MEF
FEF
p
SC
LIP
V2
V1
ce
sts
ls
BS

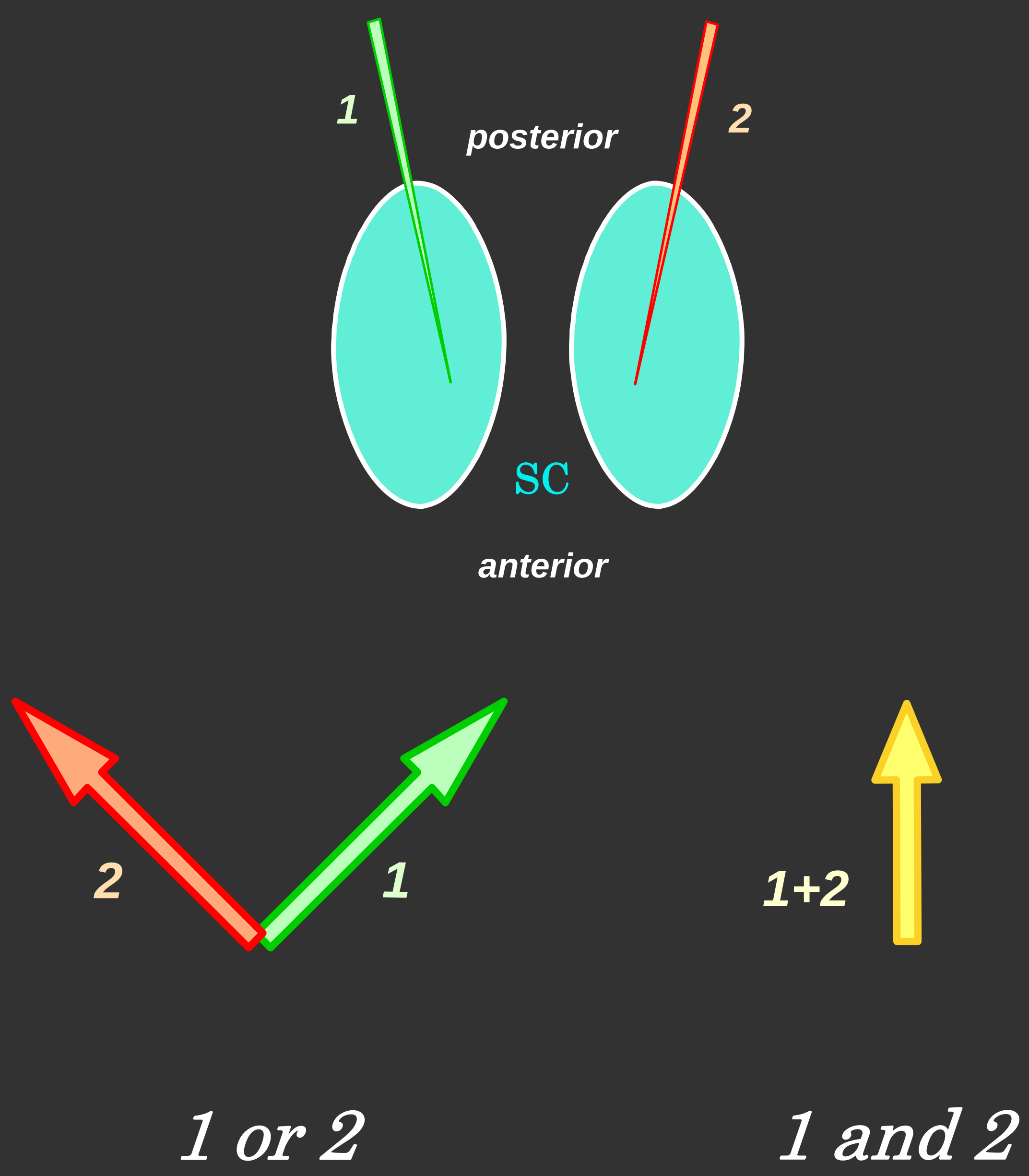

medial eye fields
frontal eye fields
parietal cortex
superior colliculus ablated
visual cortex
MEF
FEF
p
SC
LIP
V2
V1
ce
sts
ls
BS
Anterior system
Posterior system

6. The effects of paired electrical and visual stimulation

The effect of paired electrical stimulation in the superior colliculus



The effect of paired elecectrical stimulation in the left and right colliculi



Eye movements made to paired targets

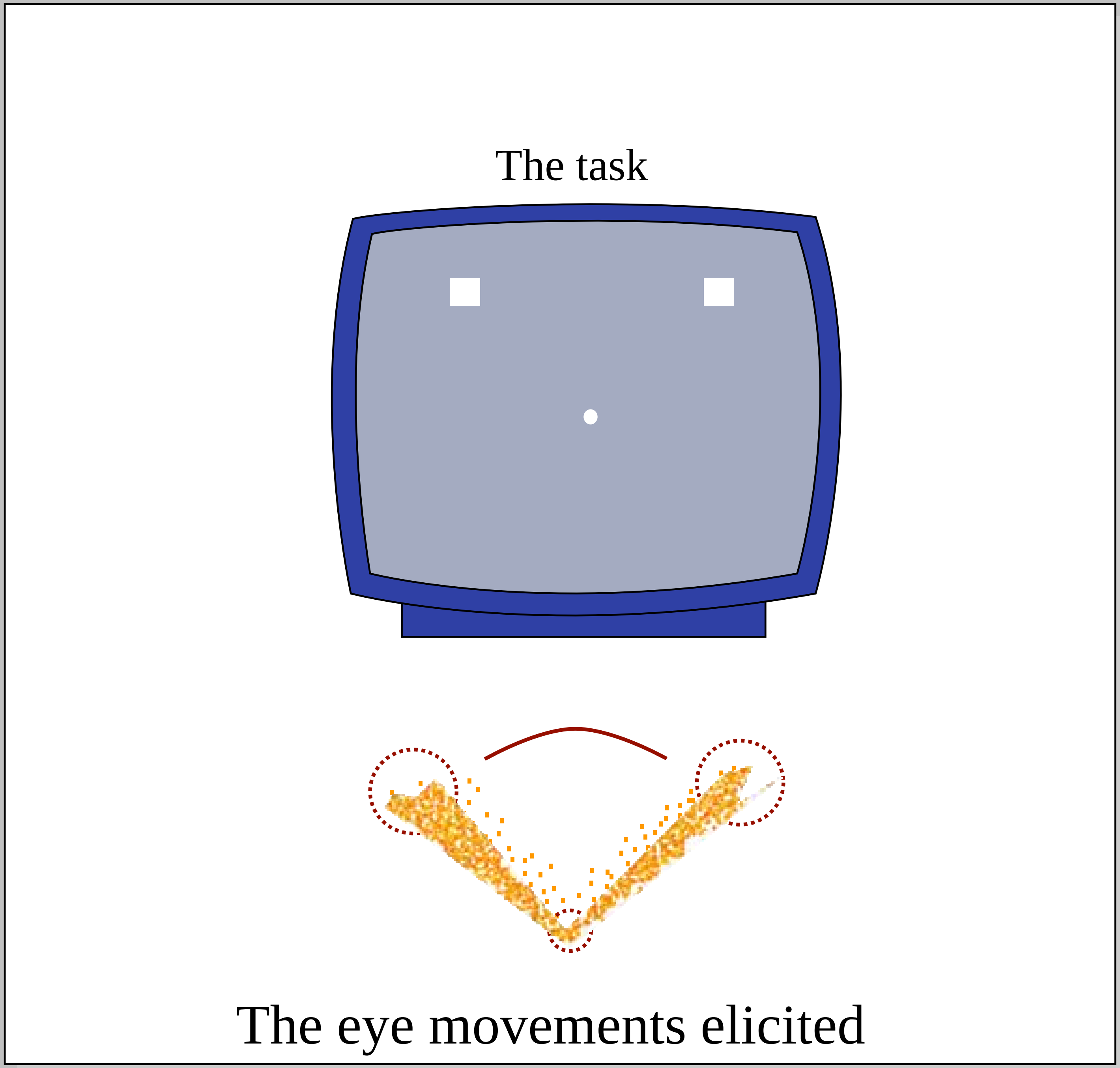
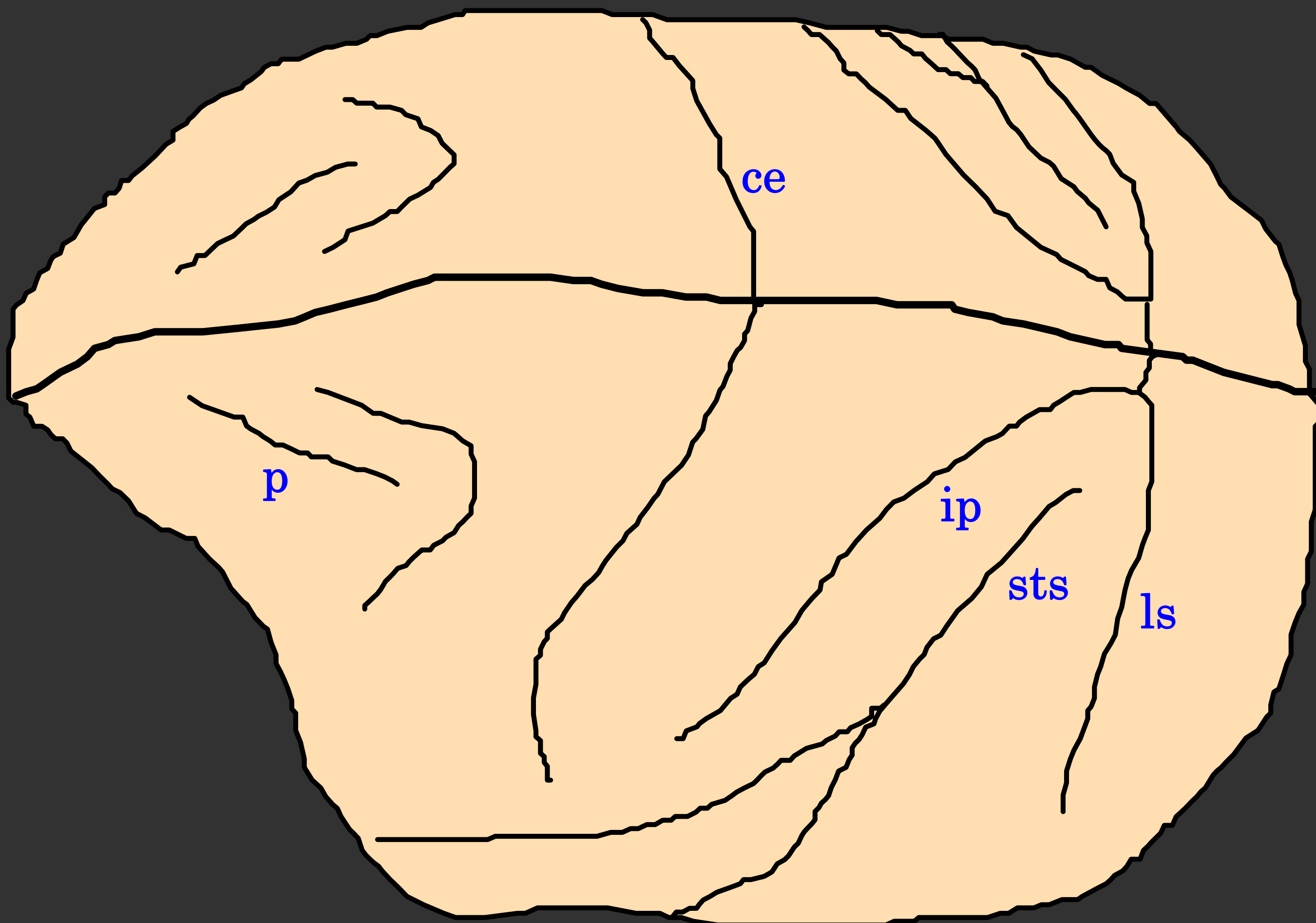


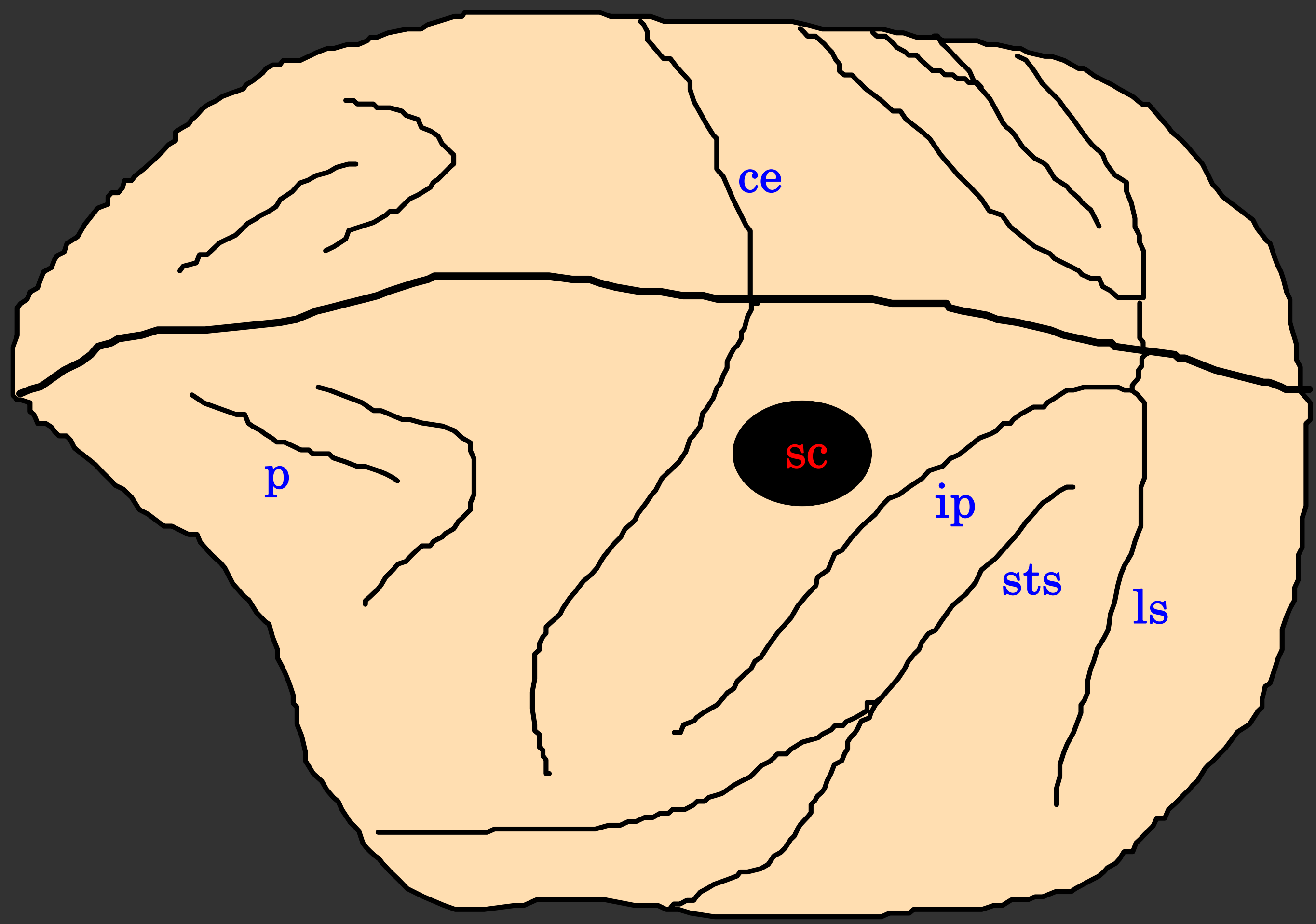
Image by MIT OpenCourseWare.

7. The effect of lesions on eye-movement control

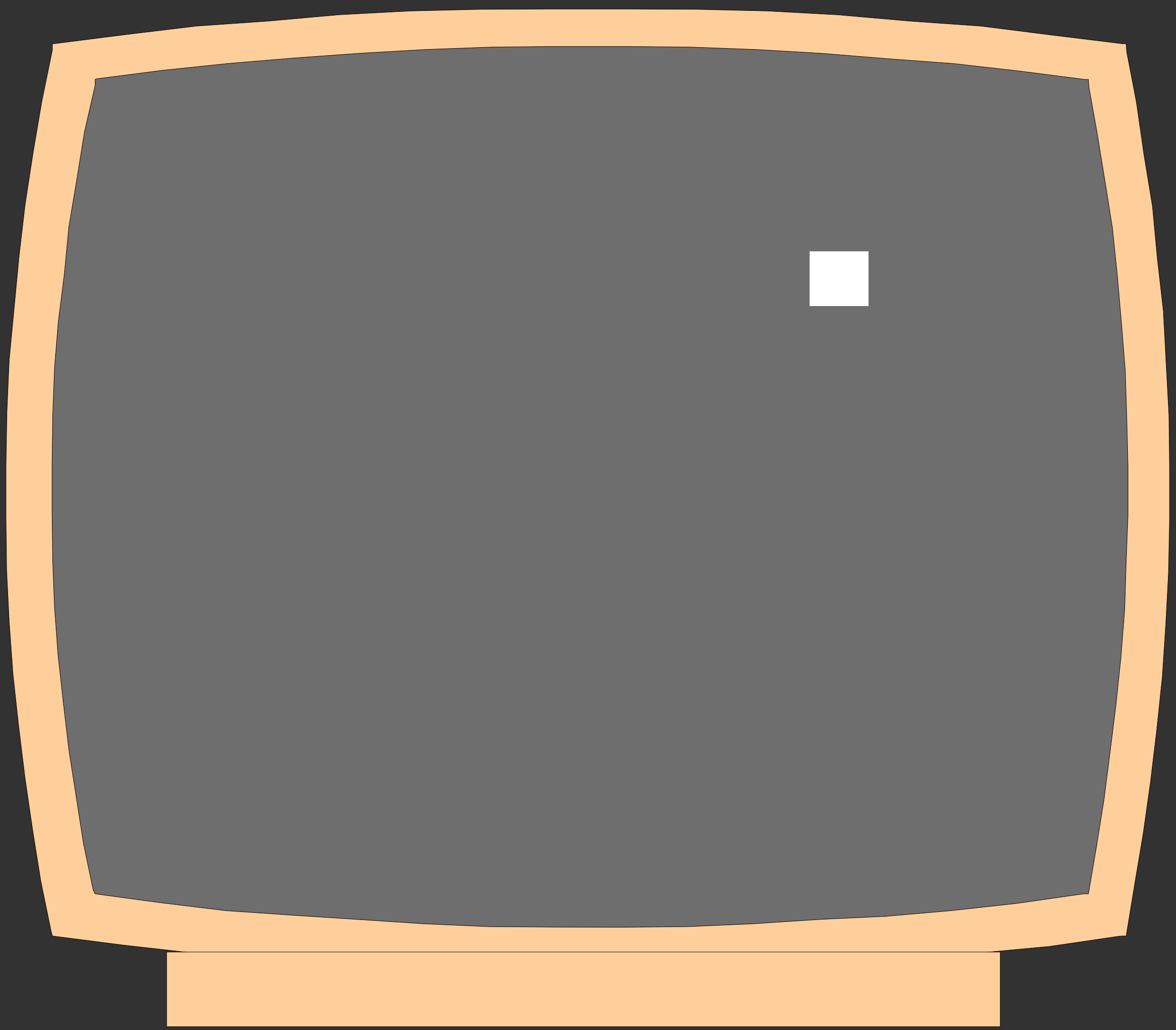
Informal testing, intact monkey



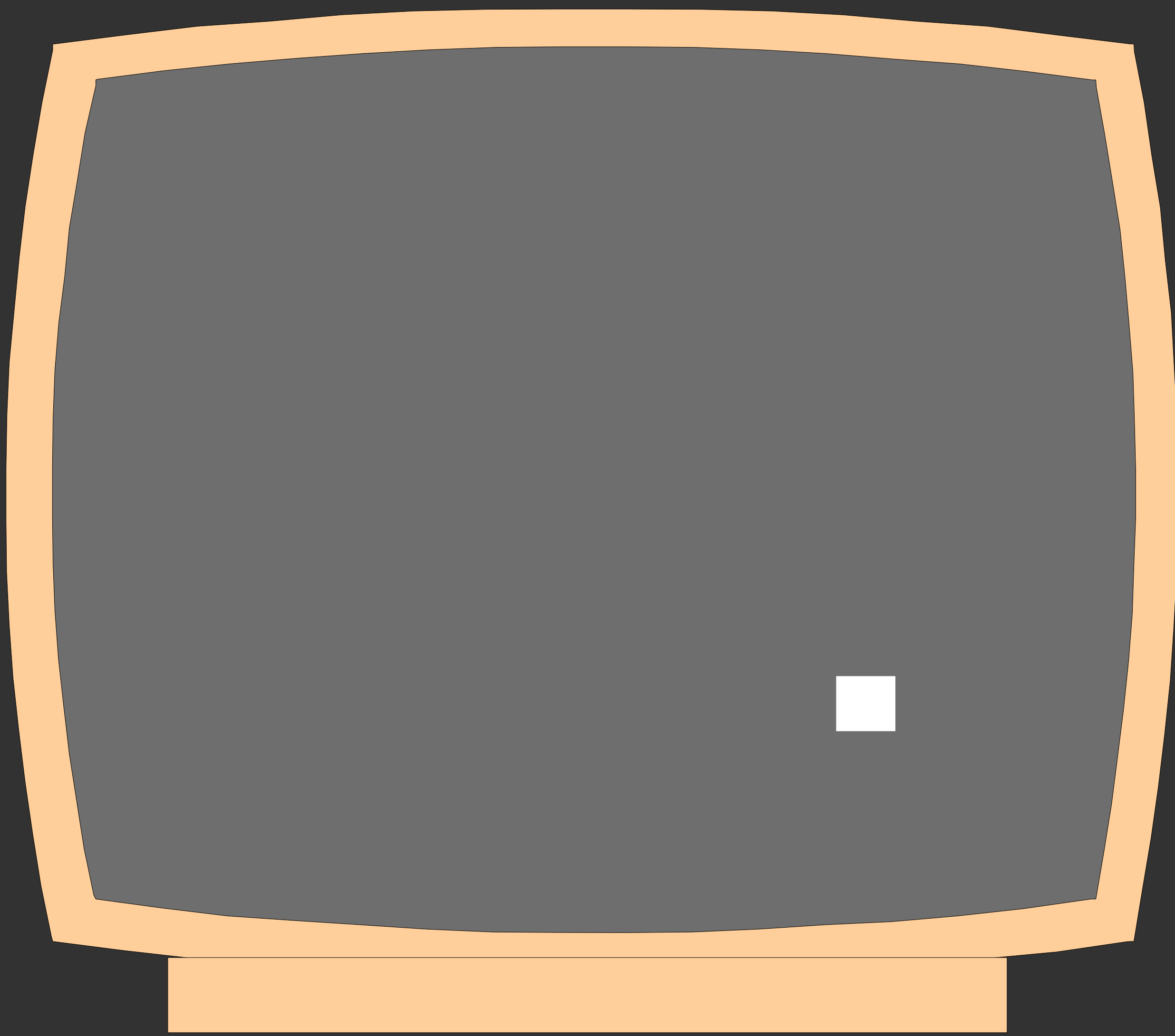
Informal testing after superior colliculus ablation



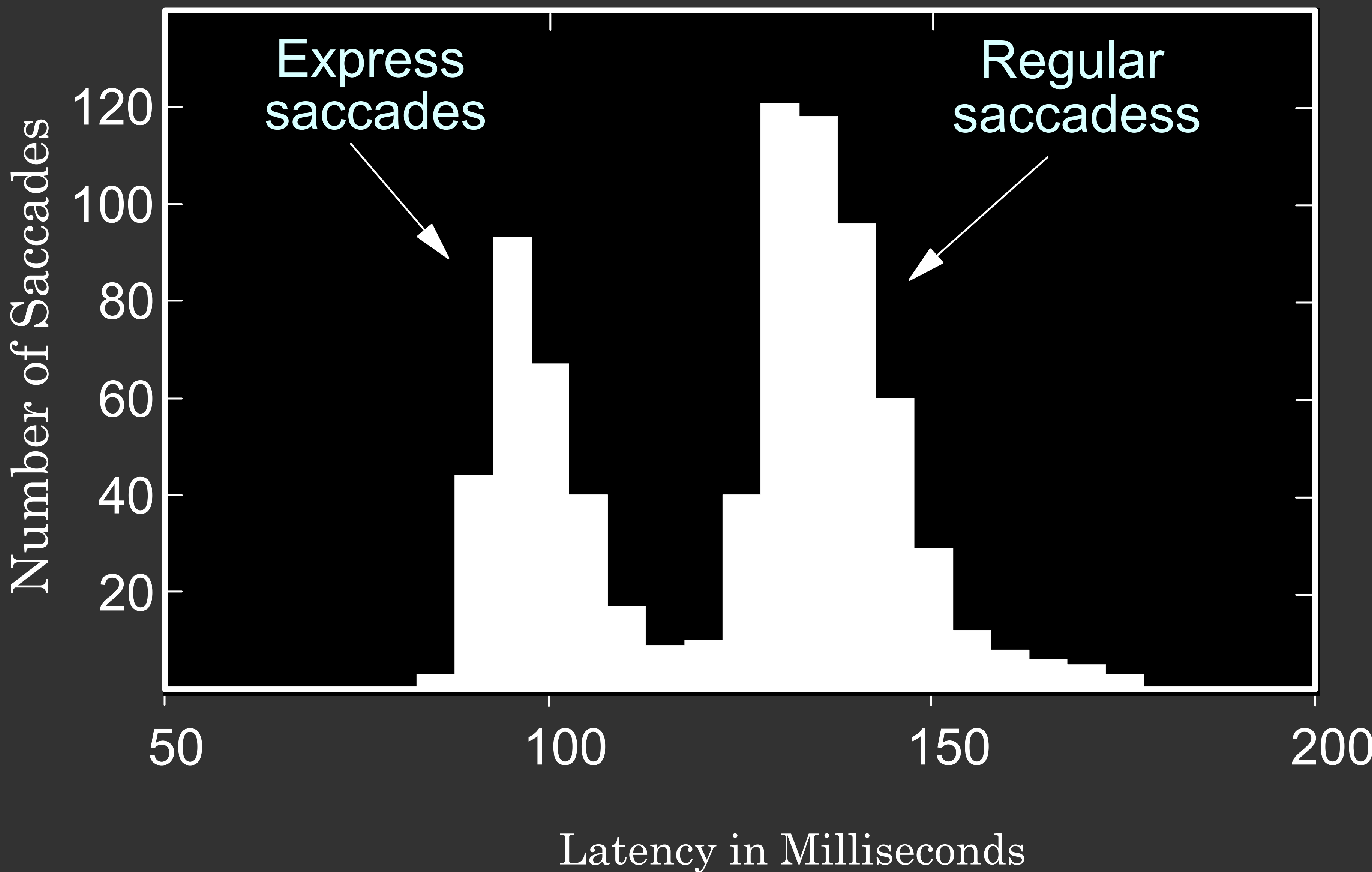
Single target task



Single target task

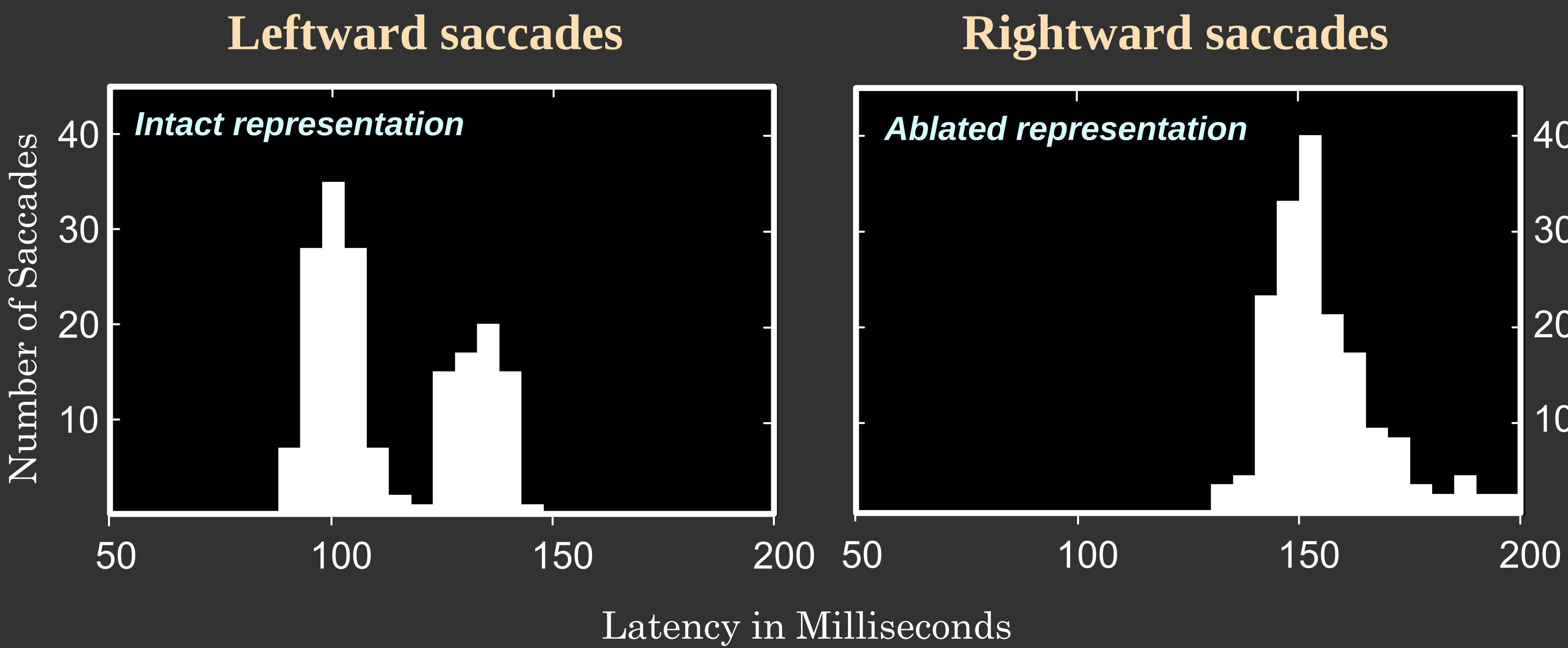


Distribution of saccadic latencies in intact monkey



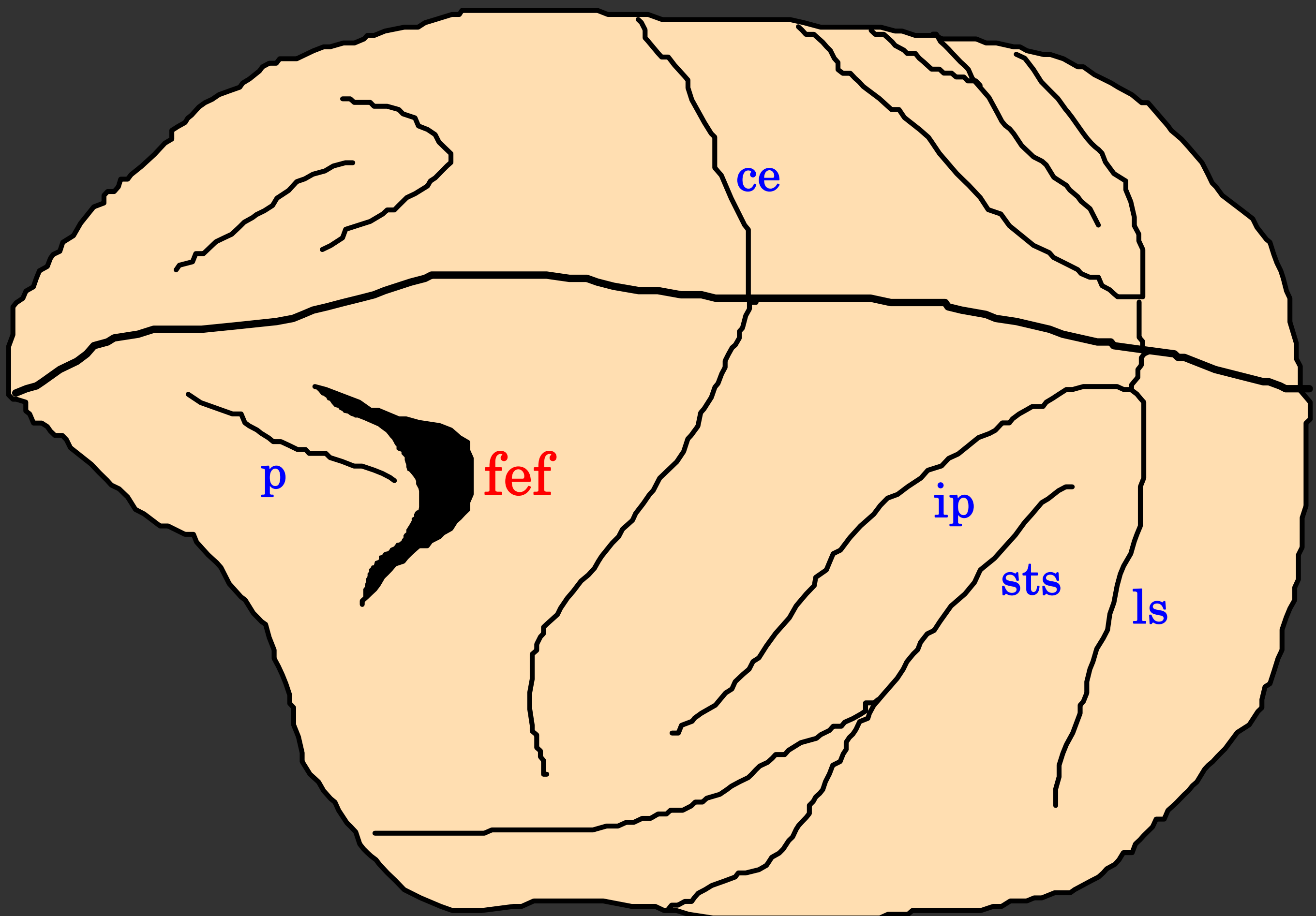
Schiller, Peter H., and Edward J. Tehovnik. "Look and See: How the Brain Moves Your Eyes About." *Progress in Brain Research* 134 (2001): 127-42. Courtesy of Elsevier, Inc., http://www.sciencedirect.com. Used with permission.

Distribution of saccadic latencies ten weeks after left superior colliculus lesion

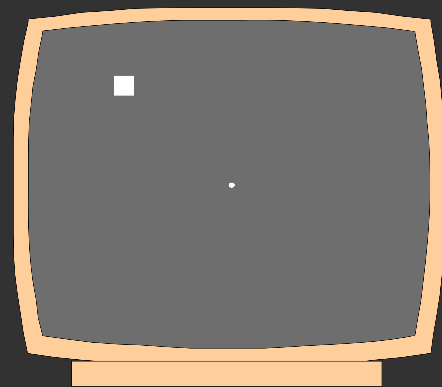


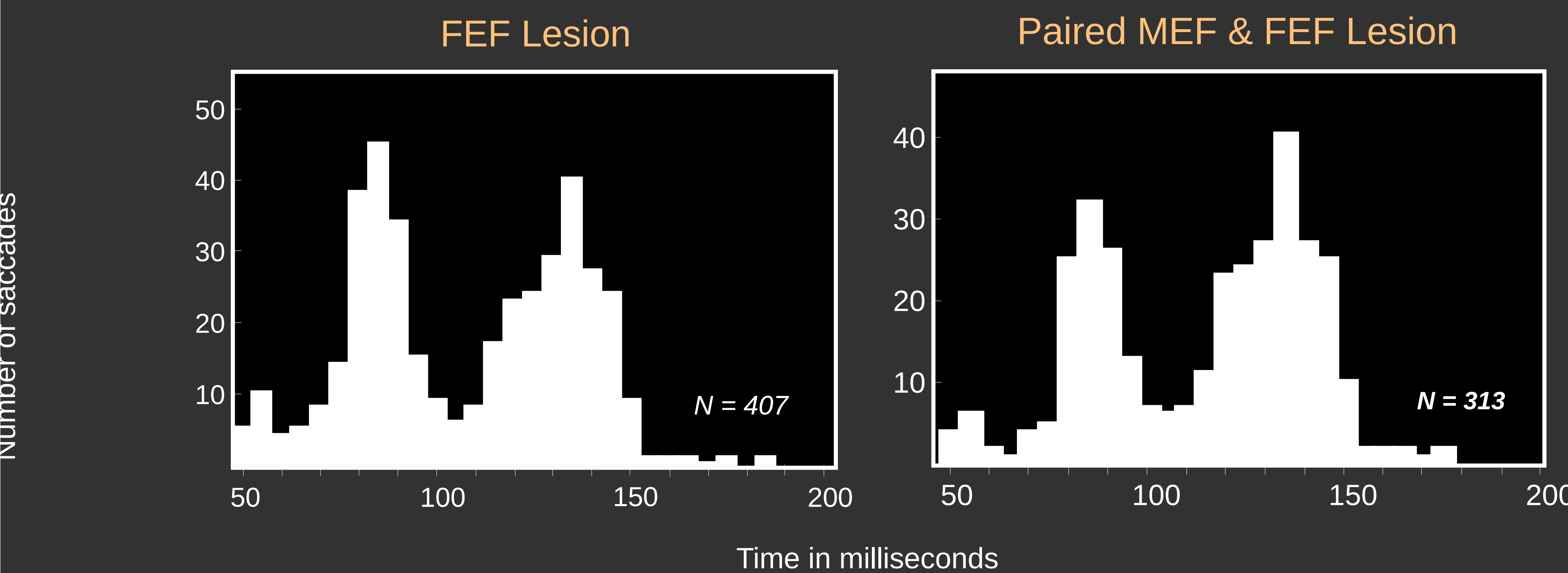
Schiller, Peter H., and Edward J. Tehovnik. "Look and See: How the Brain Moves Your Eyes About." *Progress in Brain Research* 134 (2001): 127-42. Courtesy of Elsevier, Inc., http://www.sciencedirect.com. Used with permission.

Informal testing after frontal eye field ablation



Distribution of saccadic latencies after FEF and MEF lesions





Sequential task

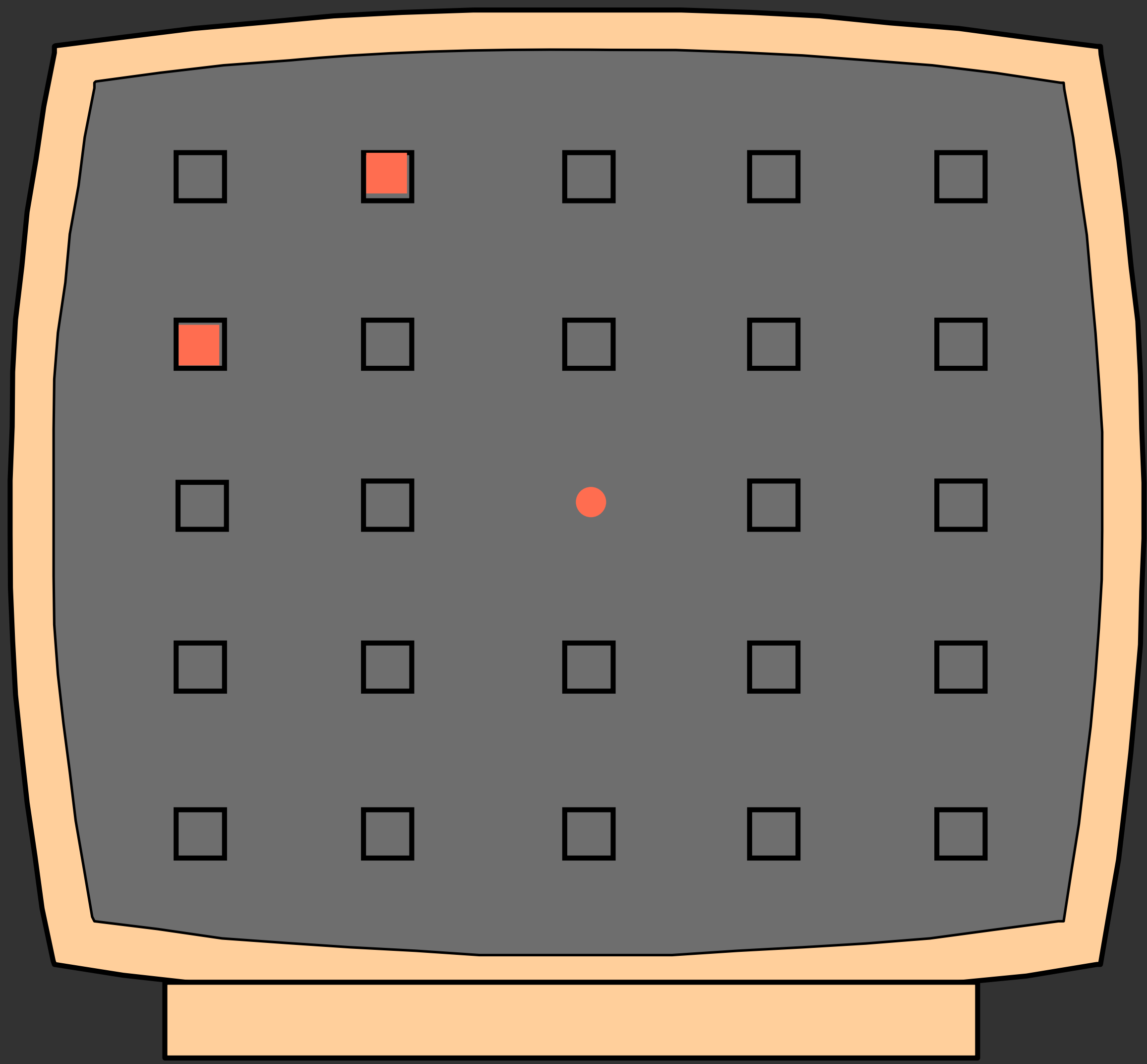


Figure removed due to copyright restrictions.

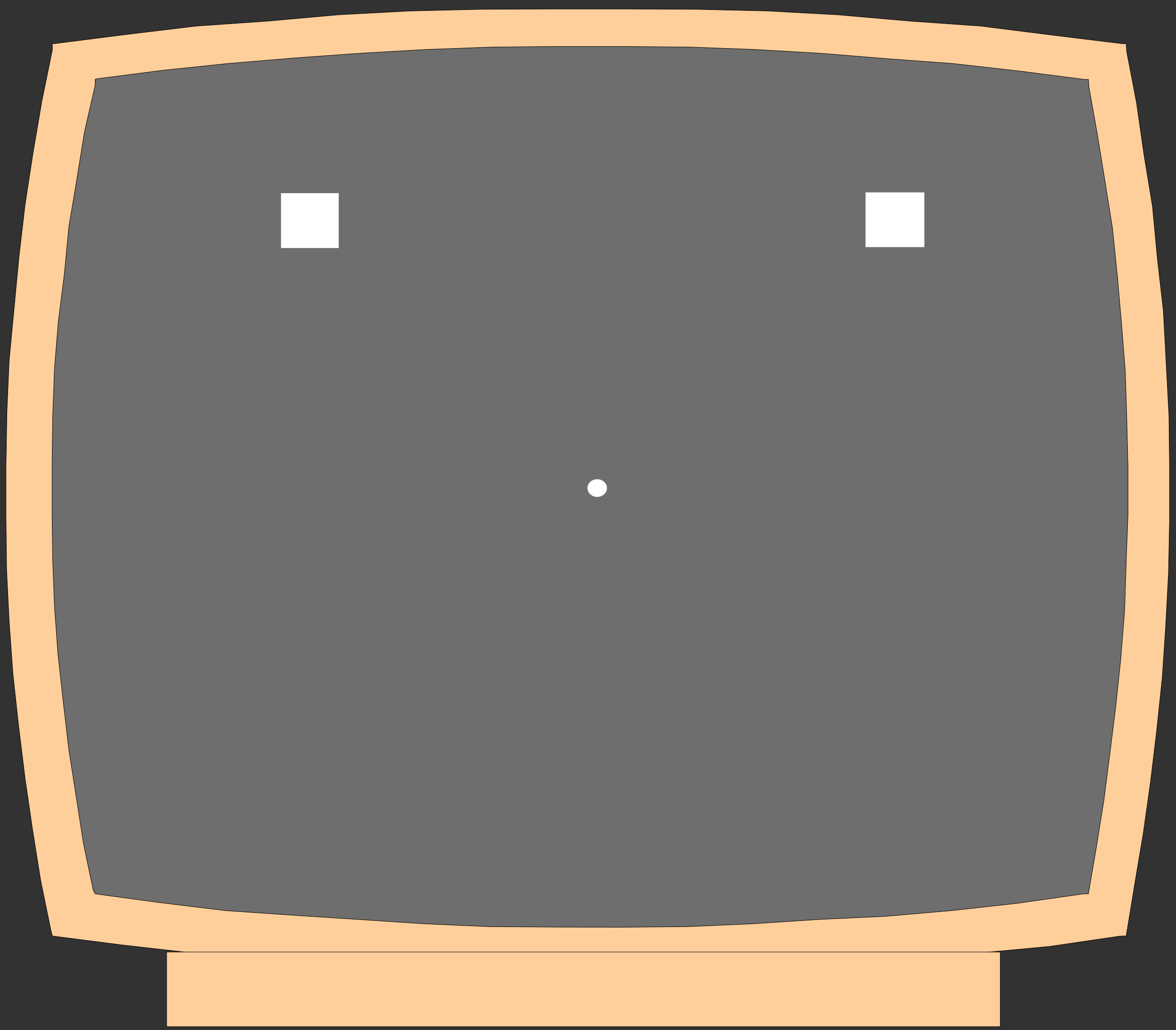
Please see lecture video or Figure 8 from Schiller, Peter H., and Edward J. Tehovnik. "Look and See: How the Brain Moves Your Eyes About." *Progress in Brain Research* 134 (2001): 127-42.

The effect of FEF and MEF lesions on executing sequential saccades

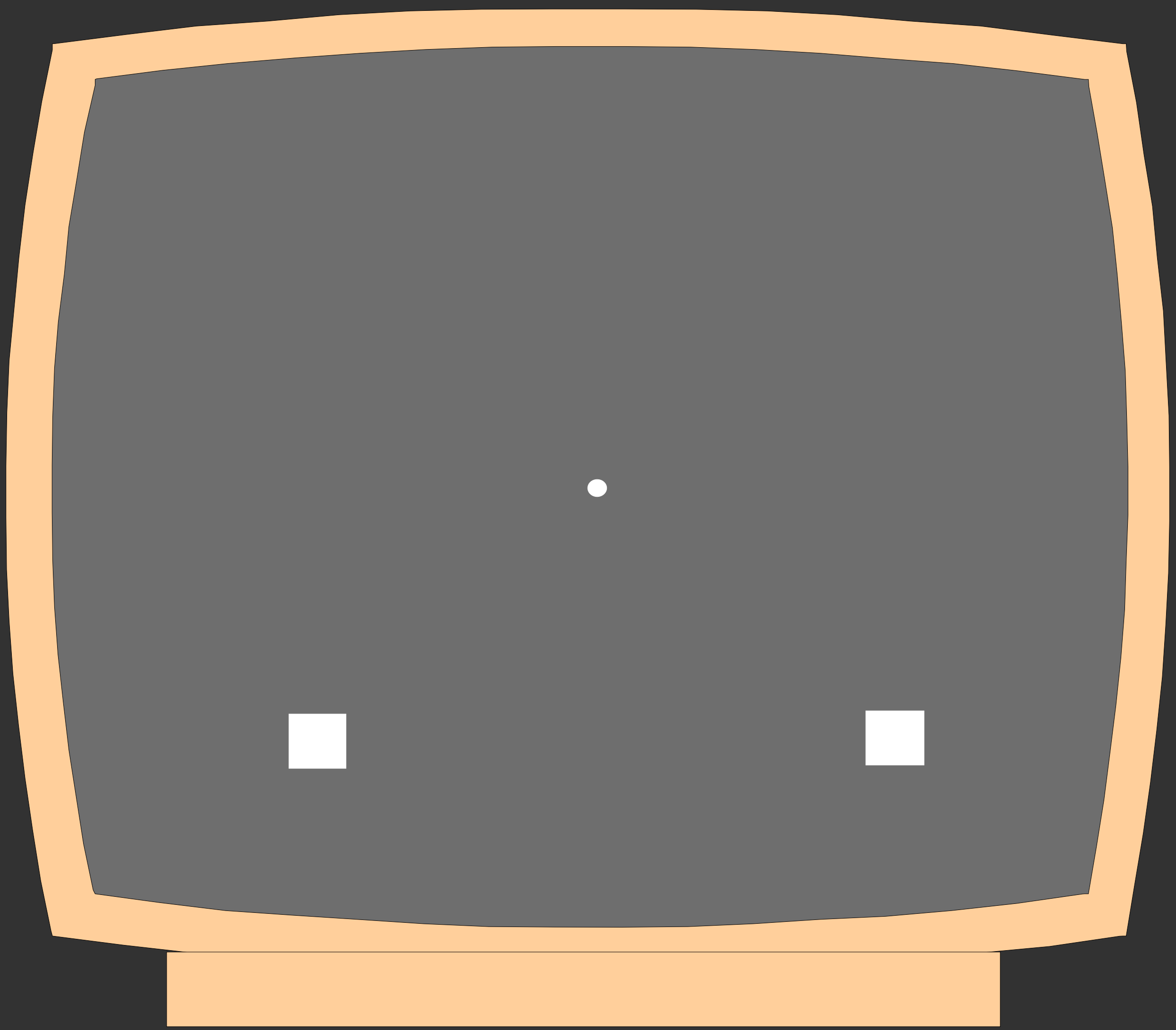
Figure removed due to copyright restrictions.

Please see lecture video or Figure 9 from Schiller, Peter H., and Edward J. Tehovnik. "Look and See: How the Brain Moves Your Eyes About." *Progress in Brain Research* 134 (2001): 127-42.

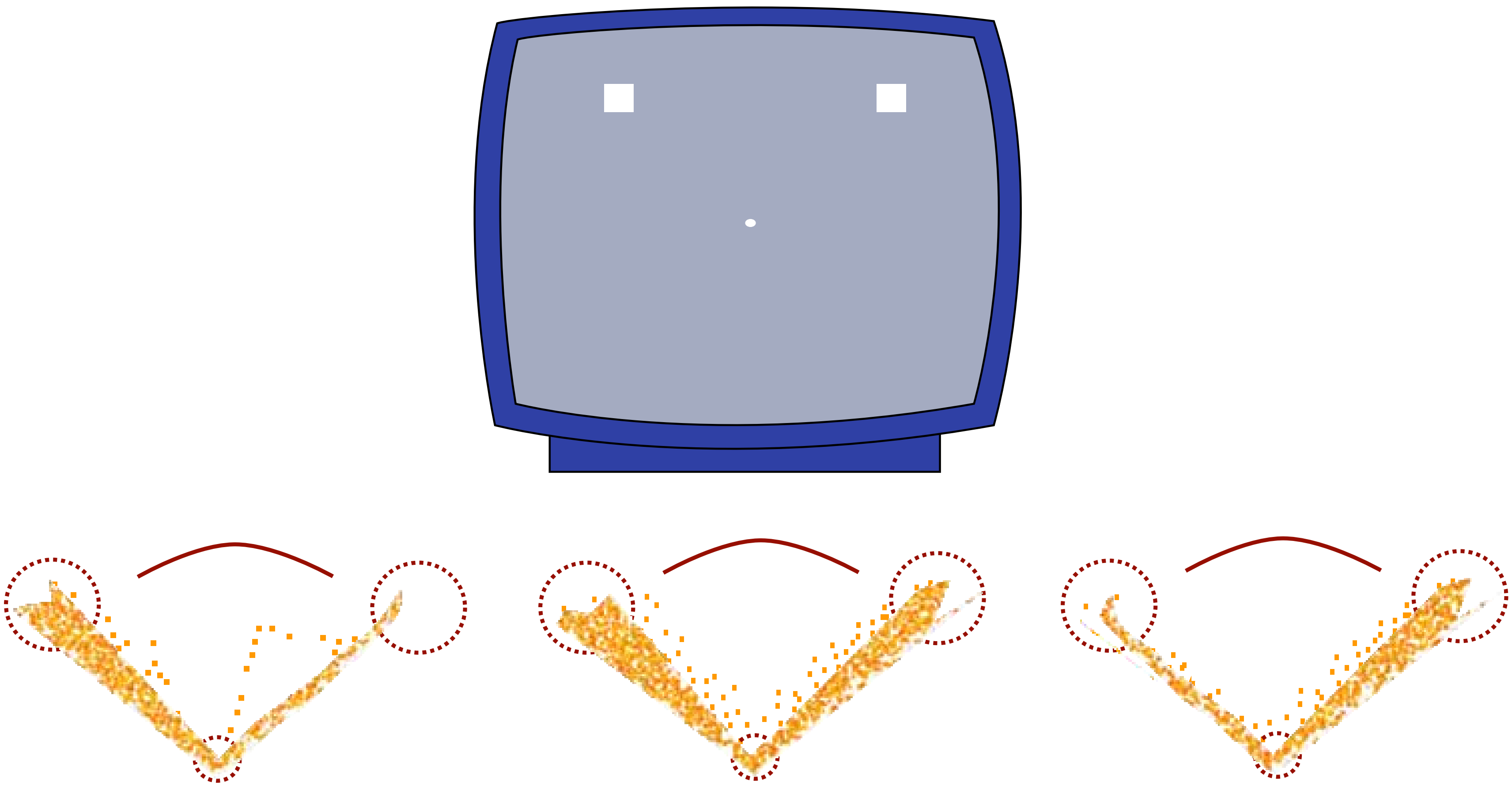
Paired target task, identical targets



Paired target task, identical targets



Eye movements made to paired targets presented with varied asynchronies

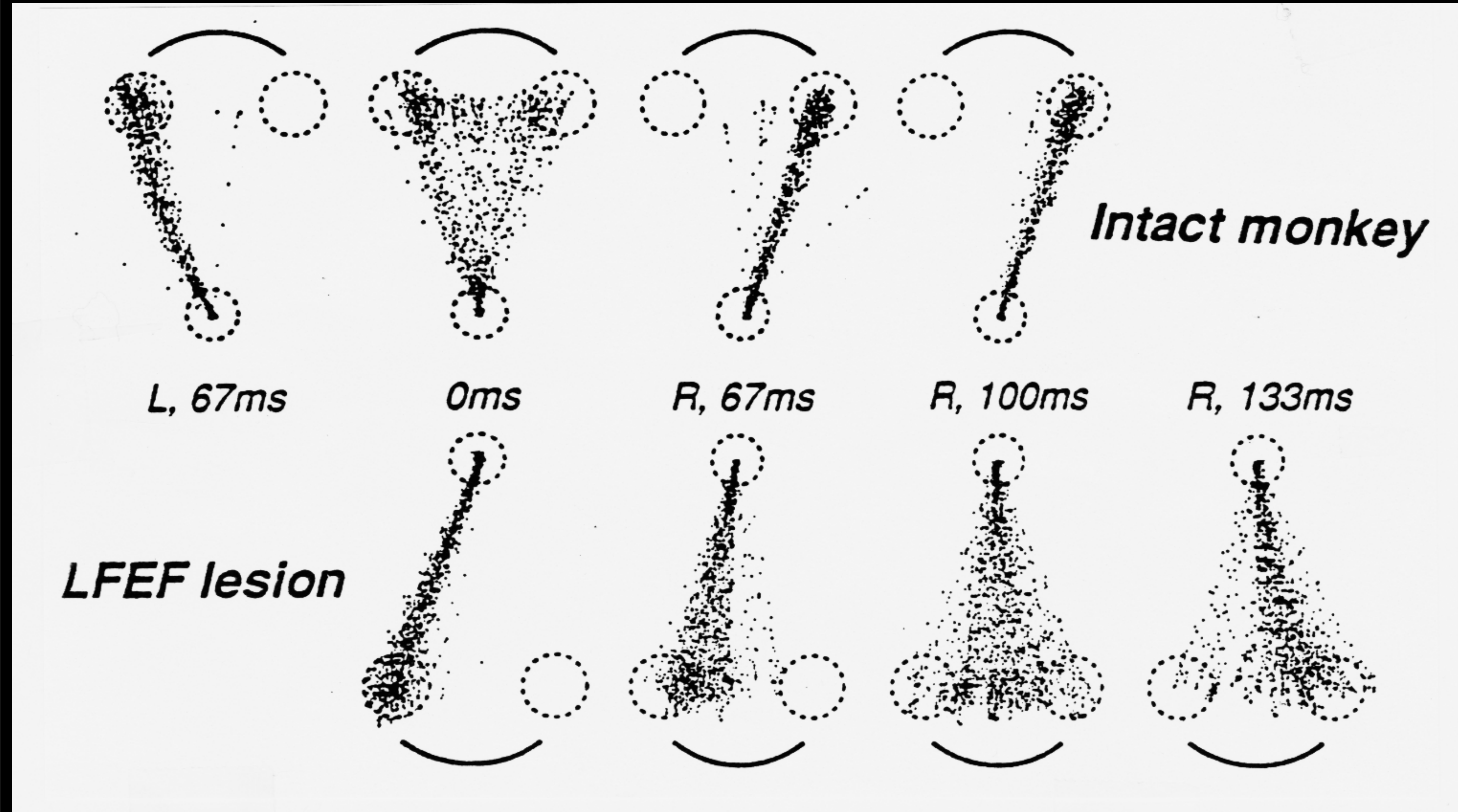


Left 34ms before right

Simultaneous

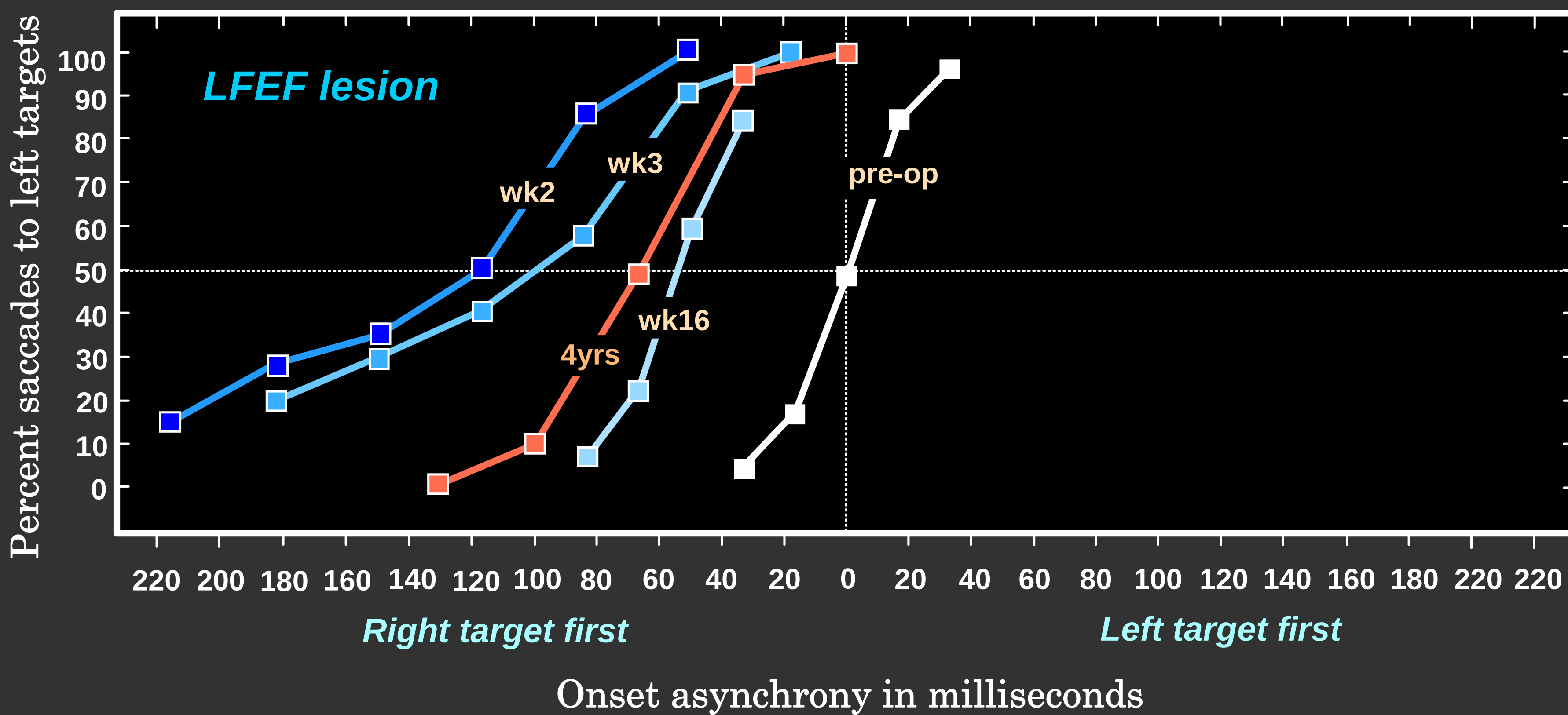
Right 34ms before left

Image by MIT OpenCourseWare.



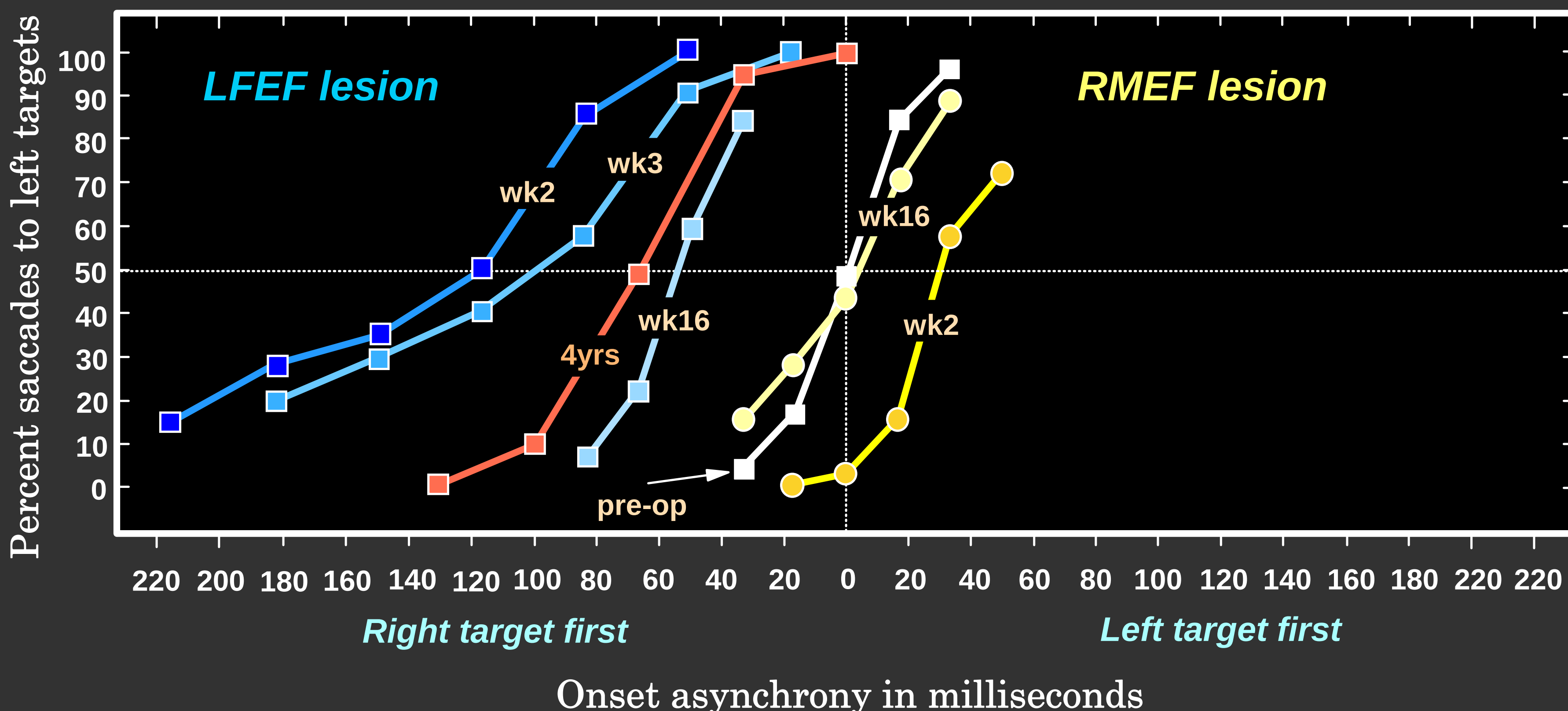
Source: Schiller, Peter H., and I-han Chou. "The Effects of Frontal Eye Field and Dorsomedial Frontal Cortex Lesions on Visually Guided Eye Movements." *Nature Neuroscience* 1, no. 3 (1998): 248-53.

Saccades made to identical paired targets presented with varied asynchronies



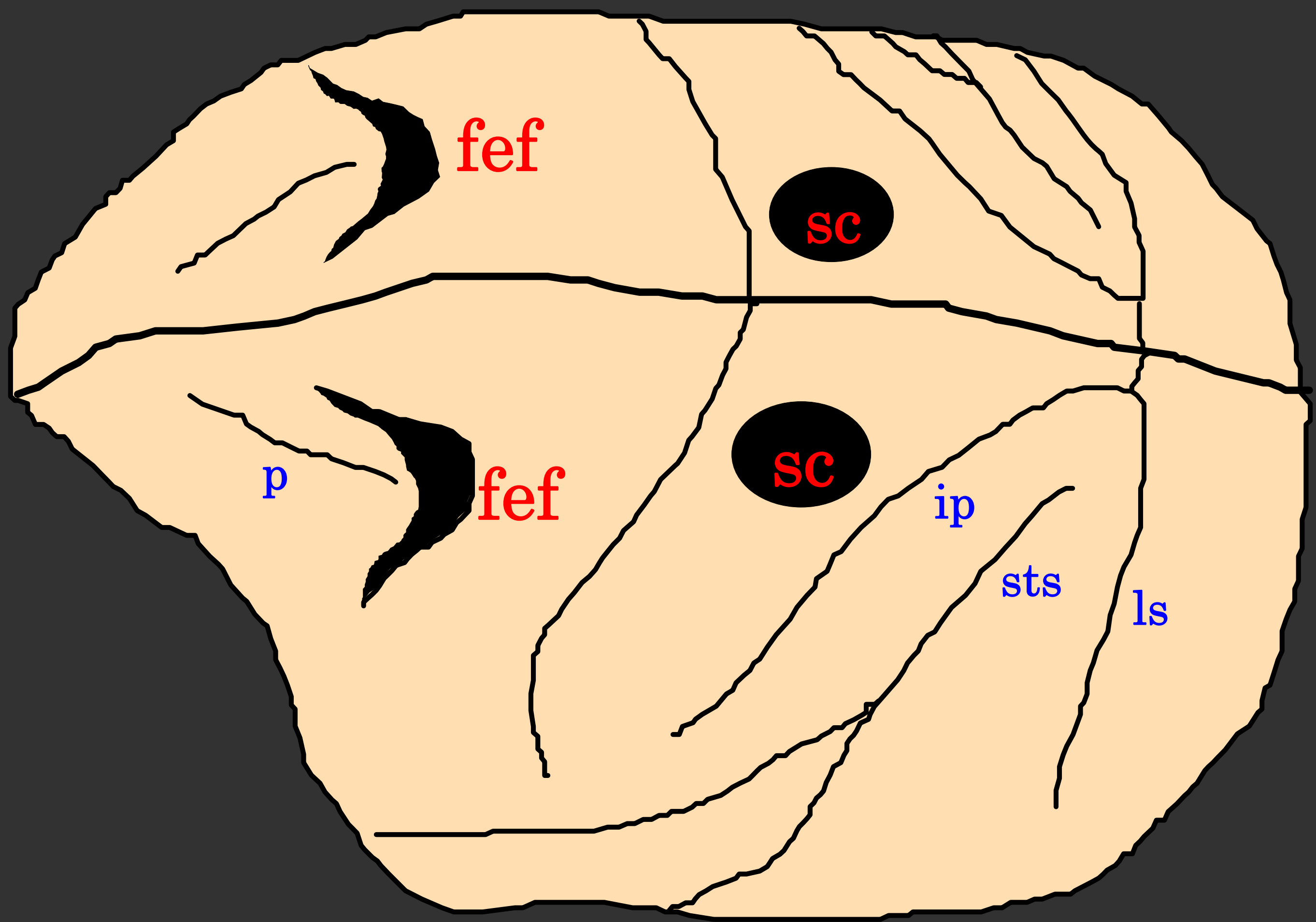
Schiller, Peter H., and Edward J. Tehovnik. "Look and See: How the Brain Moves Your Eyes About." *Progress in Brain Research* 134 (2001): 127-42. Courtesy of Elsevier, Inc., http://www.sciencedirect.com. Used with permission.

Saccades made to identical paired targets presented with varied asynchronies



Schiller, Peter H., and Edward J. Tehovnik. "Look and See: How the Brain Moves Your Eyes About." *Progress in Brain Research* 134 (2001): 127-42. Courtesy of Elsevier, Inc., http://www.sciencedirect.com. Used with permission.

Informal testing after bilateral superior colliculus and frontal eye field ablation



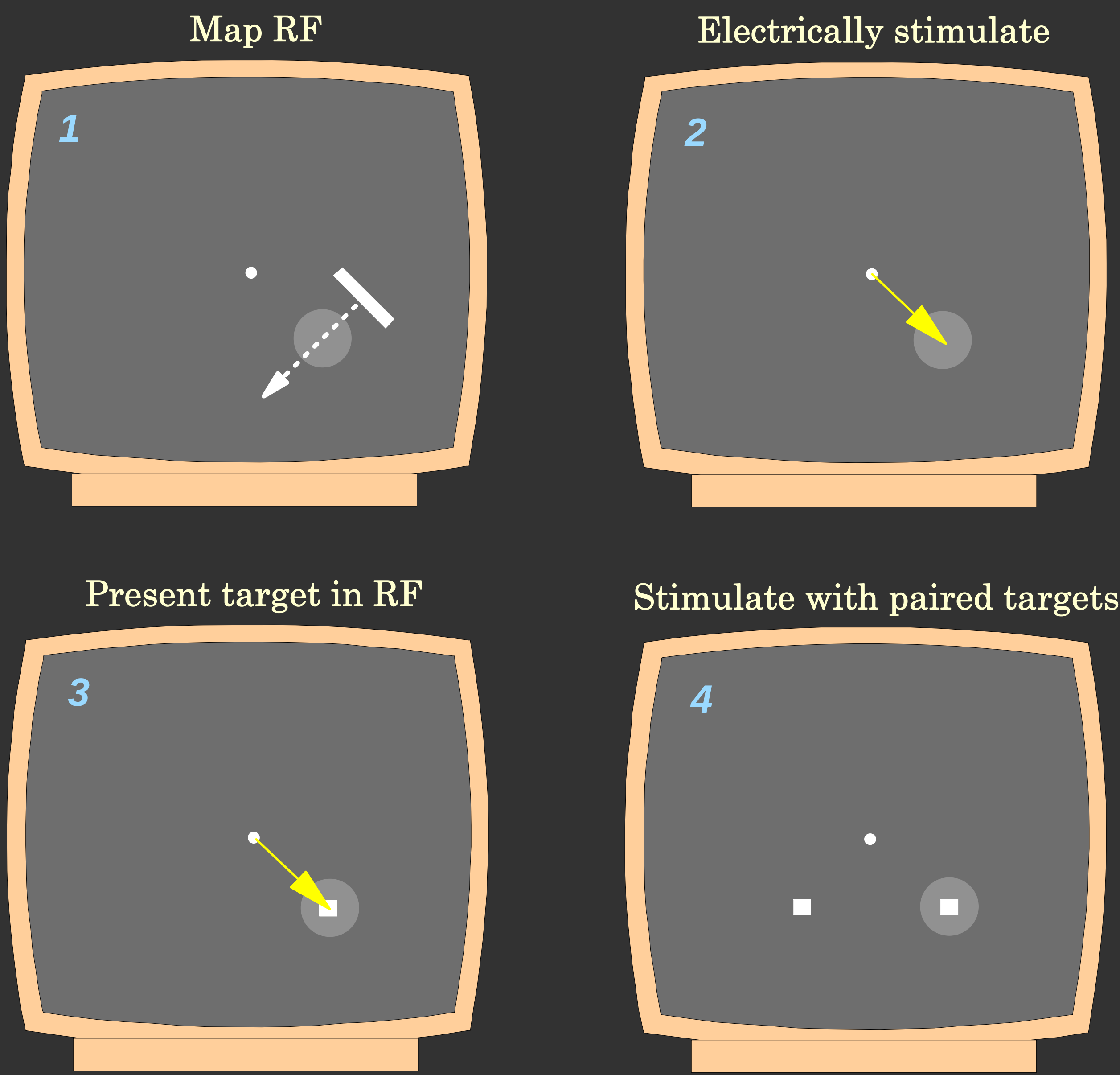
Further examination of the effects of microstimulation on eye-movement generation

The effects of pairing electrical stimulation with visual stimulation in four cortical areas

Figure removed due to copyright restrictions.

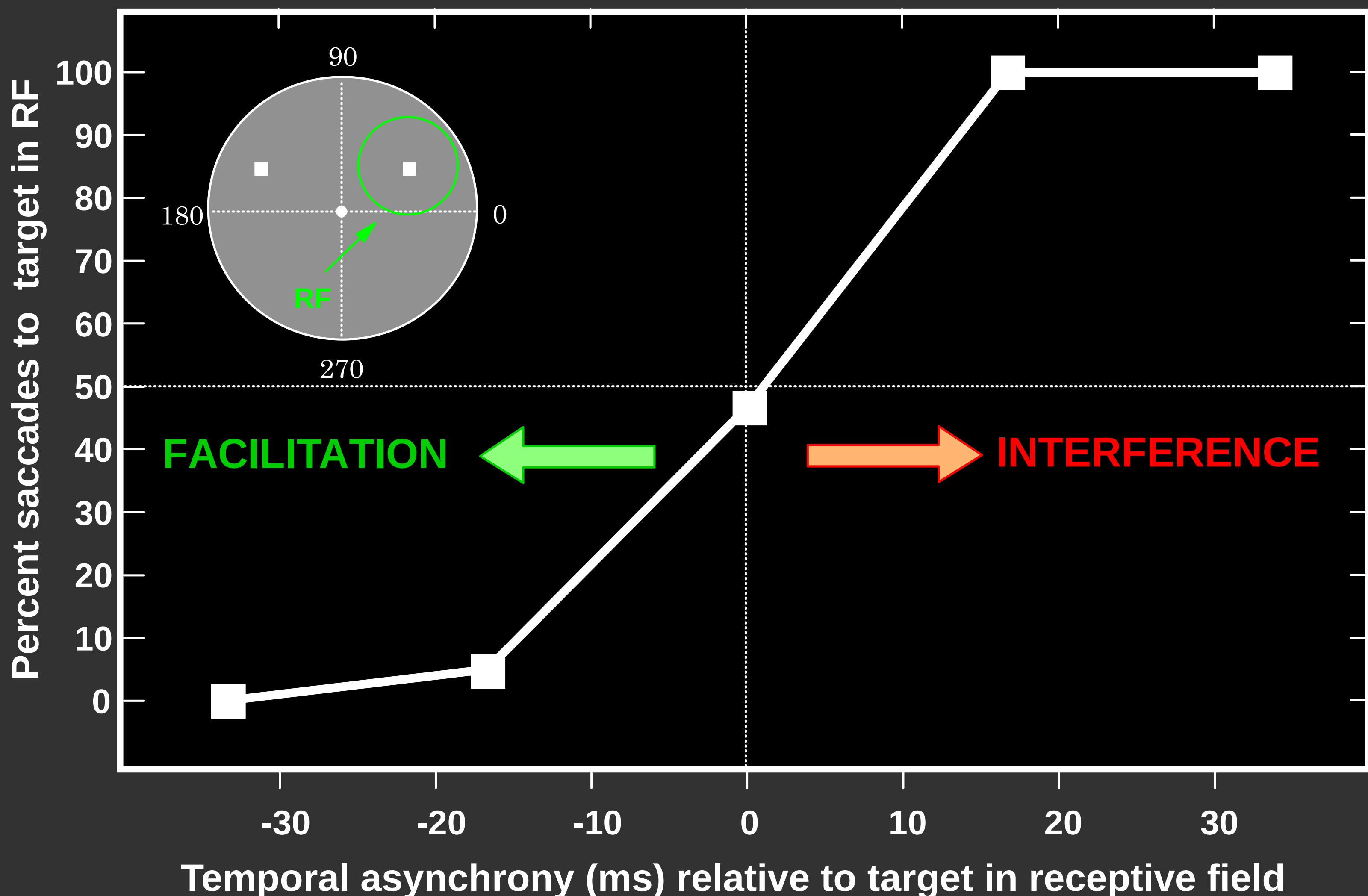
Please see lecture video or Figure 13 from Schiller, Peter H., and Edward J. Tehovnik. "Look and See: How the Brain Moves Your Eyes About." *Progress in Brain Research* 134 (2001): 127-42.

Experimental procedure:



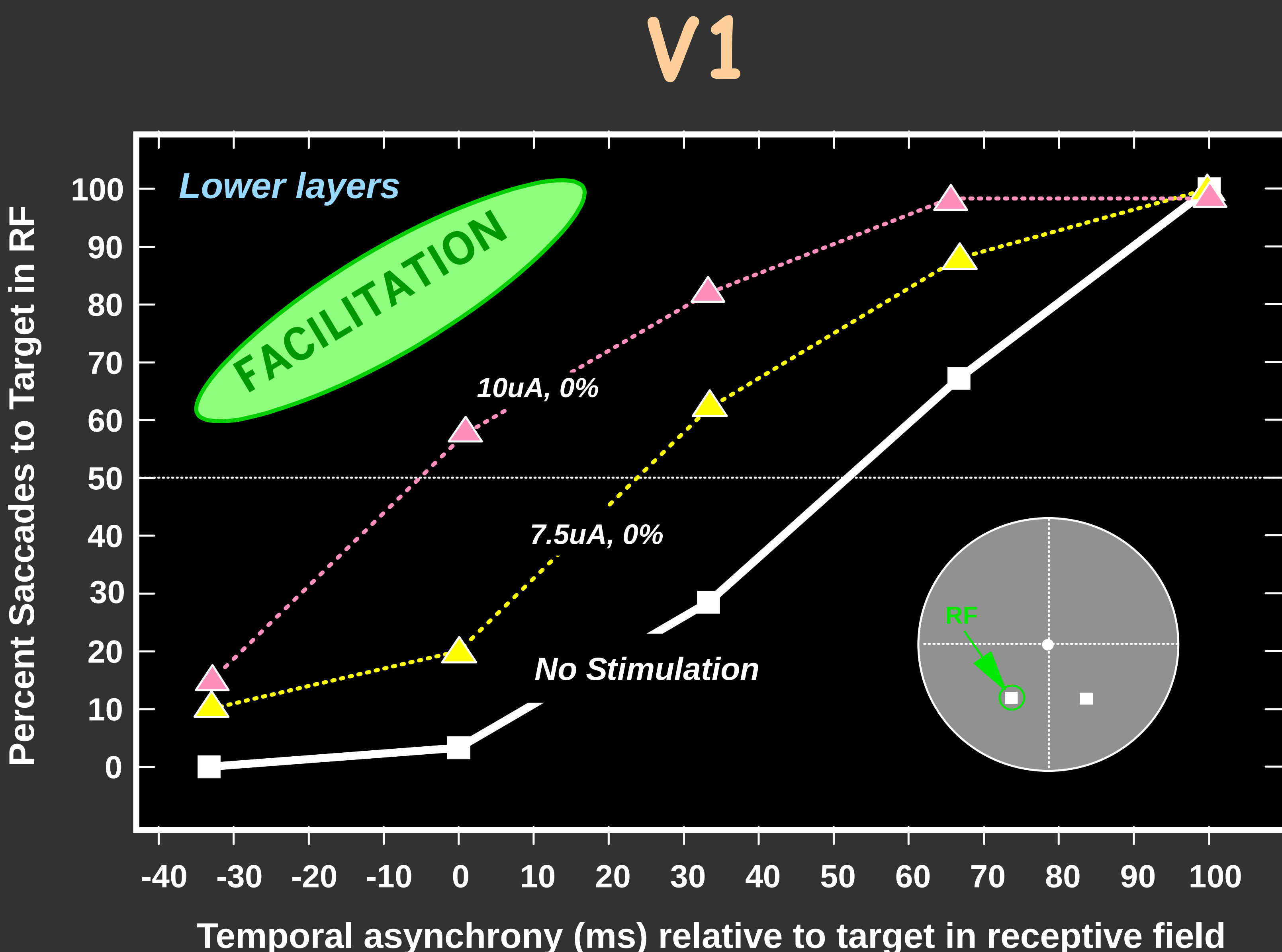
Stimulation initiated 30ms after target appearance for 80ms at 200H

Percent of time target in RF is chosen, no stimulation



Schiller, Peter H., and Edward J. Tehovnik. "Look and See: How the Brain Moves Your Eyes About." *Progress in Brain Research* 134 (2001): 127-42. Courtesy of Elsevier, Inc., http://www.sciencedirect.com. Used with permission.

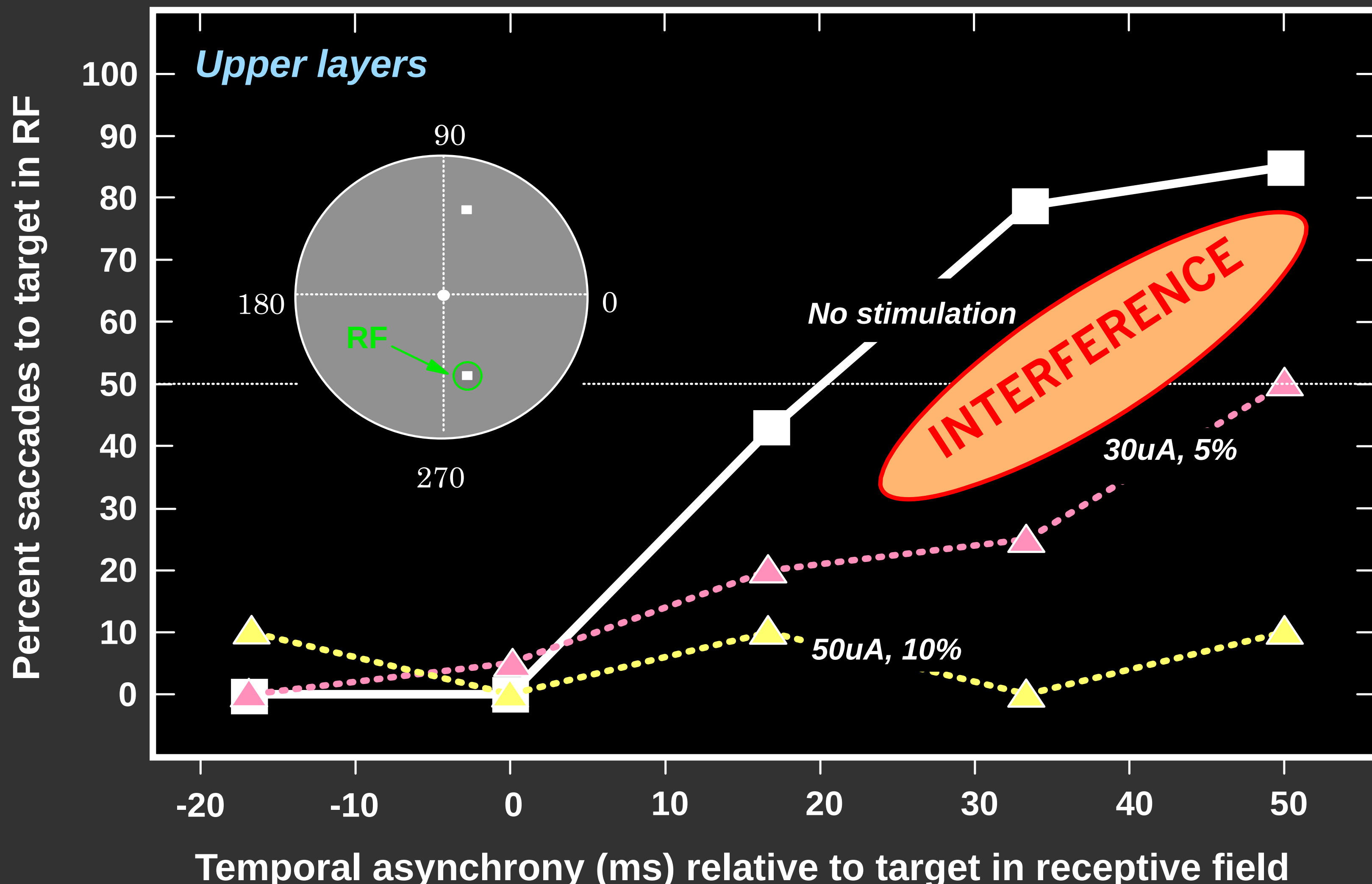
Stimulation added on selected trials



Schiller, Peter H., and Edward J. Tehovnik. "Look and See: How the Brain Moves Your Eyes About." *Progress in Brain Research* 134 (2001): 127-42. Courtesy of Elsevier, Inc., http://www.sciencedirect.com. Used with permission.

Stimulation added on selected trials

V1



Schiller, Peter H., and Edward J. Tehovnik. "Look and See: How the Brain Moves Your Eyes About." *Progress in Brain Research* 134 (2001): 127-42. Courtesy of Elsevier, Inc., http://www.sciencedirect.com. Used with permission.

Stimulation added on selected trials

Figure removed due to copyright restrictions.

Please see lecture video or Figure 15B from Schiller, Peter H., and Edward J. Tehovnik. "Look and See: How the Brain Moves Your Eyes About." *Progress in Brain Research* 134 (2001): 127-42.

Stimulation added on selected trials

Figure removed due to copyright restrictions.

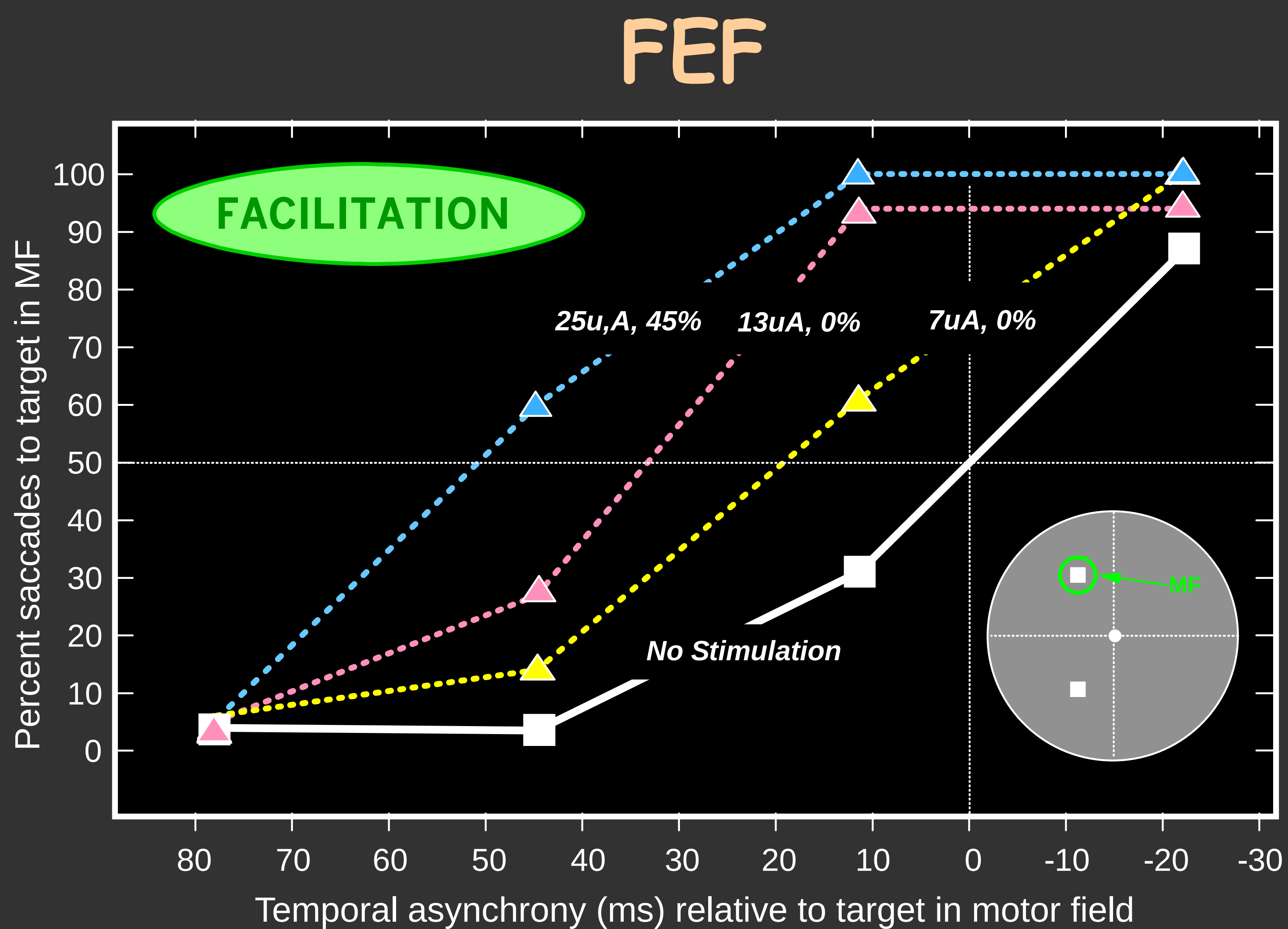
Please see lecture video or Figure 15A from Schiller, Peter H., and Edward J. Tehovnik. "Look and See: How the Brain Moves Your Eyes About." *Progress in Brain Research* 134 (2001): 127-42.

Saccadic latencies in LIP with increasing current levels

Figure removed due to copyright restrictions.

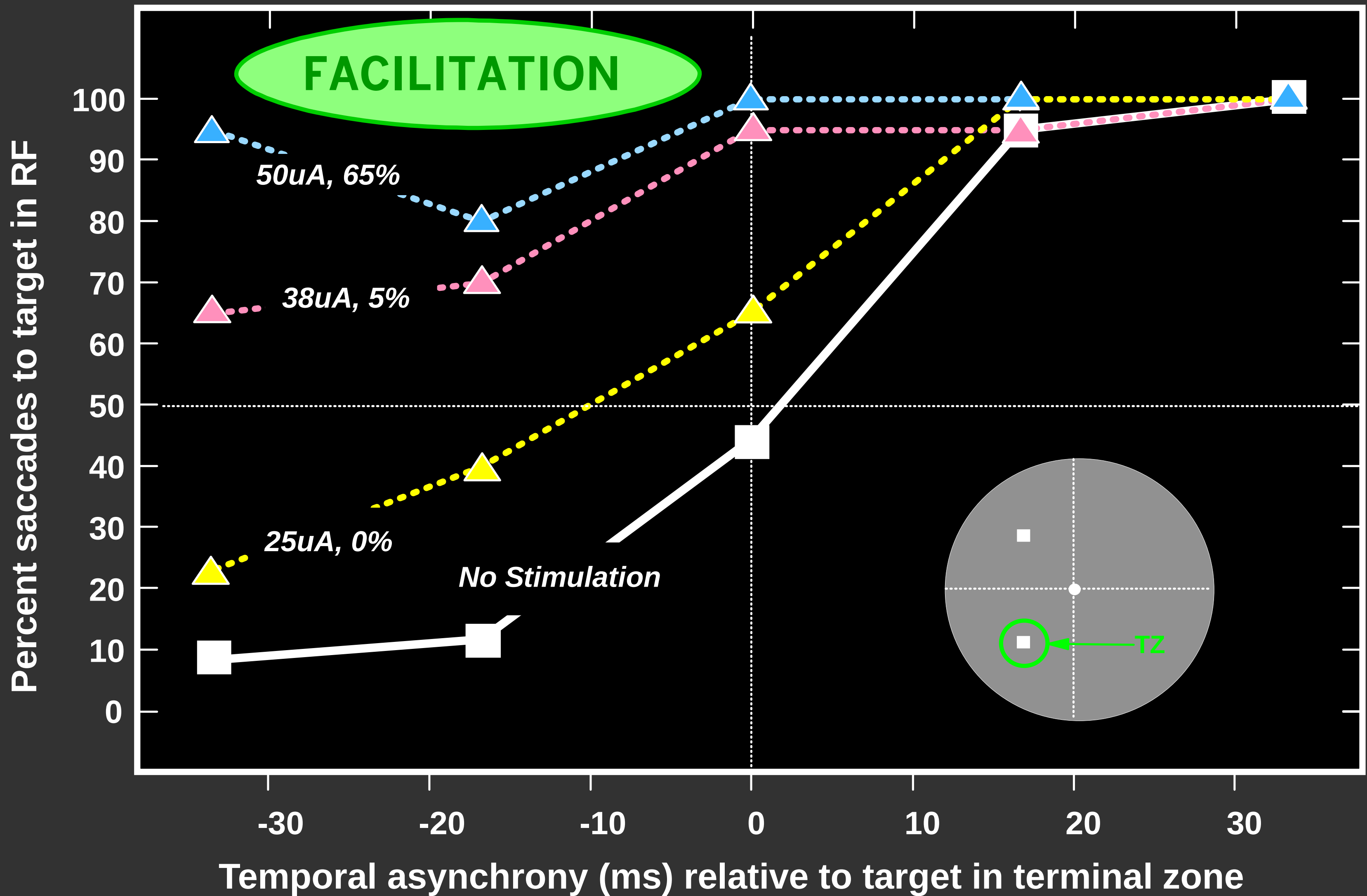
Please see lecture video or Figure 16 from Schiller, Peter H., and Edward J. Tehovnik. "Look and See: How the Brain Moves Your Eyes About." *Progress in Brain Research* 134 (2001): 127-42.

Stimulation added on selected trials

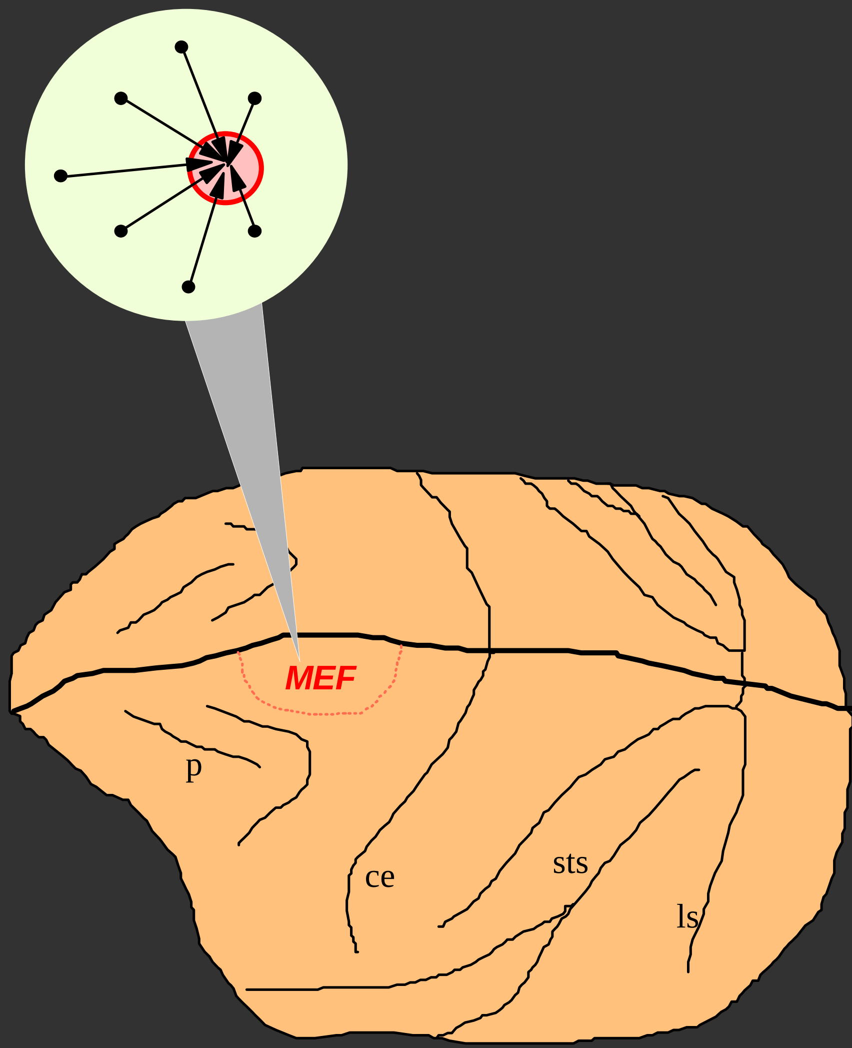


Stimulation added on selected trials

MEF



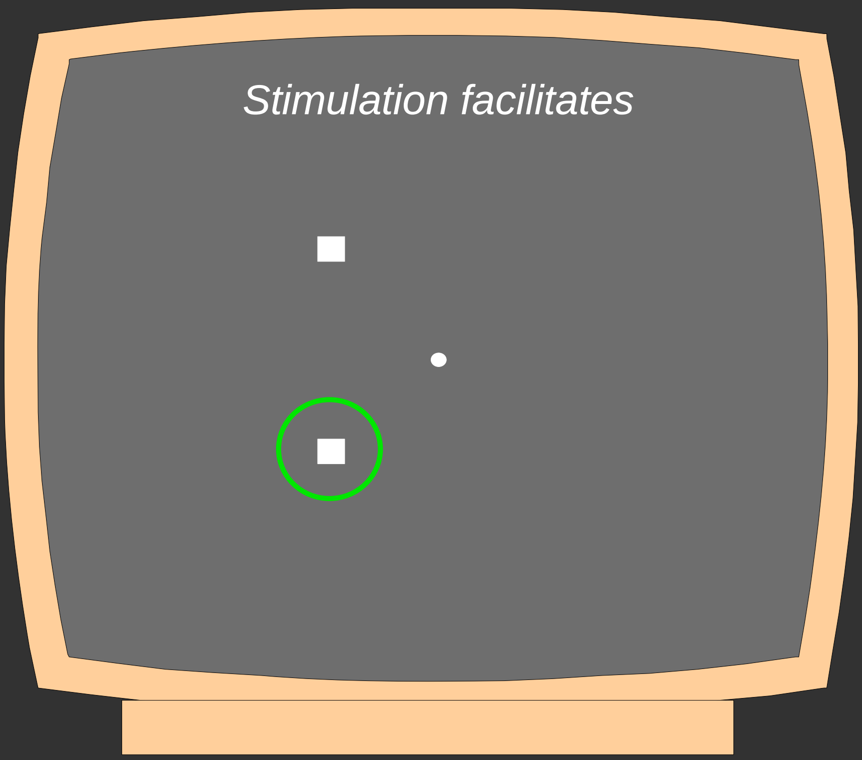
medial eye fields

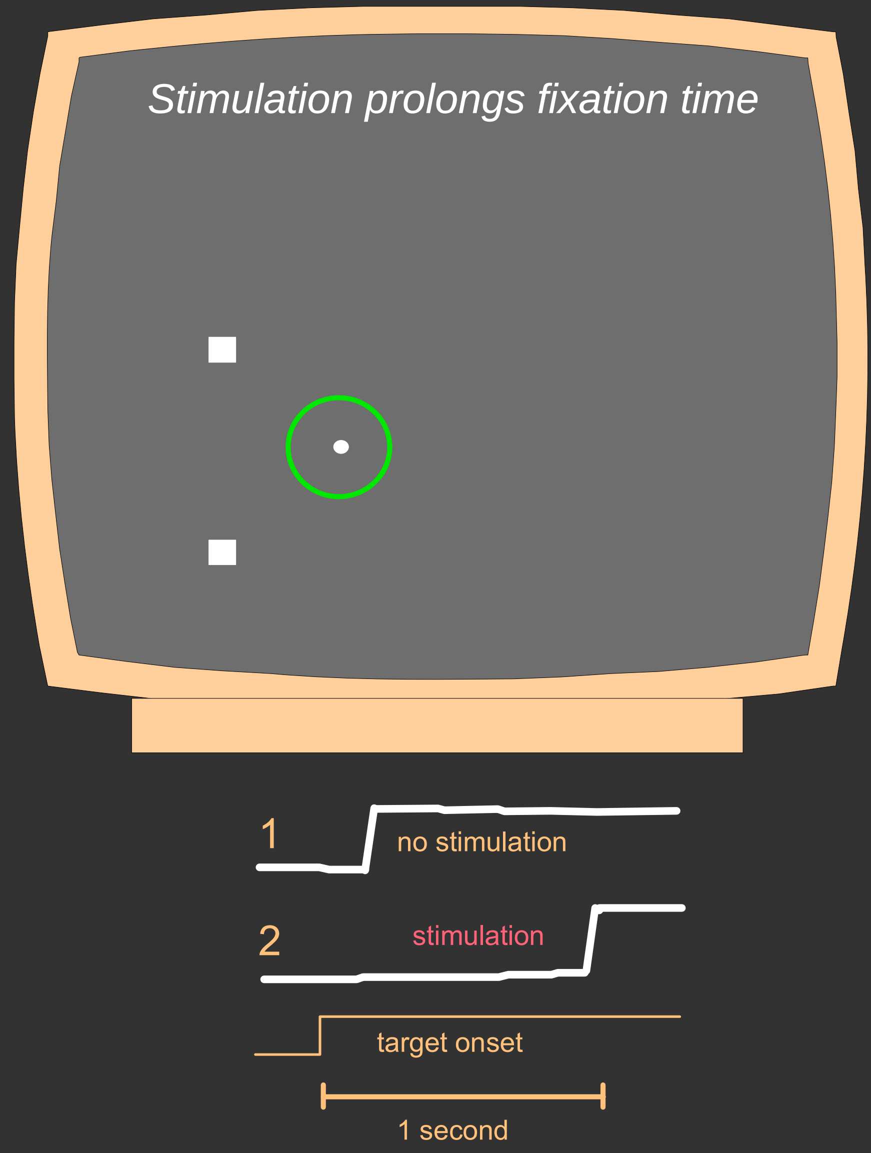


MEF

One target in motor field

Fixation spot in motor field



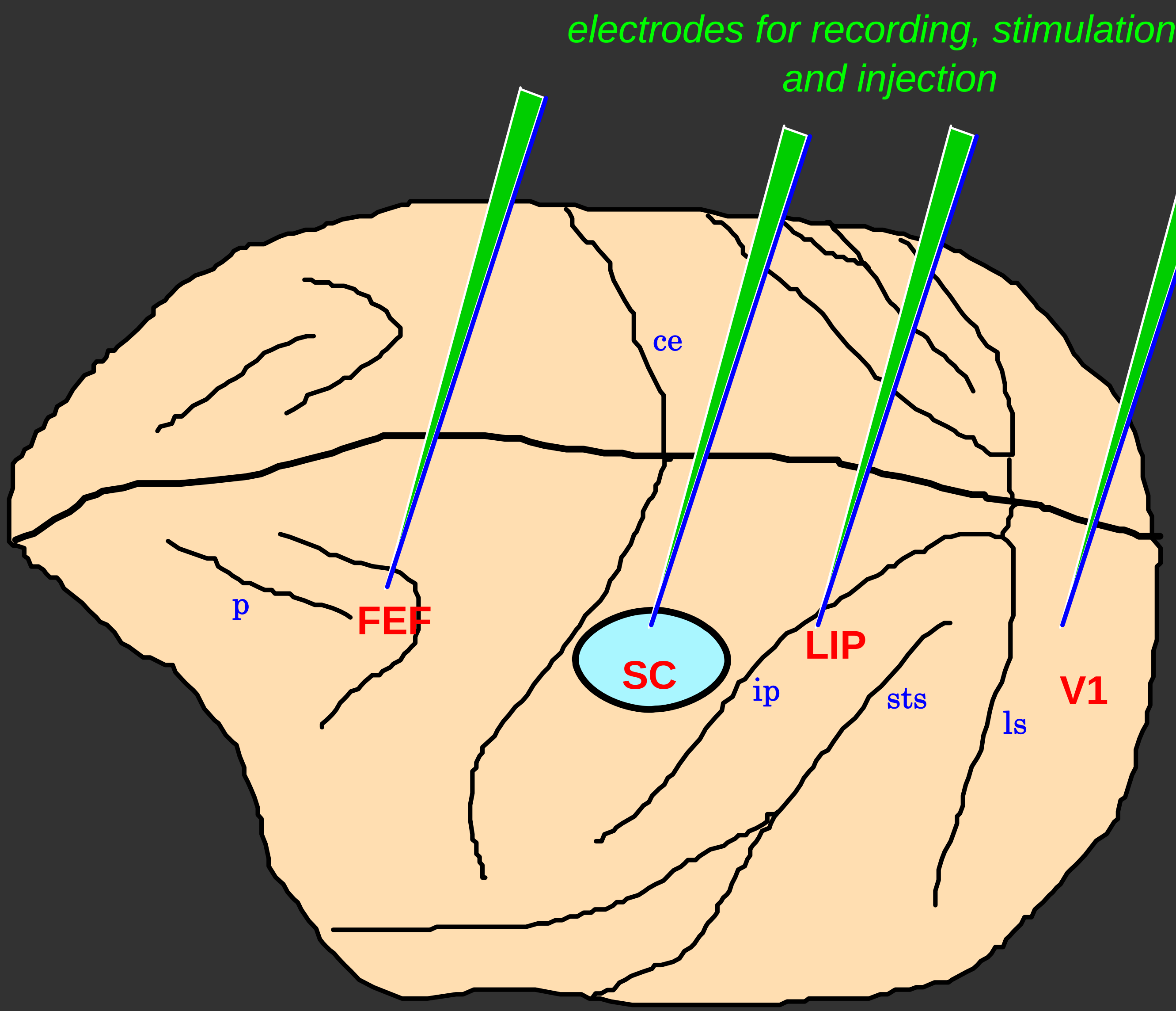


Summary of the effects of electrical stimulation:

	FACILITATION	INTERFERENCE	FIX INCREASE	NO EFFECT
V1 & V2, upper		✓		
V1 & V2, lower	✓			
V4				✓
LIP	✓	✓	✓	
FEF	✓			
MEF	✓		✓	

8. Pharmacological studies

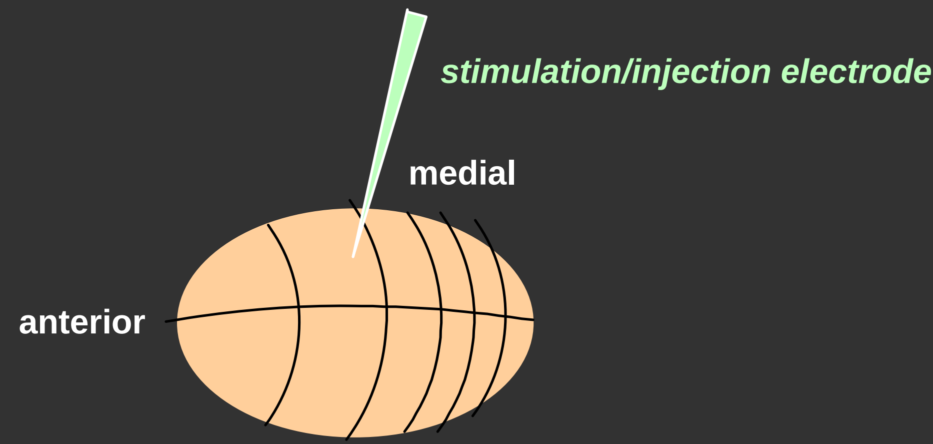
Pharmacological manipulation



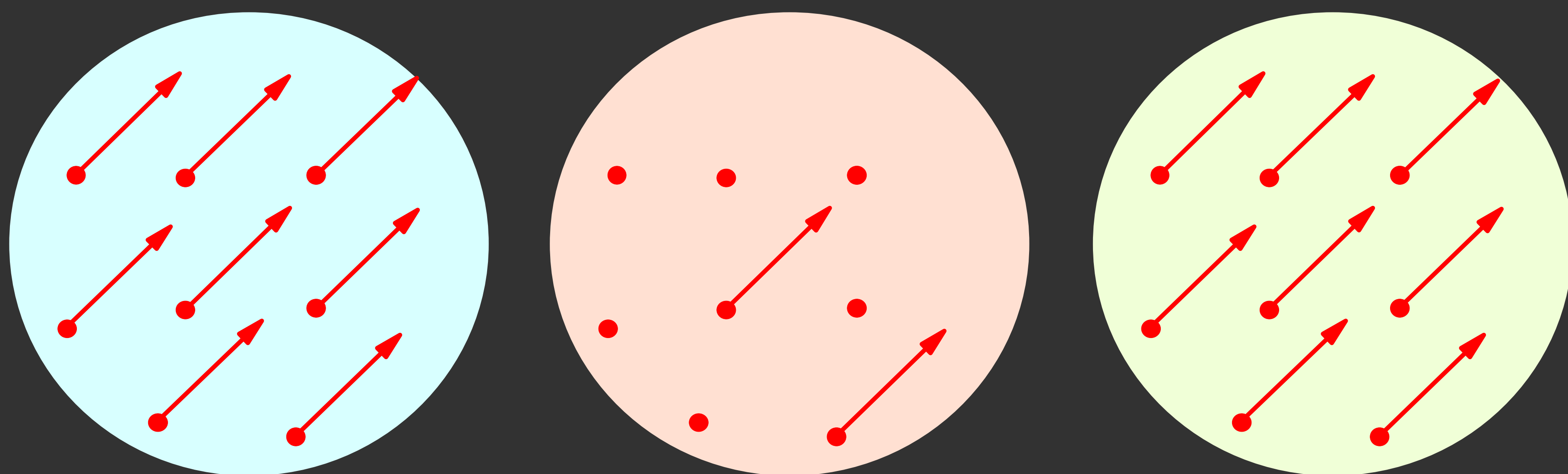
Bicuculline: a GABA antagonist. Therefore when infused inhibition is decreased

Muscimol: a GABA agonist. Therefore when infused inhibition is increased

Effects of stimulation and injection in the superior colliculus



Electrical stimulation | Muscimol injection | Bicuculline injection



stimulation elicited saccades

inhibition of saccades with vectors represented at injected site

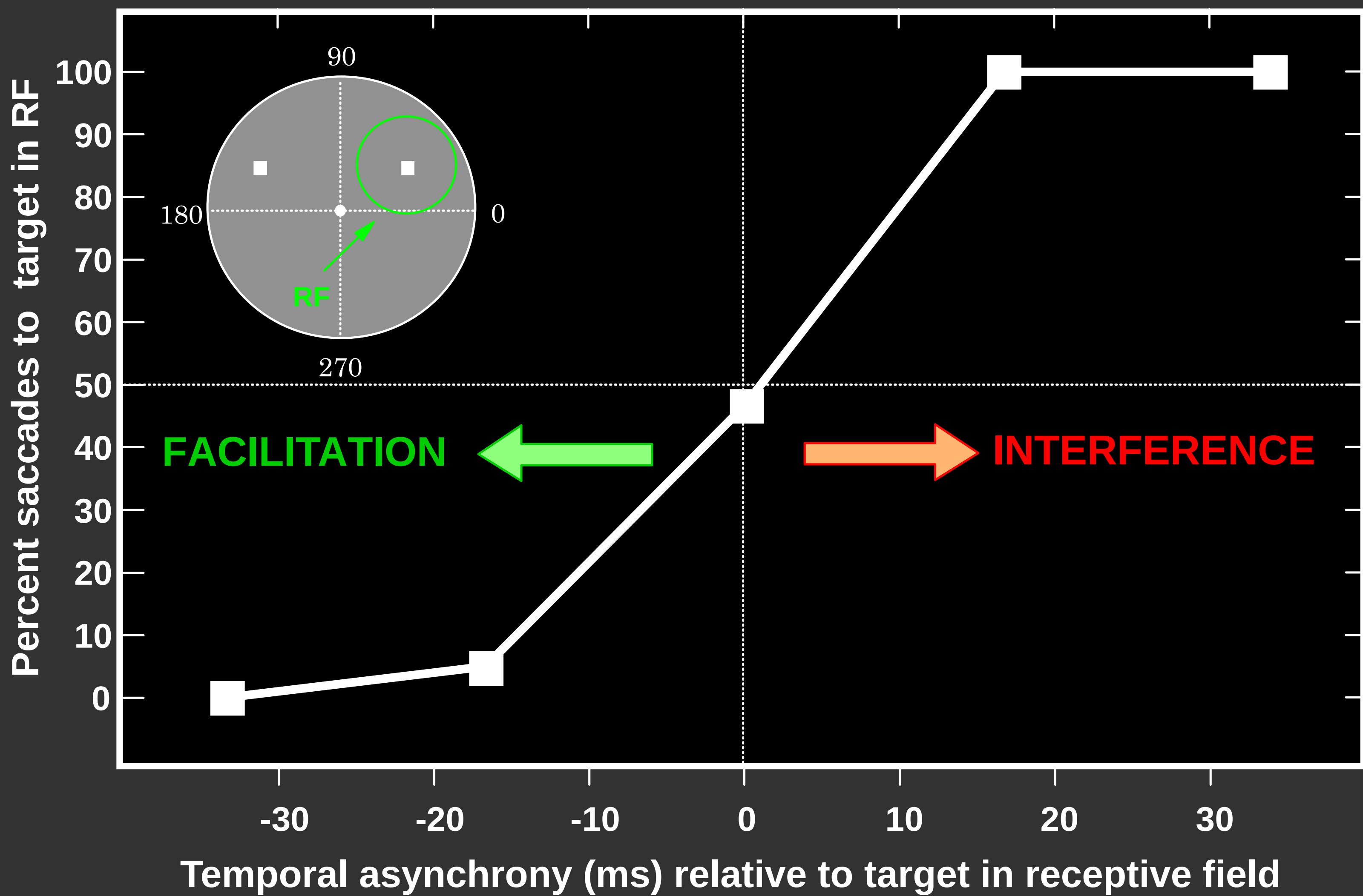
spontaneous saccades with vectors represented at injected site

Hikosaka and Wurtz

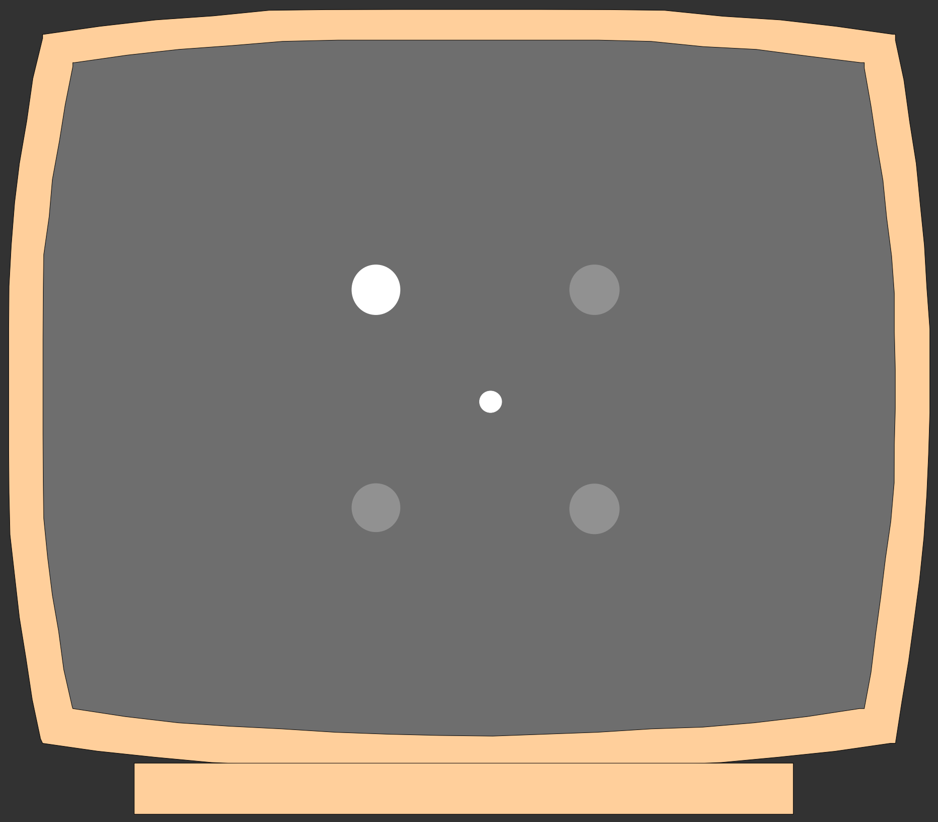
To assess the role of inhibitory circuits in cortex two behavioral tasks were used:

1. Paired target task
2. Visual discrimination task (oddity)

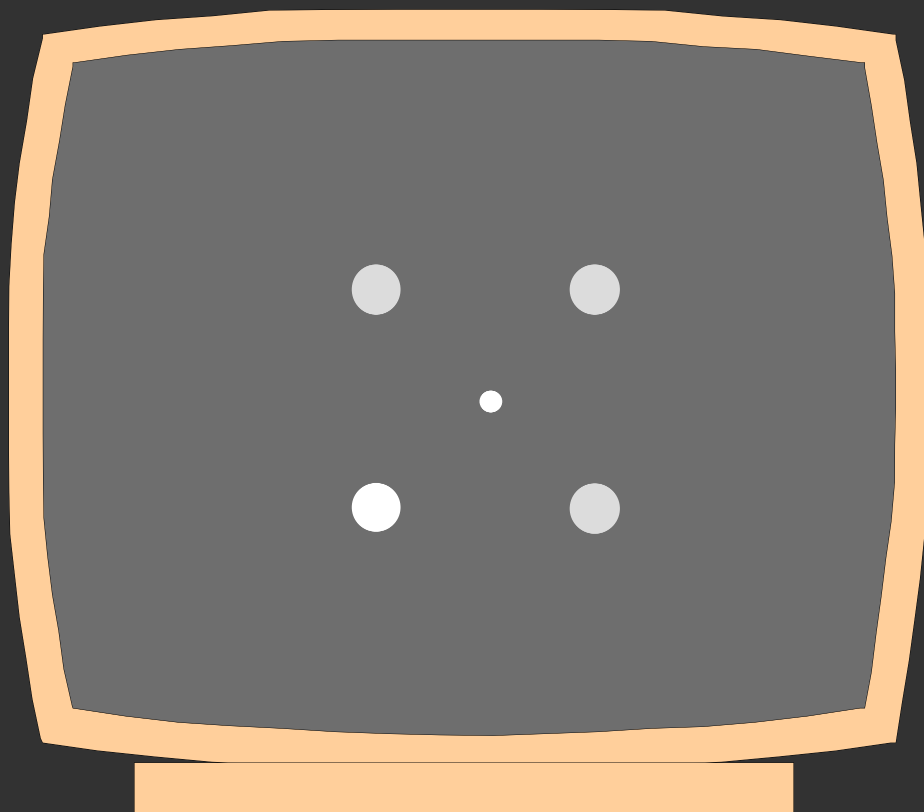
Paired target task



The oddity task



The oddity task



The effects of muscimol injection in cortex

Muscimol injection in V1, paired target task

Figure removed due to copyright restrictions.

Please see lecture video or the top panel of Figure 2 from Schiller, Peter H., and Edward J. Tehovnik. "Cortical Inhibitory Circuits in Eye-movement Generation." *European Journal of Neuroscience* 18, no. 11 (2003): 3127-33.

Muscimol injection in FEF, paired target task

Figure removed due to copyright restrictions.

Please see lecture video or the middle panel of Figure 2 from Schiller, Peter H., and Edward J. Tehovnik. " Cortical Inhibitory Circuits in Eye-movement Generation." *European Journal of Neuroscience* 18, no. 11 (2003): 3127-33.

Muscimol injection in LIP, paired target task

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Please see lecture video or the bottom panel of Figure 2 from Schiller, Peter H., and Edward J. Tehovnik. "Cortical Inhibitory Circuits in Eye-movement Generation." *European Journal of Neuroscience* 18, no. 11 (2003): 3127-33.

Muscimol injection, oddities task

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Please see lecture video or Figure 3 from Schiller, Peter H., and Edward J. Tehovnik. "Cortical Inhibitory Circuits in Eye-movement Generation." *European Journal of Neuroscience* 18, no. 11 (2003): 3127-33.

The effects of bicuculline injection in cortex

Bicuculline injection in V1, paired target task

Image removed due to copyright restrictions.

Please see lecture video or the top panel of Figure 4 from Schiller, Peter H., and Edward J. Tehovnik. "Cortical Inhibitory Circuits in Eye-movement Generation." *European Journal of Neuroscience* 18, no. 11 (2003): 3127-33.

Bicuculline injection in FEF, paired target task

Image removed due to copyright restrictions.

Please see lecture video or the middle panel of Figure 4 from Schiller, Peter H., and Edward J. Tehovnik. "Cortical Inhibitory Circuits in Eye-movement Generation." *European Journal of Neuroscience* 18, no. 11 (2003): 3127-33.

The effect of local bicuculline injection in the FEF on eye movements made to three targets

Figure removed due to copyright restrictions.

Please see lecture video or middle panel of Figure 7 from Schiller, Peter H., and Edward J. Tehovnik. "Neural Mechanisms Underlying Target Selection with Saccadic Eye Movements." *Progress in Brain Research* 149 (2005): 157-71.

Bicuculline injection in LIP, paired target task

Image removed due to copyright restrictions.

Please see lecture video or the bottom panel of Figure 4 from Schiller, Peter H., and Edward J. Tehovnik. "Cortical Inhibitory Circuits in Eye-movement Generation." *European Journal of Neuroscience* 18, no. 11 (2003): 3127-33.

Bicuculline injection, oddities task

Figure removed due to copyright restrictions.

Please see lecture video or Figure 5 from Schiller, Peter H., and Edward J. Tehovnik. "Cortical Inhibitory Circuits in Eye-movement Generation." *European Journal of Neuroscience* 18, no. 11 (2003): 3127-33.

Summary of the effects of the GABA agonist muscimol and the GABA antagonist bicuculline

Target selection

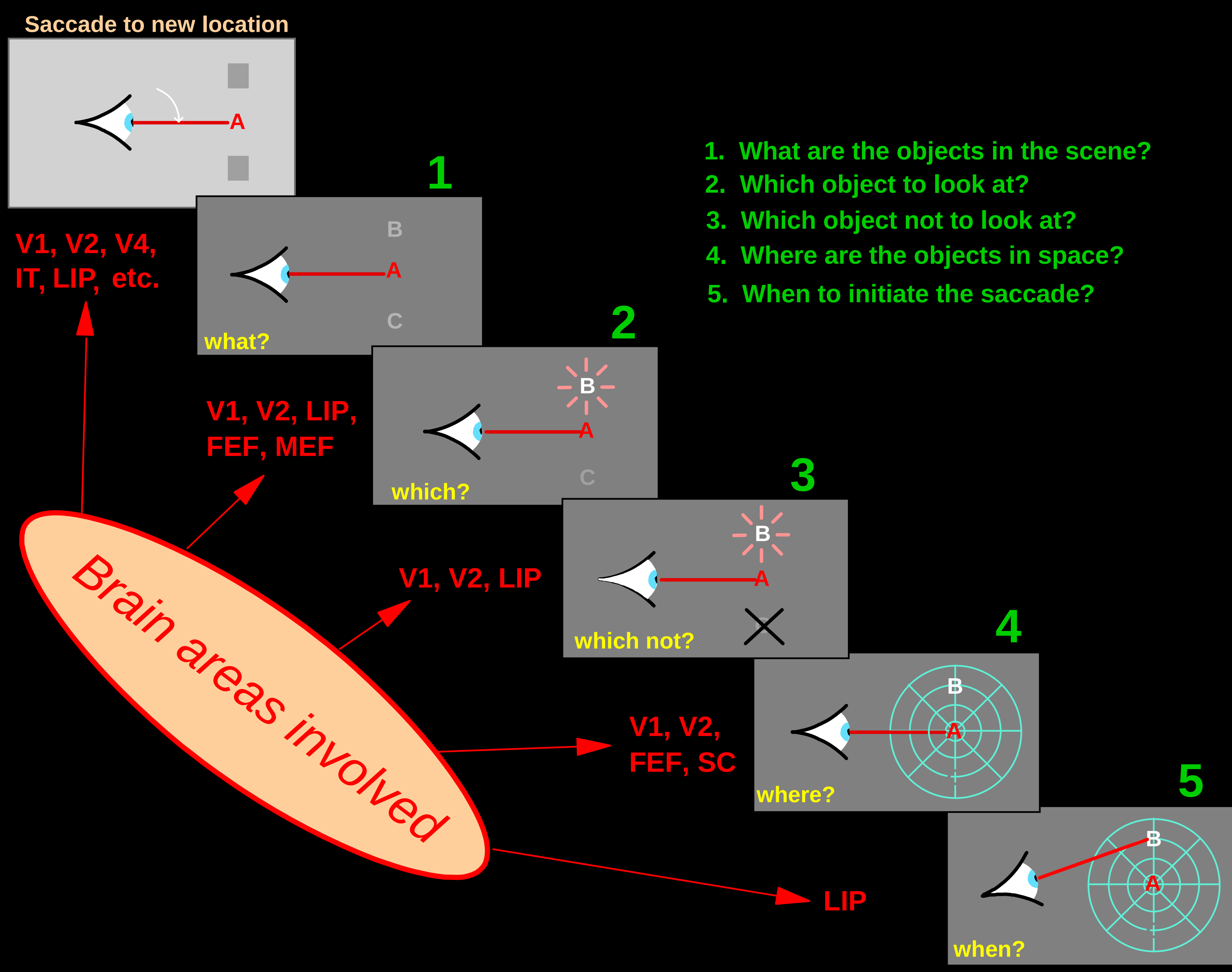
	muscimol	bicuculline
V1	INTERFERENCE	INTERFERENCE
FEF	INTERFERENCE	FACILITATION
LIP	NO EFFECT	NO EFFECT

	muscimol	bicuculline
SC	INTERFERENCE	FACILITATION

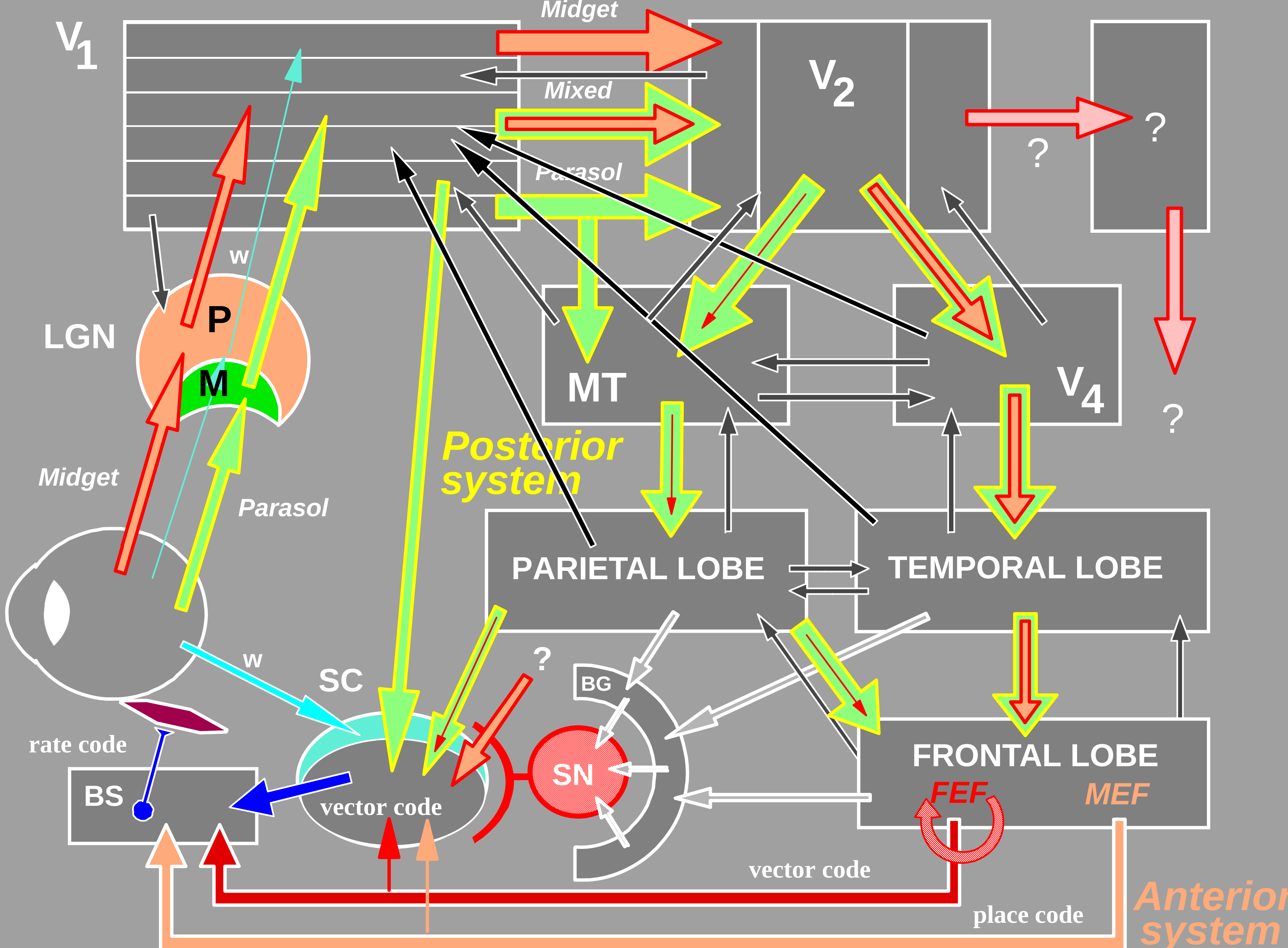
Visual discrimination

	muscimol	bicuculline
V1	DEFICIT	DEFICIT
FEF	MILD DEFICIT	NO EFFECT
LIP	NO EFFECT	NO EFFECT

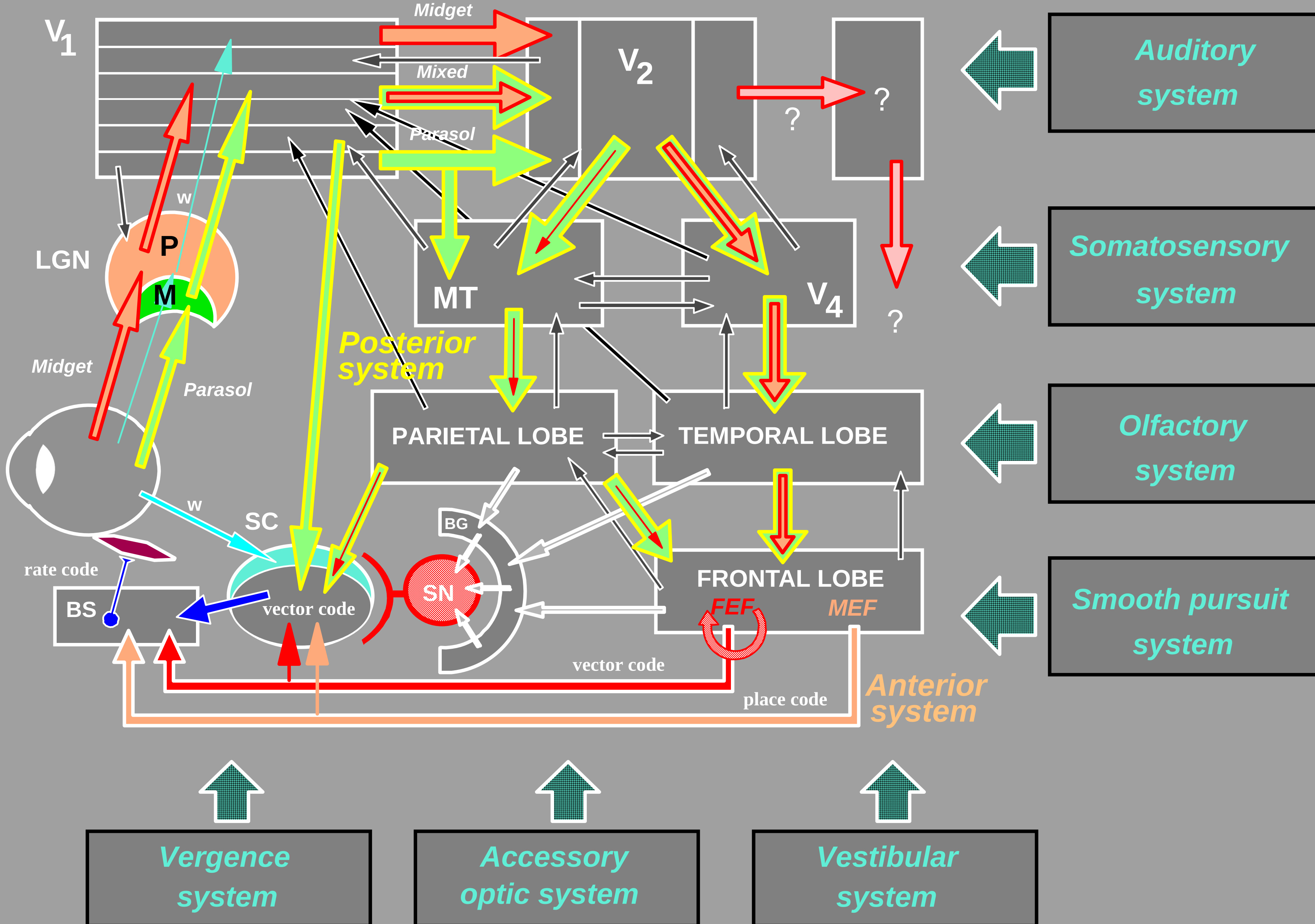
Hikosaka and Wurtz


Saccade to new location
A
V1, V2, V4,
IT, LIP, etc.
1
B
A
C
what?
1. What are the objects in the scene?
2. Which object to look at?
3. Which object not to look at?
4. Where are the objects in space?
5. When to initiate the saccade?
2
V1, V2, LIP,
FEF, MEF
B
A
C
which?
3
B
A
which not?
V1, V2, LIP
Brain areas involved
4
B
A
where?
V1, V2,
FEF, SC
5
B
A
when?
LIP

Summary wiring diagrams



V_1
Midget
Mixed
Parasol
V_2
?
?
LGN
P
M
w
MT
V_4
?
Midget
Parasol
Posterior system
PARIETAL LOBE
TEMPORAL LOBE
w
SC
?
BG
rate code
SN
FRONTAL LOBE
FEF
MEF
BS
vector code
vector code
place code
Anterior system


V1
Midget
Mixed
Parasol
V2
?
?
?
MT
V4
LGN
P
M
w
Midget
Parasol
Posterior system
PARIETAL LOBE
TEMPORAL LOBE
FRONTAL LOBE
FEF
MEF
w
SC
BG
SN
rate code
BS
vector code
vector code
place code
Anterior system
Auditory system
Somatosensory system
Olfactory system
Smooth pursuit system
Vergence system
Accessory optic system
Vestibular system

Summary:

1. Two major cortical systems control visually guided saccadic eye movements: The anterior and the posterior.
2. The anterior system has direct access to the brainstem whereas the posterior system passes through the colliculus.
3. Inhibitory circuits, as from the substantia nigra and in the frontal eye fields, are essential for generating properly directed saccadic eye-movements.
4. Areas V1, V2, FEF, LIP and SC carry a vector code. MEF carries a place code.
5. Paired ablation of the FEF and SC eliminates visually guided saccadic eye movements.
6. The posterior system is essential for producing express saccades.
7. The FEF plays a central role in the planning of saccadic sequences and target selection.
8. The posterior system is important for object identification, for deciding where to look and where not to look. LIP in addition is important for deciding when to look. The FEF and MEF contribute to where to look.
9. The role of the medial eye fields remains a puzzle. It may be involved in hand-eye coordination, in establishing spatial relationships and in visuo-motor learning.

Thank you