ENHANCED VISUAL COGNITION IN THE CONGENITALLY DEAF

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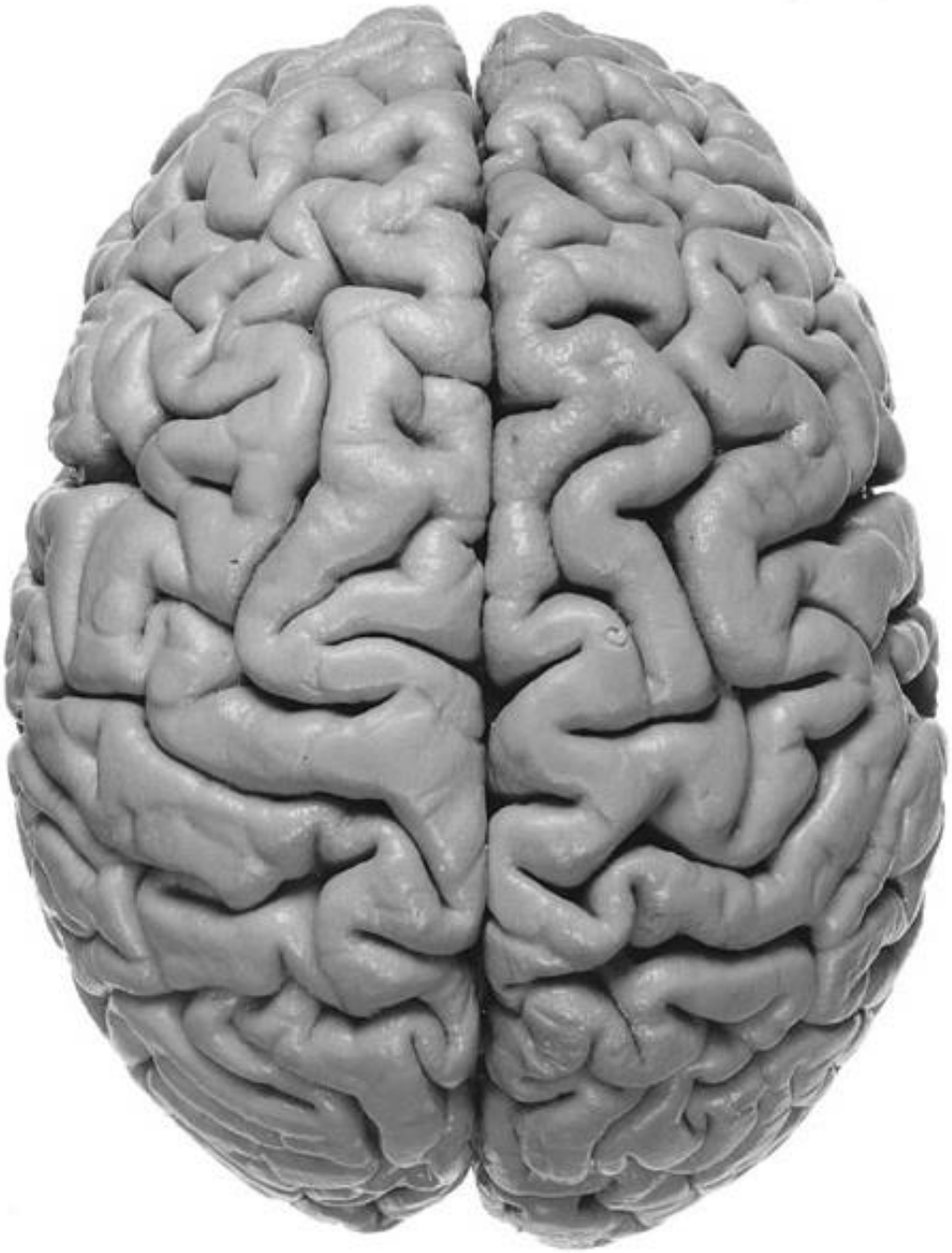
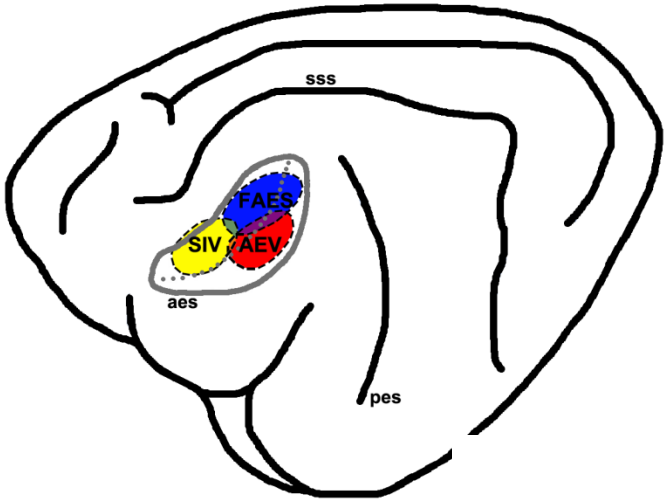
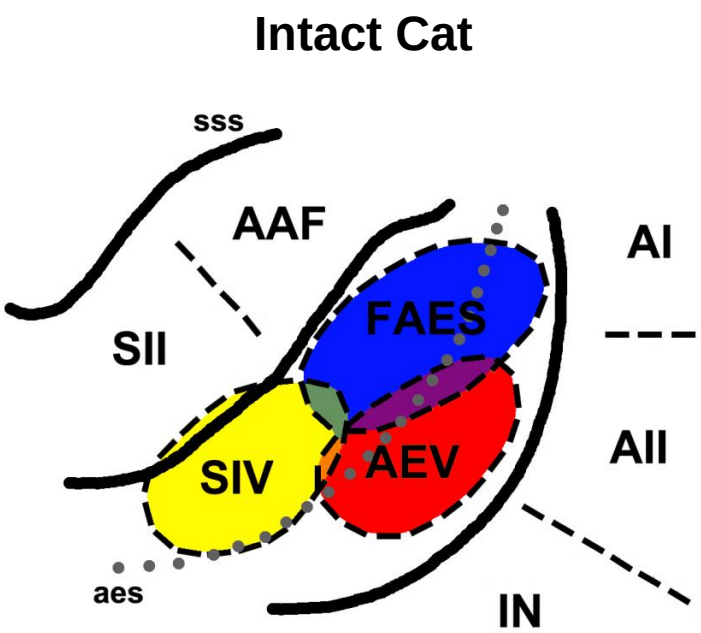


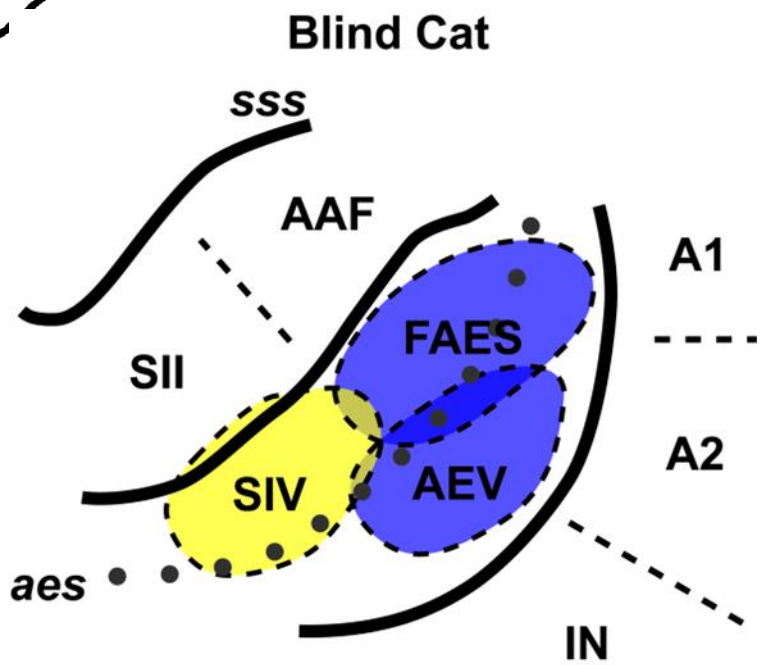
Cortical Plasticity

Changes that occur in the function and organization of the cerebral cortex as a consequence of experience.

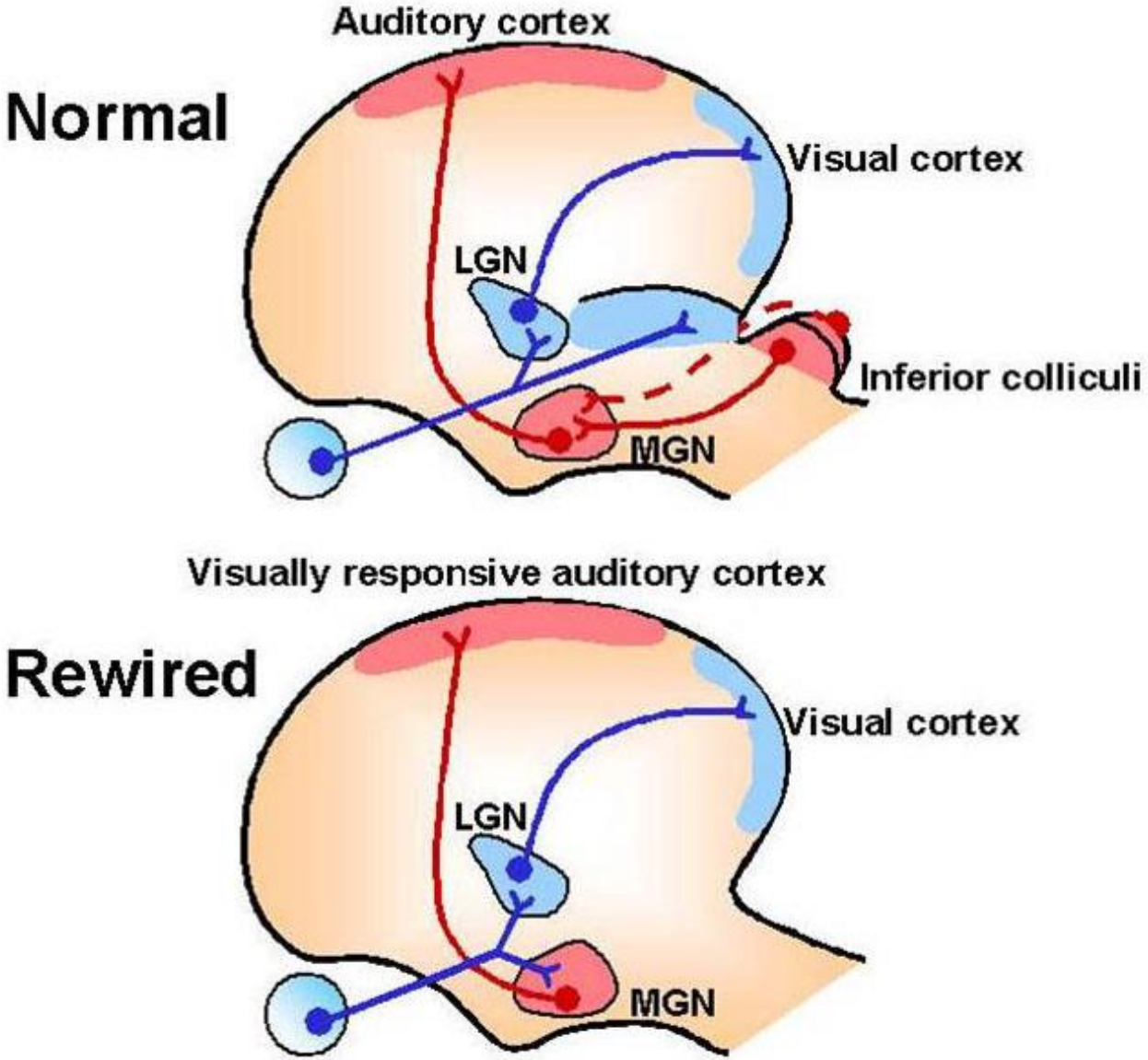
Rauschecker:
Sensory Substitution in Visual Cortex







Sur:
Sensory Substitution in Auditory Cortex



Adaptive cross-modal plasticity

Following the impairment of a sensory system, it is enhanced perceptual performance identified in the remaining systems whereby one or more modalities compensates for the loss of another modality.

(e.g., enhanced auditory spatial localization in the blind)

Do the deaf see better?

Bavelier et al. (2006)

- Visual orienting and reorienting
  - Paranis and Samar (1985)
  - Bosworth and Dobkins (2002)
- Visual motion processing
  - Neville and Lawson (1987)
  - Bavelier and Neville (2002)
- Visual stimulus onset detection
  - Loke and Song (1991)

Questions

- What visual functions are enhanced during deafness?

- If there are enhanced visual functions during deafness, what is the neural substrate supporting these superior visual abilities?

Visual Psychophysical Tasks

1. Vernier Acuity
2. Grating Acuity
3. Orientation Discrimination
4. Direction of Motion Discrimination
5. Velocity of Motion Discrimination
6. Detection of Movement
7. Detection across the Visual Field

Psychophysical Summary

Congenitally Deaf Cats have visual abilities similar to Hearing Cats on the following tasks:

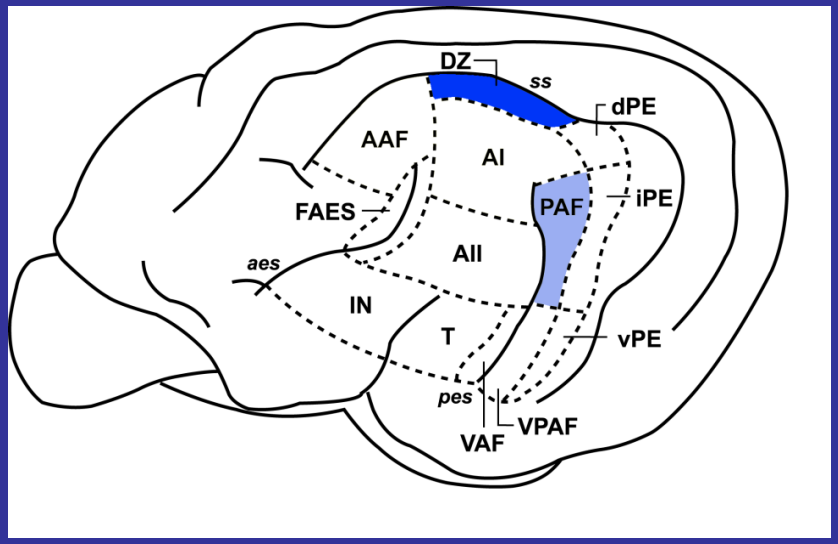
- Vernier Acuity
- Grating Acuity
- Orientation Discrimination
- Direction of Motion Discrimination
- Velocity of Motion Discrimination

Congenitally Deaf Cats have visual abilities superior to Hearing Cats on the following tasks:

- Detection of Movement
- Visual Detection in the Peripheral Field

Deactivation Summary

Task	PAF Deactivation	DZ Deactivation
Visual Detection in the Peripheral Field	**Deficit**	No deficit
Detection of Movement	No deficit	**Deficit**



From Lomber, Meredith & Kral (2010) *Nature Neuroscience* **13**: 1421-1427

The Supramodal Hypothesis

"Cortical areas that have been physiologically reorganized in response to sensory loss (deafness/ blindness) will be involved in behaviours that are similar to those of hearing/sighted subjects, but are mediated by the replacement modality".

Experimental Aims

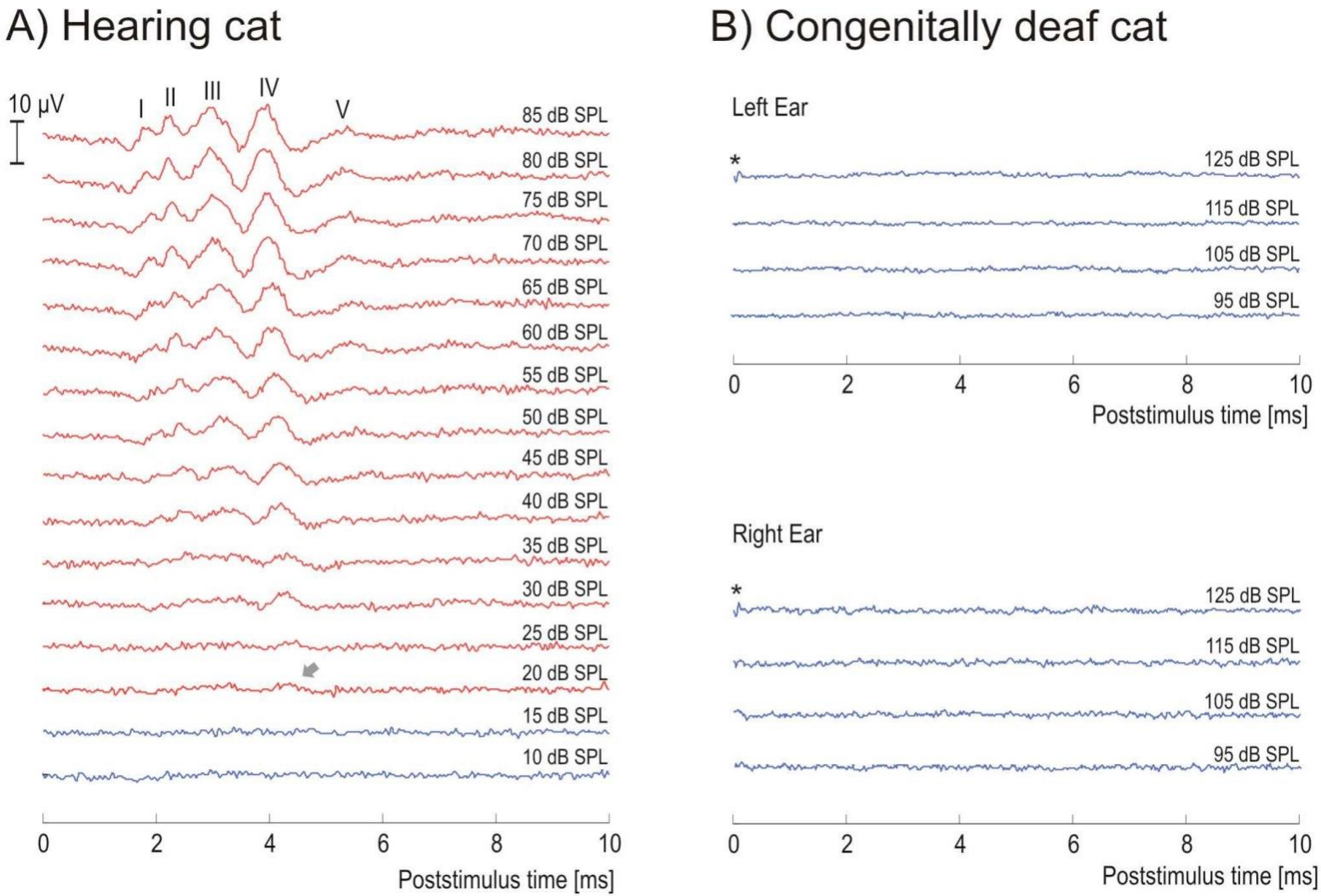
1) Determine if the learning or recall of any visual discriminations are enhanced as a consequence of deafness.

2) Determine what role “deaf” auditory cortex may play in mediating the superior cognitive functions.

Experimental Approach

- White cats/Hearing cats born
- Deafness/Hearing confirmed with ABR's at 1M
- After reaching maturity, start training on the learning and recall of visual discriminations
- Implant cooling loops over desired regions of "deaf" or "hearing" auditory cortex to permit their focal reversible deactivation
- Test all cats on all discriminations during reversible deactivation of each cortical locus
- Acute cortical recordings/ tracer injections
- Perfuse and process tissue

ABRs


A) Hearing cat
10 µV
I
II
III
IV
V
85 dB SPL
80 dB SPL
75 dB SPL
70 dB SPL
65 dB SPL
60 dB SPL
55 dB SPL
50 dB SPL
45 dB SPL
40 dB SPL
35 dB SPL
30 dB SPL
25 dB SPL
20 dB SPL
15 dB SPL
10 dB SPL
0
2
4
6
8
10
Poststimulus time [ms]
B) Congenitally deaf cat
Left Ear
*
125 dB SPL
115 dB SPL
105 dB SPL
95 dB SPL
0
2
4
6
8
10
Poststimulus time [ms]
Right Ear
*
125 dB SPL
115 dB SPL
105 dB SPL
95 dB SPL
0
2
4
6
8
10
Poststimulus time [ms]

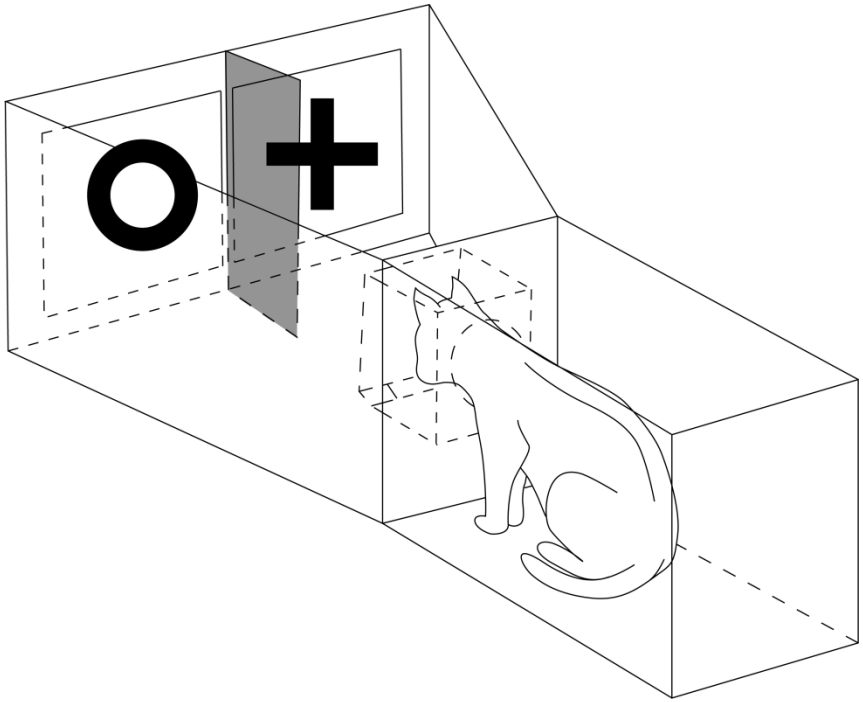
Aim 1

Determine if the learning or recall of any visual discriminations are enhanced as a consequence of deafness.

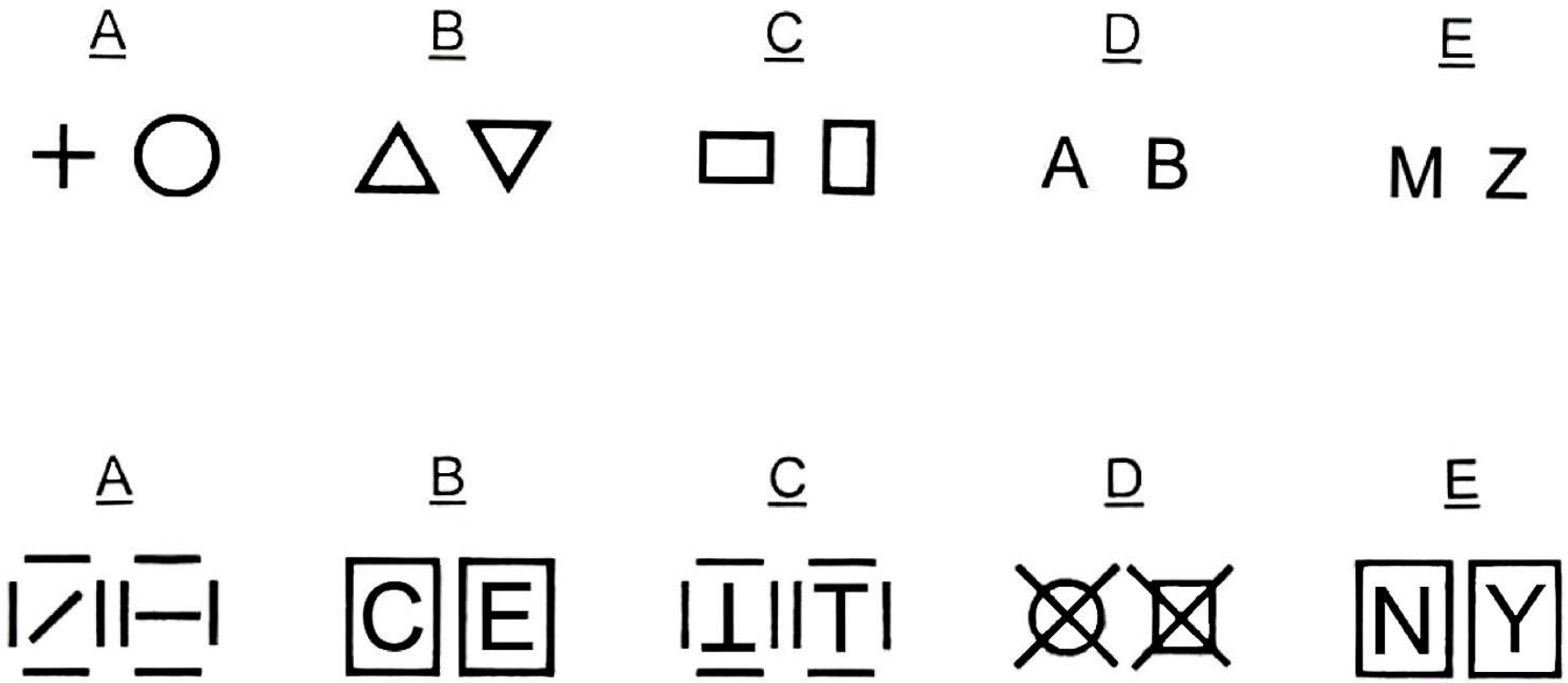
Test both deaf and hearing cats on a battery of visual discriminations to ascertain if the learning or recall of any visual discriminations are enhanced as a consequence of deafness.

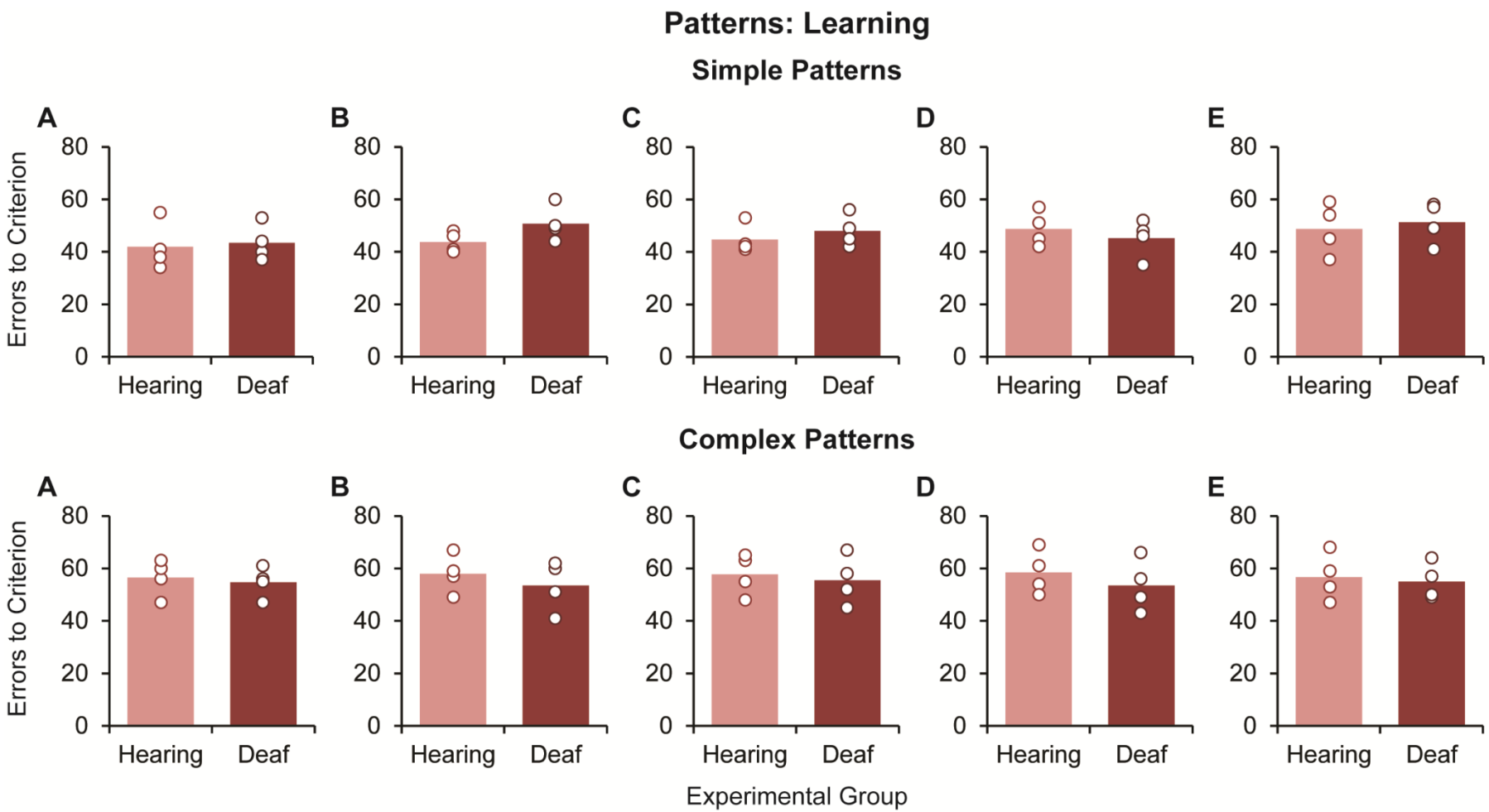
Visual Discriminations

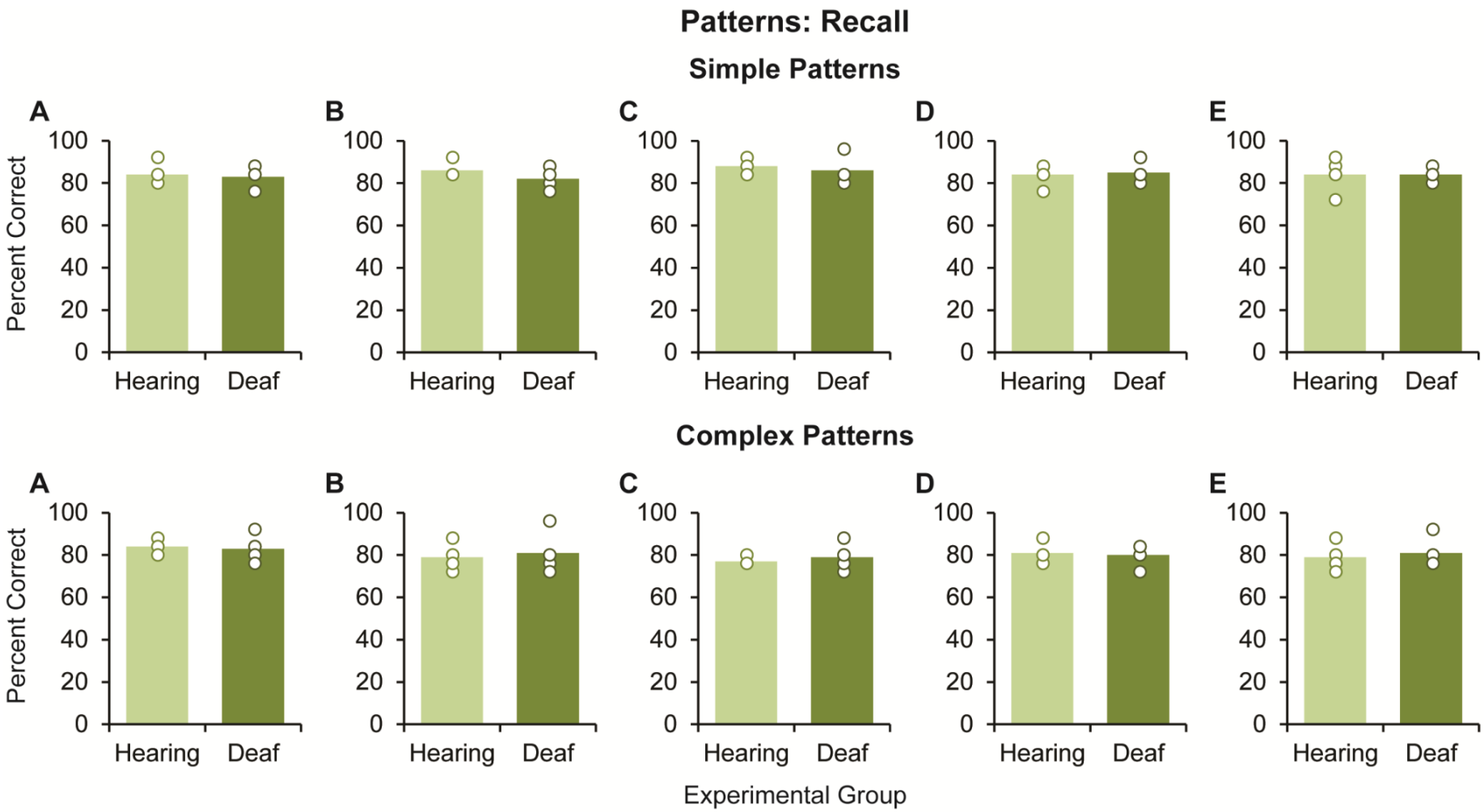
1. Simple Patterns
2. Complex Patterns
3. Simple Objects
4. Junk Objects
5. Natural Scenes
6. Conspecific Faces
7. Human Faces



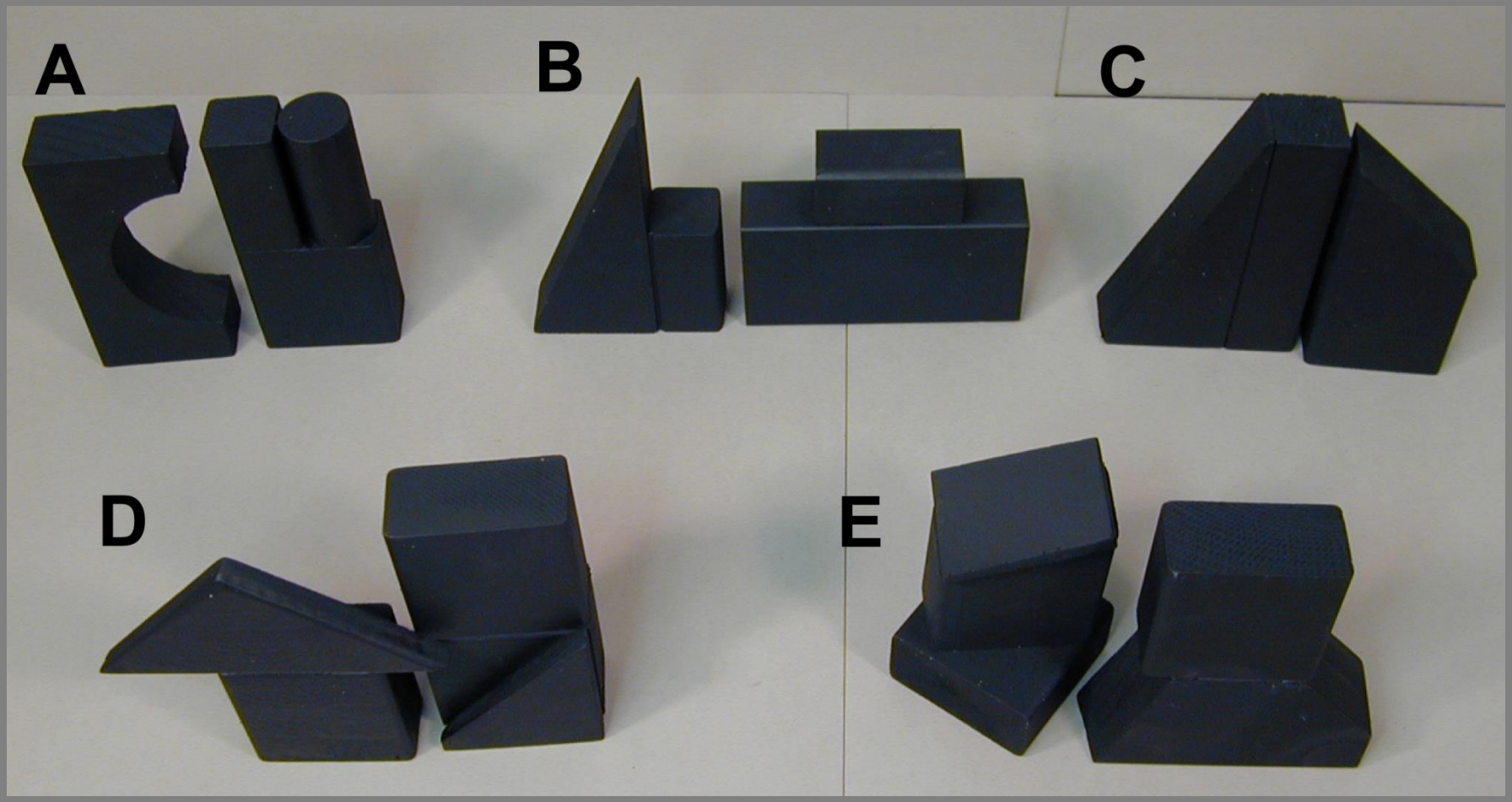
Patterns



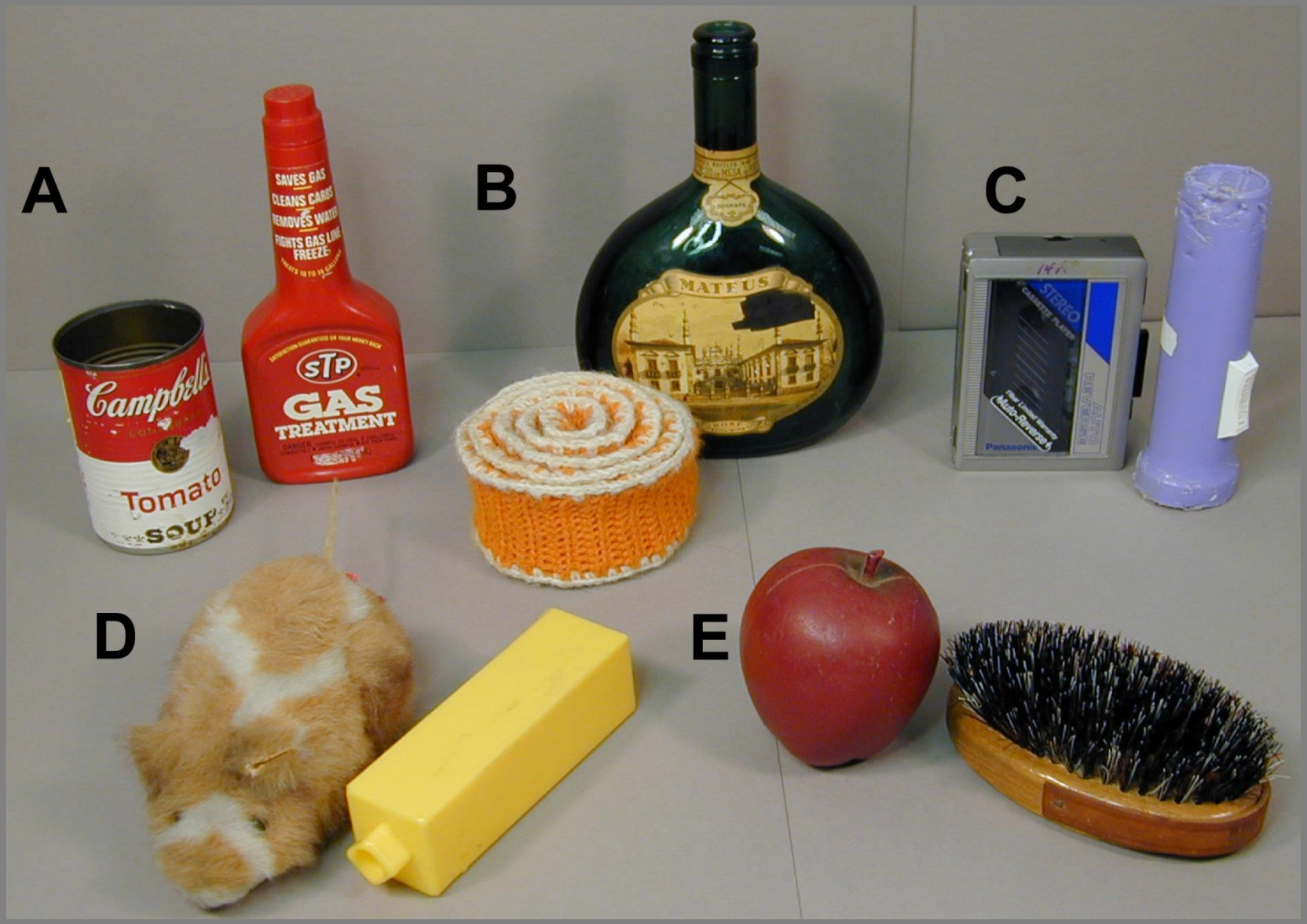

Patterns: Learning
Simple Patterns
A
B
C
D
E
Errors to Criterion
80
60
40
20
0
Hearing
Deaf
Complex Patterns
Experimental Group

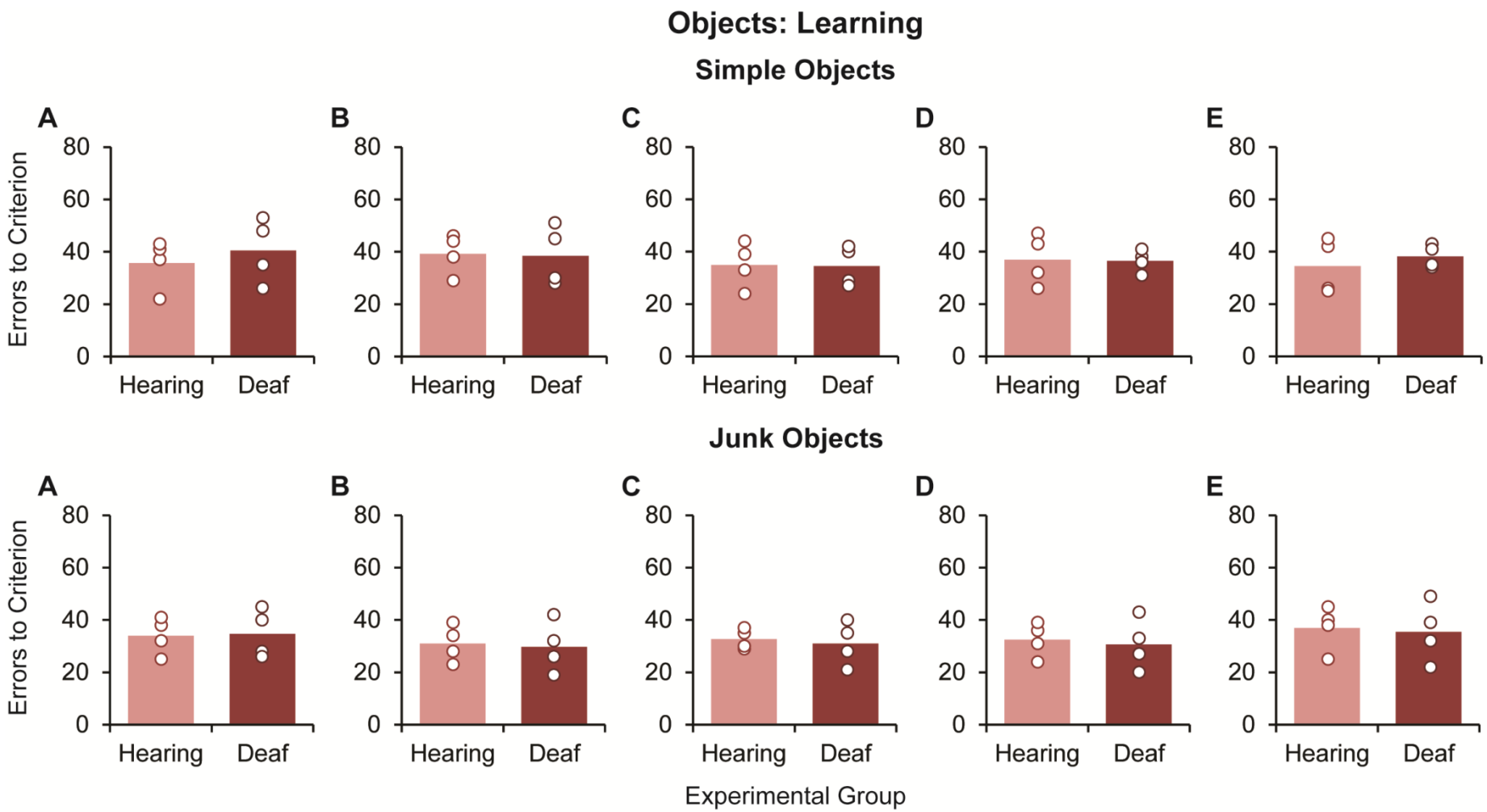

Patterns: Recall
Simple Patterns
A
B
C
D
E
Percent Correct
100
80
60
40
20
0
Hearing
Deaf
Complex Patterns
Experimental Group

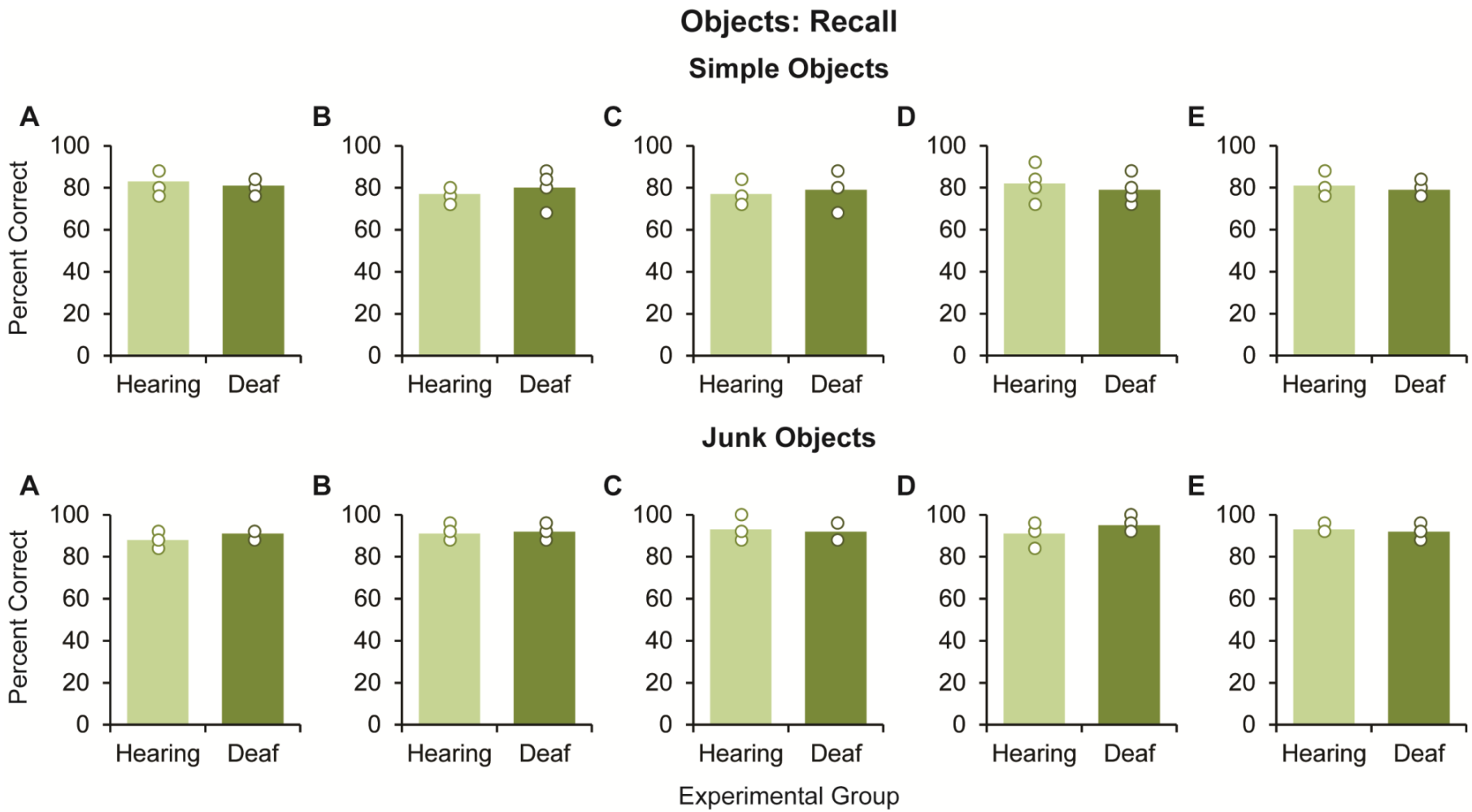
Simple Objects

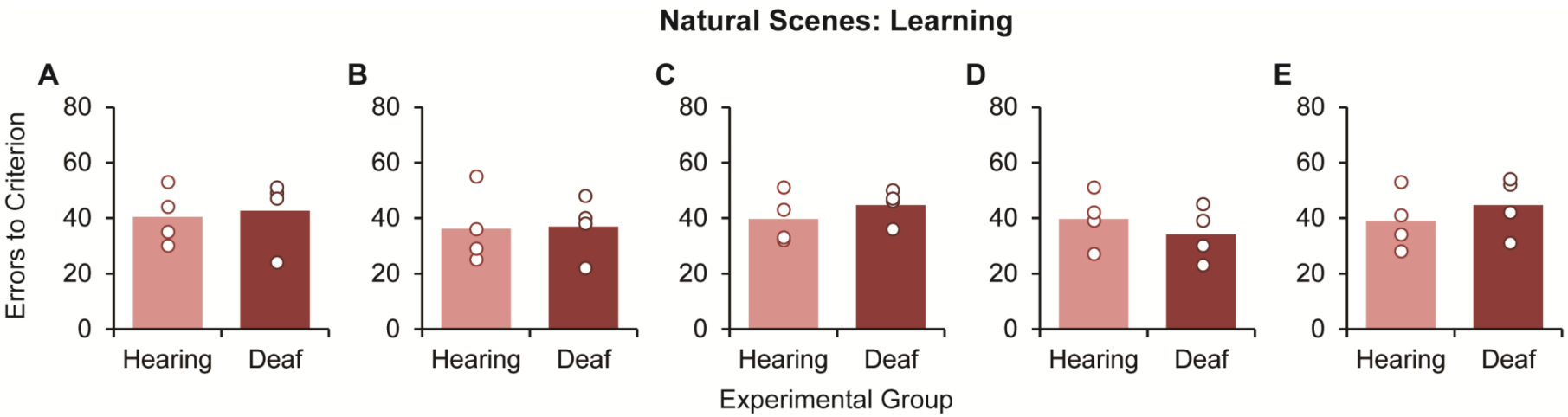


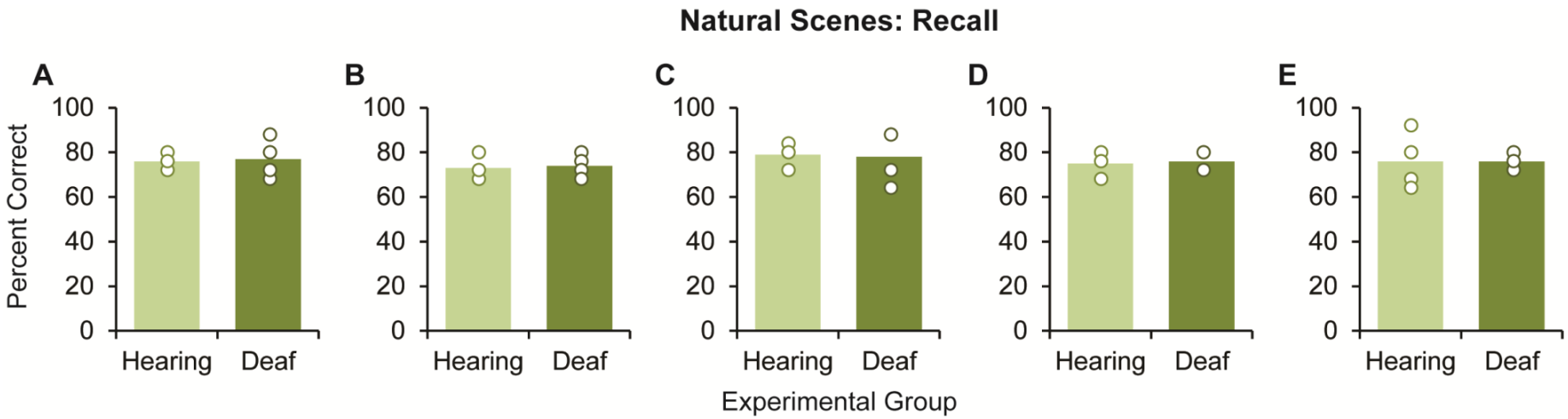
Junk Objects




Objects: Learning
Simple Objects
A
B
C
D
E
Errors to Criterion
80
60
40
20
0
Hearing
Deaf
Junk Objects
Experimental Group

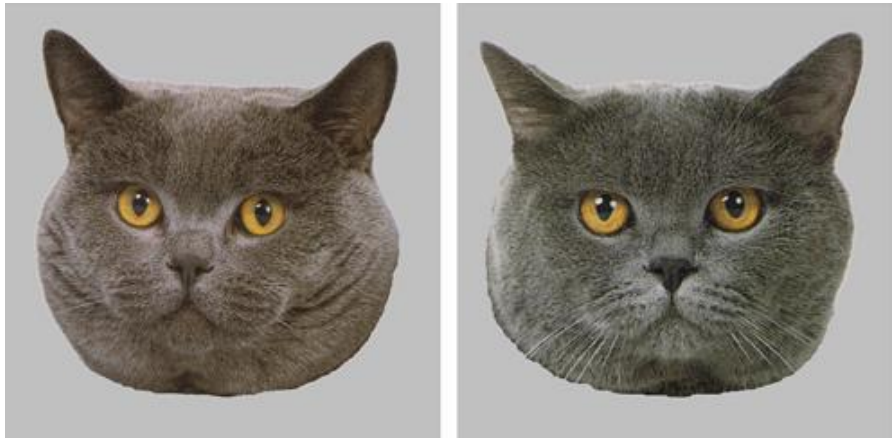

Objects: Recall
Simple Objects
A
B
C
D
E
Percent Correct
100
80
60
40
20
0
Hearing
Deaf
Junk Objects
Experimental Group


Natural Scenes: Learning
A
B
C
D
E
Errors to Criterion
80
60
40
20
0
Hearing
Deaf
Experimental Group

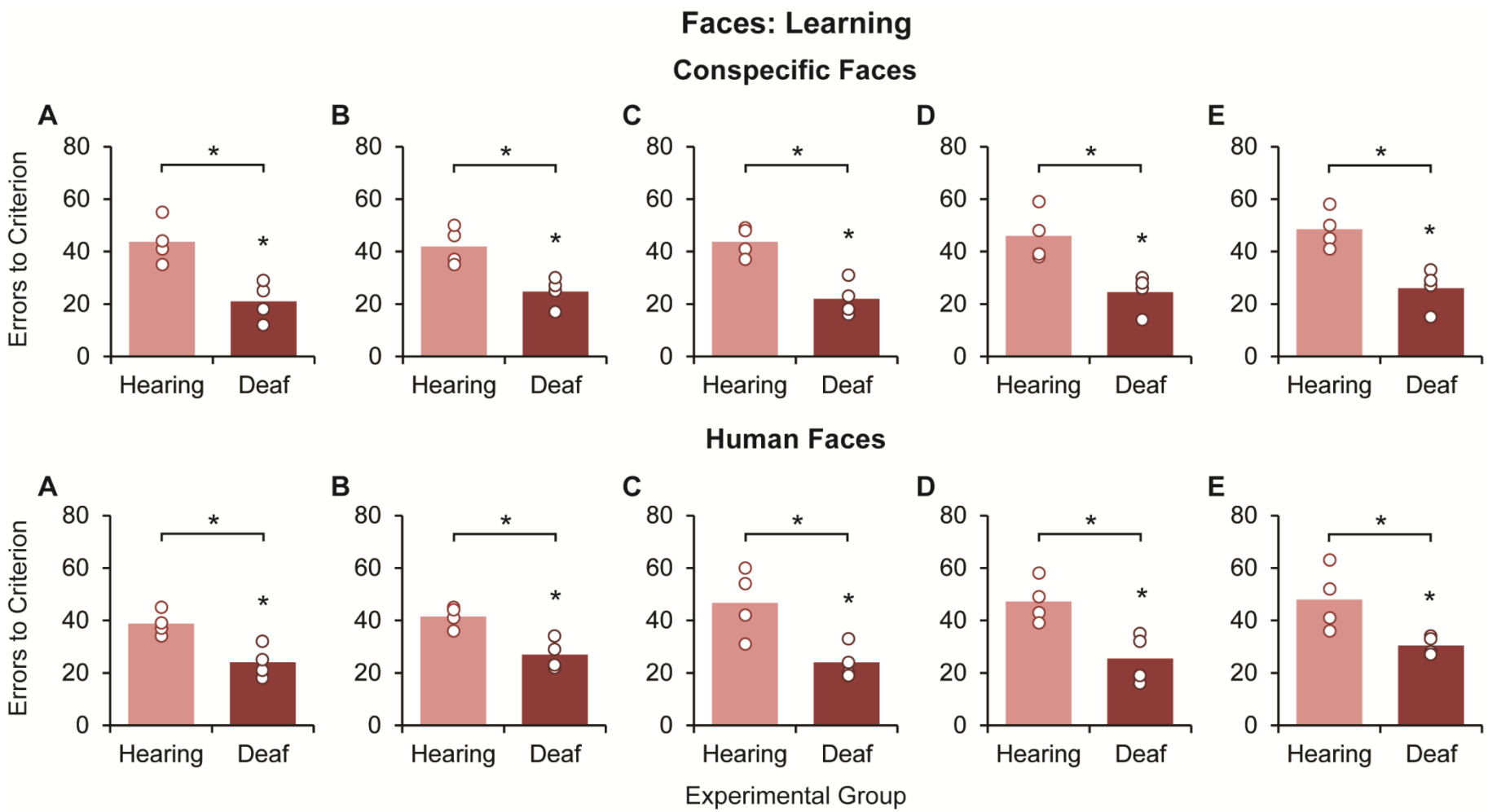

Natural Scenes: Recall
A
B
C
D
E
Percent Correct
100
80
60
40
20
0
Hearing
Deaf
Experimental Group

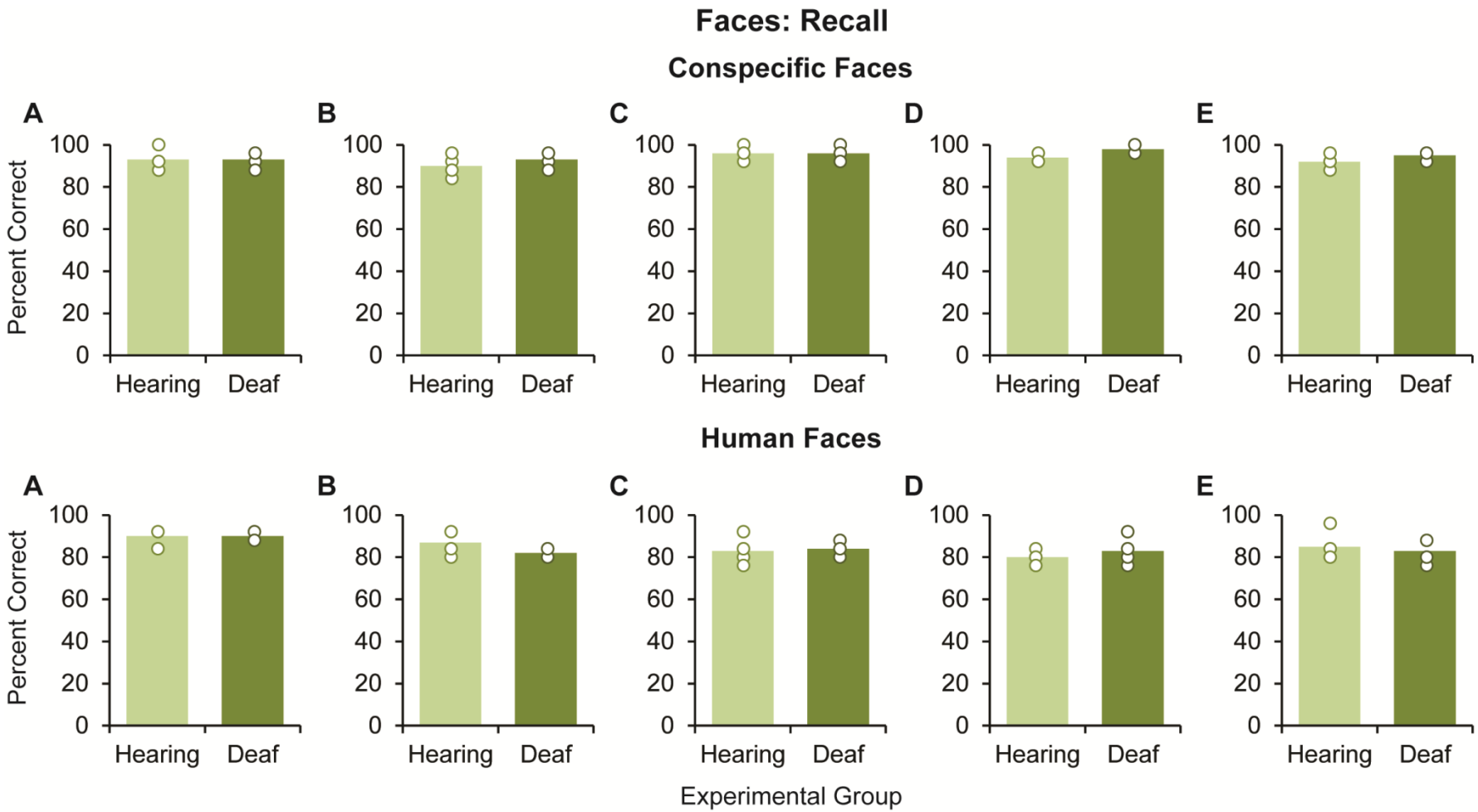
Faces

Conspecific



Human


Faces: Learning
Conspecific Faces
A
B
C
D
E
Errors to Criterion
80
60
40
20
0
*
Hearing
Deaf
Human Faces
Experimental Group


Faces: Recall
Conspecific Faces
A
B
C
D
E
Percent Correct
100
80
60
40
20
0
Hearing
Deaf
Human Faces
Experimental Group

Summary

Congenitally Deaf Cats have learning and recall abilities similar to Hearing Cats on the following discriminations:

- Simple Patterns
- Complex Patterns
- Simple Objects
- Junk Objects
- Natural Scenes

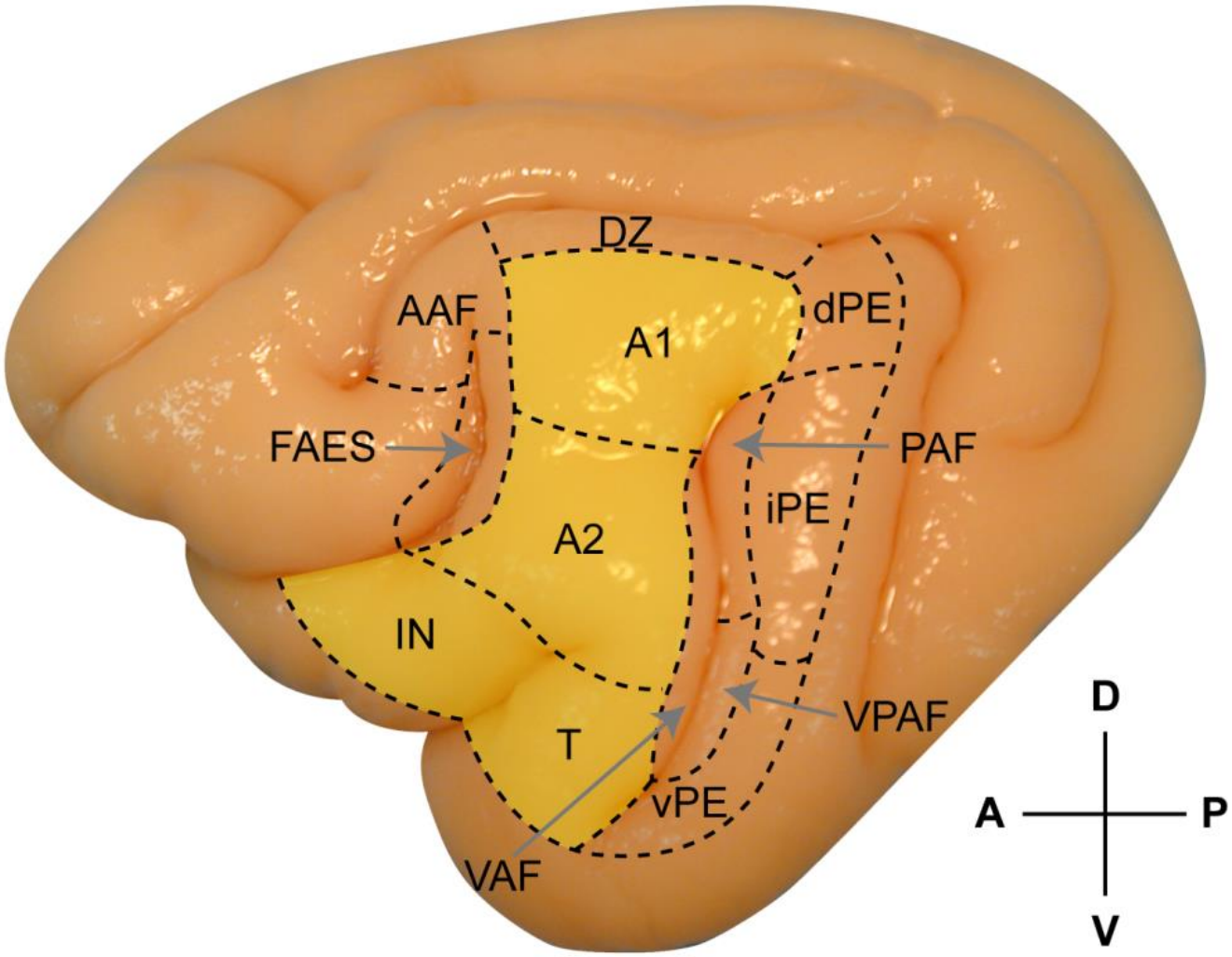
Congenitally Deaf Cats have learning, but not recall, abilities superior to Hearing Cats on the following tasks:

- Conspecific Faces
- Human Faces

Aim 2

Determine what role “deaf” auditory cortex may play in mediating the superior cognitive functions.

Deactivate specific sites in “deaf” auditory cortex while the deaf cats perform the visual discriminations for which they possess enhanced cognitive abilities.


DZ
AAF
A1
dPE
FAES
PAF
iPE
A2
IN
VPAF
T
vPE
VAF
D
A
P
V

Types of Neural Deactivation

Permanent

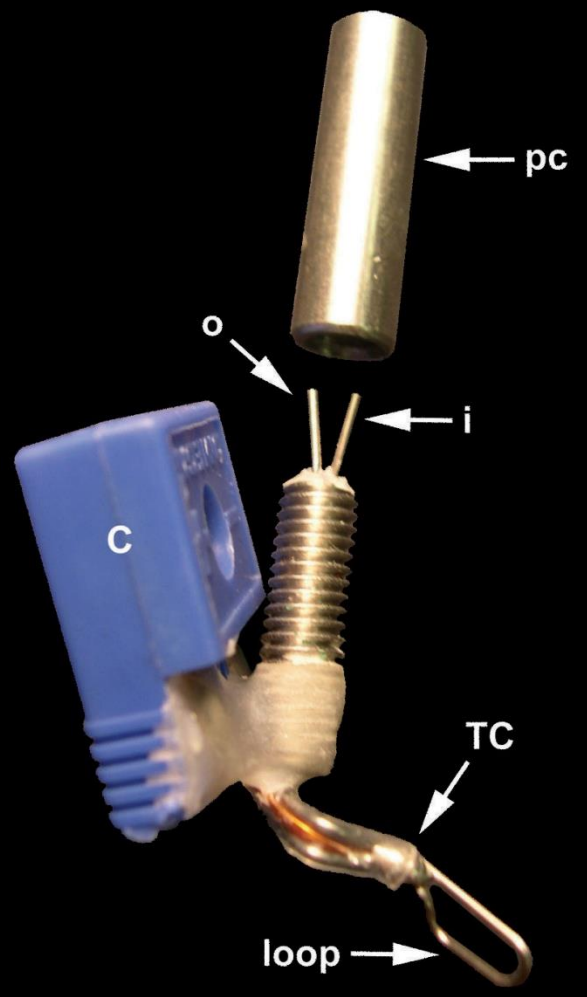
- Physical ablation
- Chemical (neurotoxins)
- Electrolytic

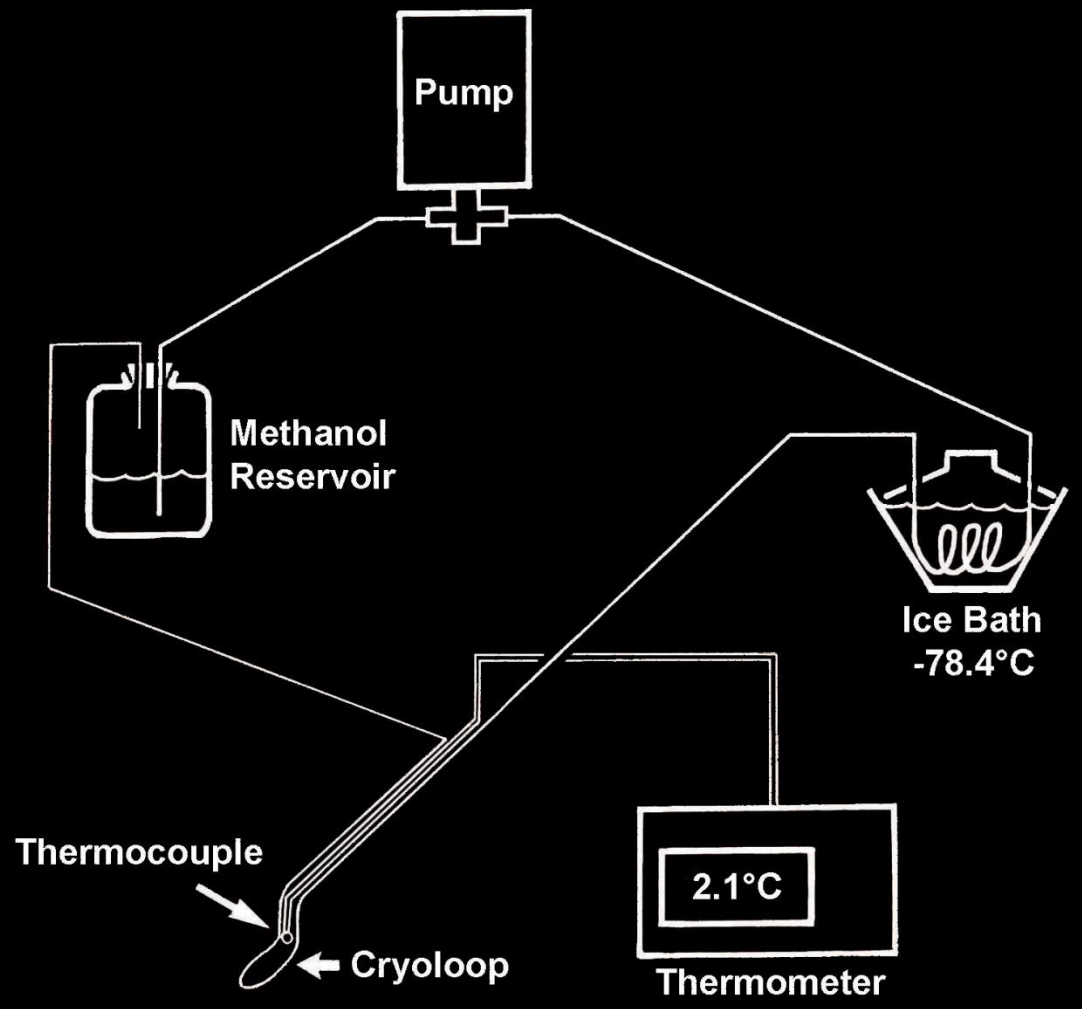
Reversible

- Chemical (Lidocaine, Muscimol, GABA)
- Thermal – Cooling
  - (Thermoelectric-Peltier, Cryoloop)

From Lomber (1999) *J. Neurosci. Meth.* **86**: 109-117.

The Cryoloop Technique

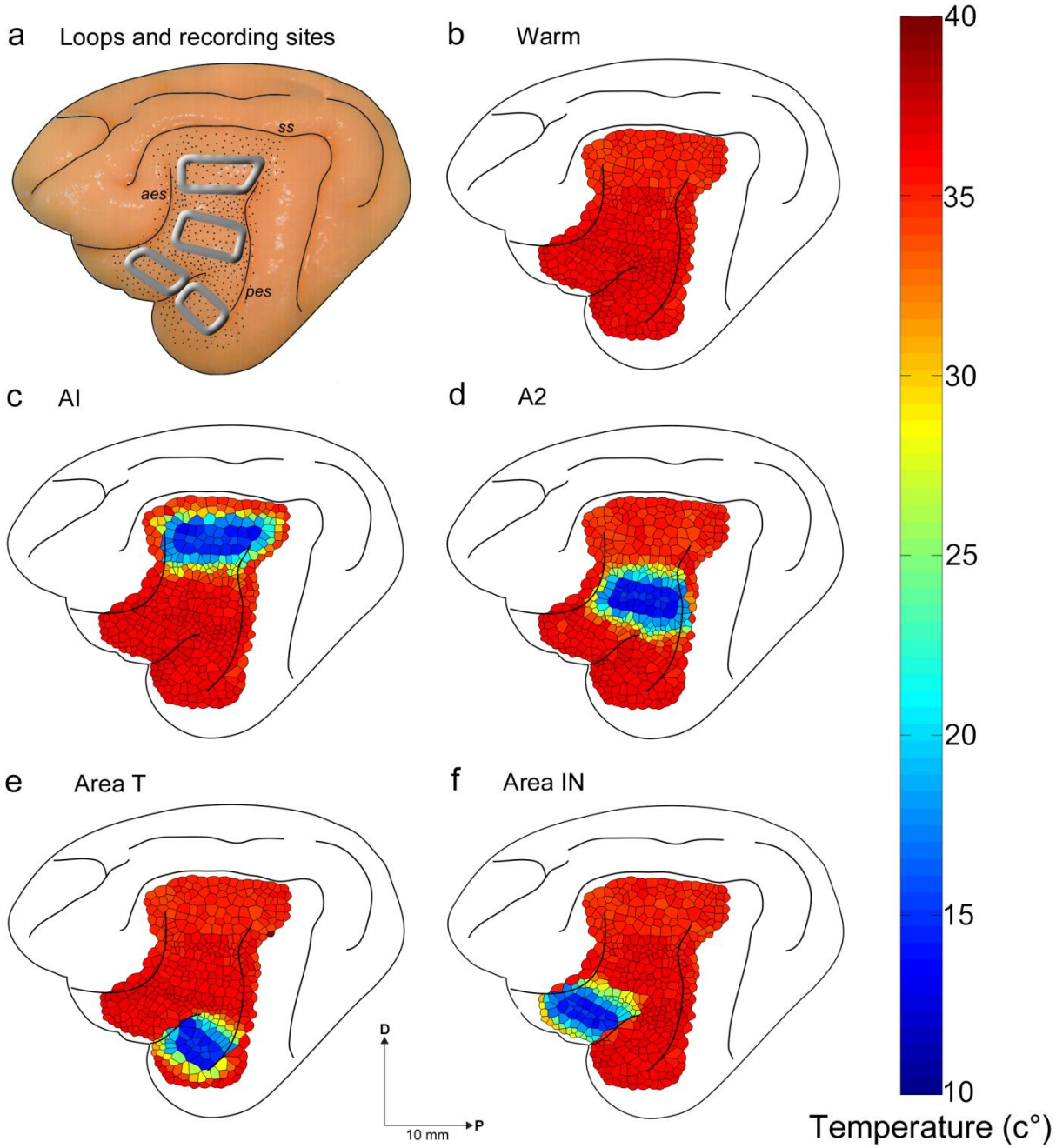


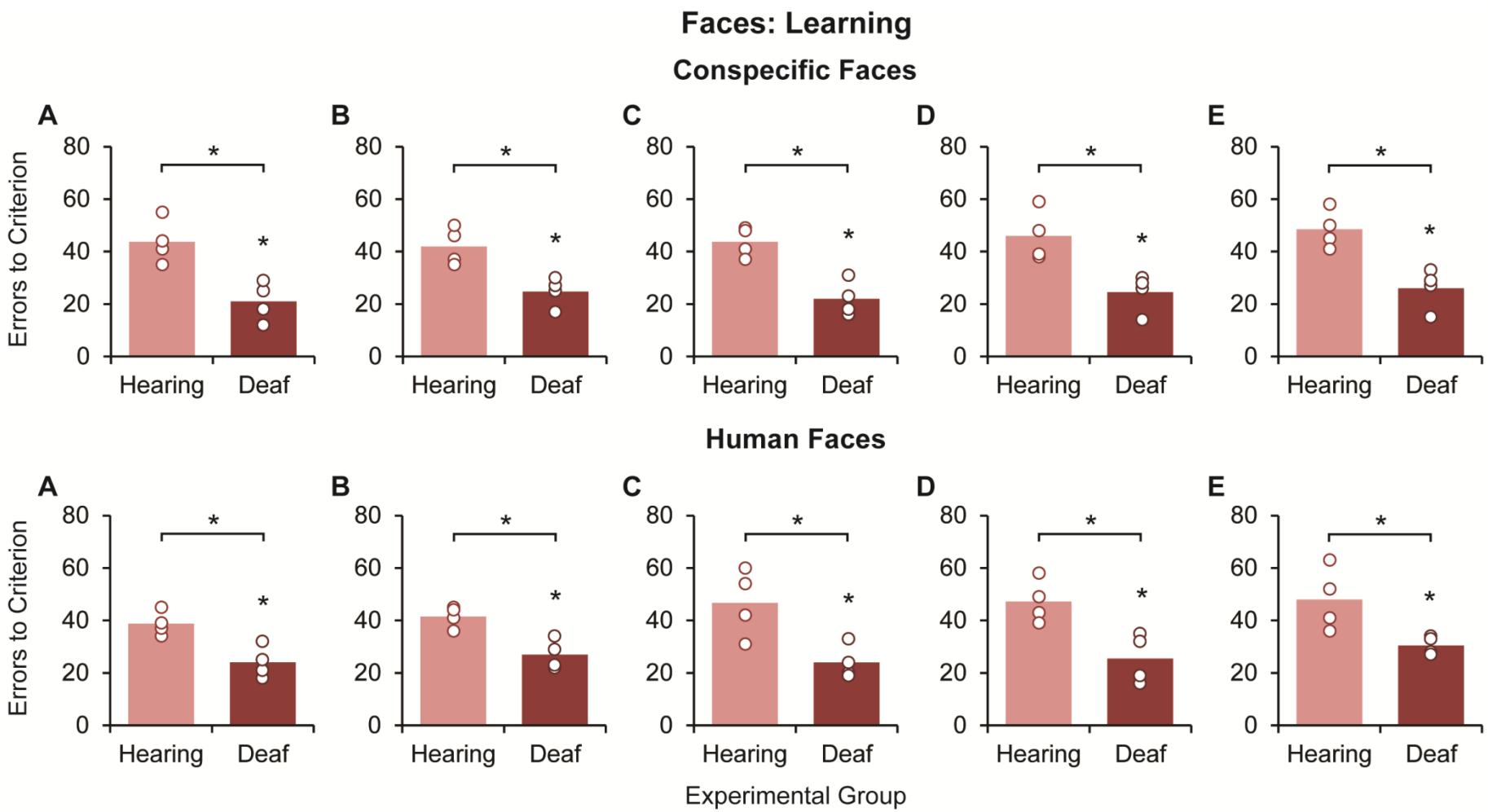


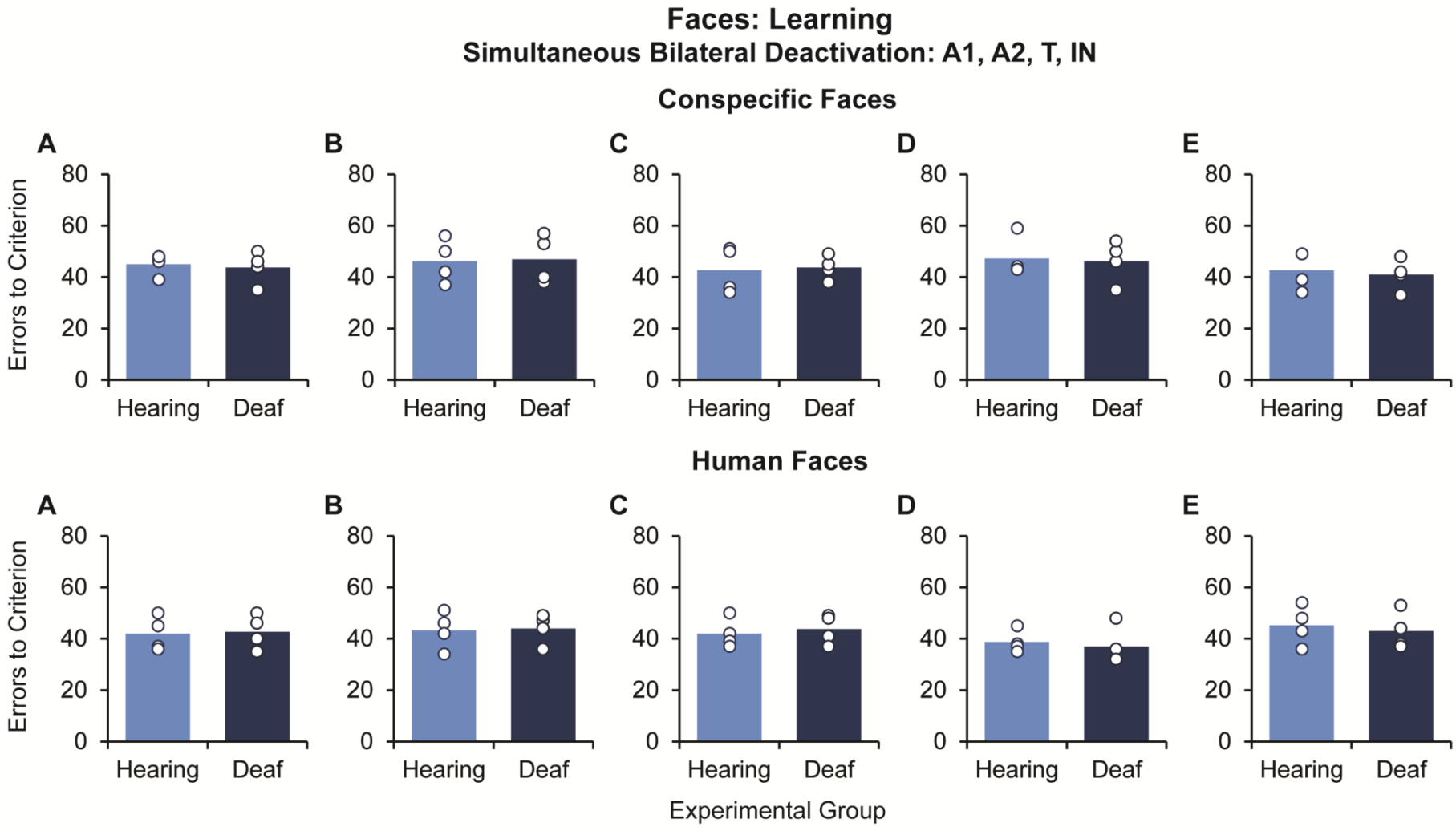
From Lomber et al. (1999) *J. Neurosci. Meth.* **86**: 179-194

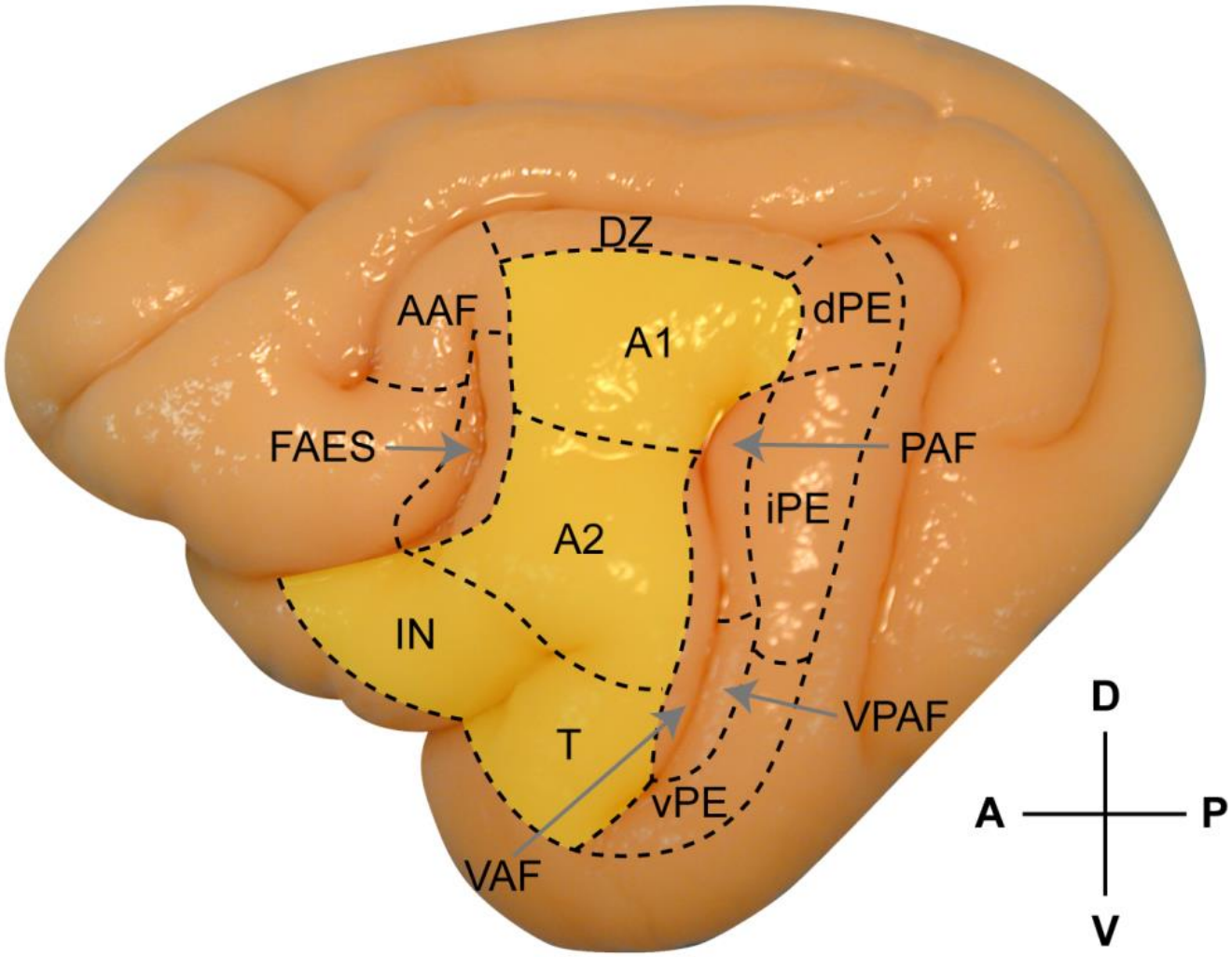
What you need to know about reversible cooling deactivation

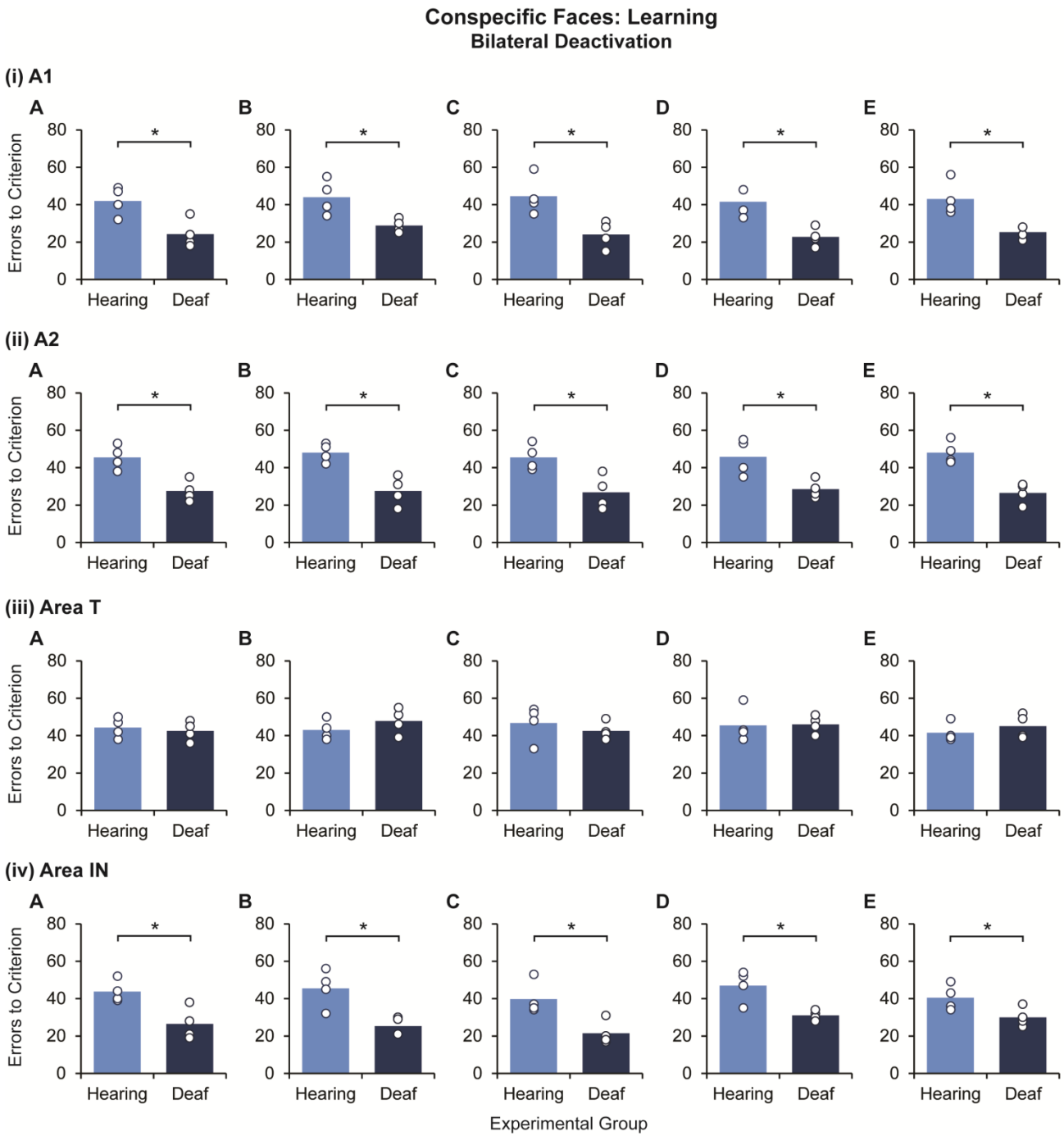
- Tissue temps <20°C eliminate synaptic transmission
- Disrupts calcium uptake at the axon terminal
- Doesn’t impair axonal transmission
- Highly localized
- Deactivation can be induced or reversed in minutes
- Each animal serves as its own control
- Multiple cortical sites can be examined in each animal


a
Loops and recording sites
ss
aes
pes
b
Warm
c
AI
d
A2
e
Area T
f
Area IN
D
P
10 mm
40
35
30
25
20
15
10
Temperature (c°)

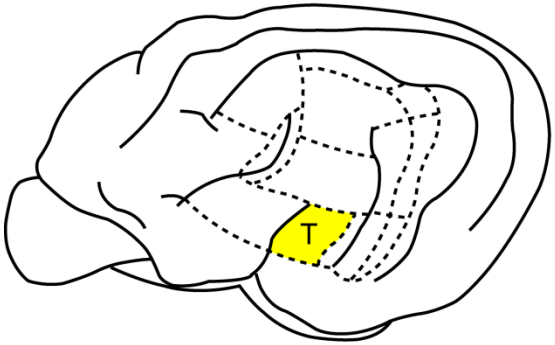

Faces: Learning
Conspecific Faces
A
B
C
D
E
Errors to Criterion
80
60
40
20
0
*
Hearing
Deaf
Human Faces
Experimental Group

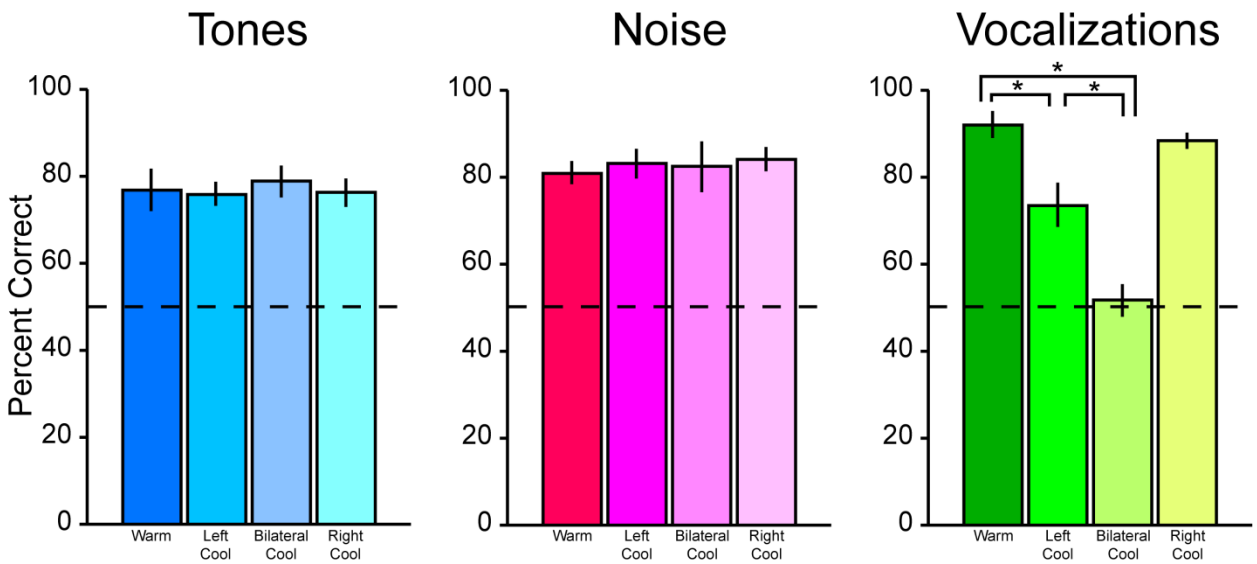

Faces: Learning
Simultaneous Bilateral Deactivation: A1, A2, T, IN
Conspecific Faces
Human Faces
A
B
C
D
E
Errors to Criterion
0
20
40
60
80
Hearing
Deaf
Experimental Group


DZ
AAF
A1
dPE
FAES
PAF
iPE
A2
IN
VPAF
T
vPE
VAF
D
A
P
V


Conspecific Faces: Learning
Bilateral Deactivation
(i) A1
(ii) A2
(iii) Area T
(iv) Area IN
A
B
C
D
E
Errors to Criterion
0
20
40
60
80
*
Hearing
Deaf
Experimental Group

Why Area T?


T


Tones
Noise
Vocalizations
Percent Correct
100
80
60
40
20
0
Warm
Left Cool
Bilateral Cool
Right Cool
*
*
*

The Supramodal Hypothesis

"Cortical areas that have been physiologically reorganized in response to sensory loss (deafness/ blindness) will be involved in behaviours that are similar to those of hearing/sighted subjects, but are mediated by the replacement modality".

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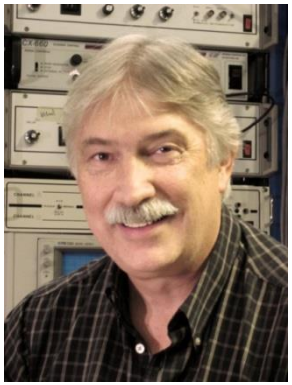


CIHR IRSC
Canadian Institutes of Health Research
Instituts de recherche en santé du Canada

NSERC
CRSNG

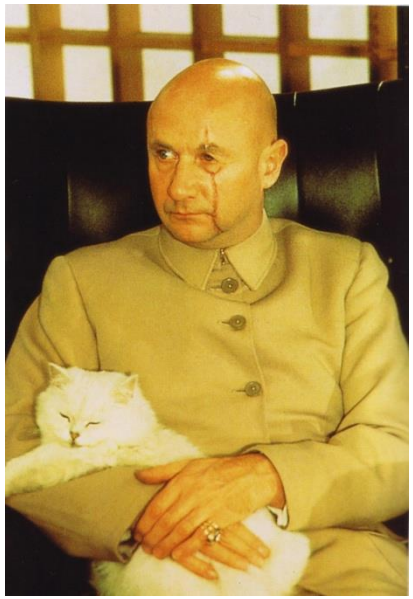
THE hearing foundation OF CANADA
La Fondation canadienne de l'ouie

Canada Foundation for Innovation
Fondation canadienne pour l'innovation

DFG


EX12

For additional information:



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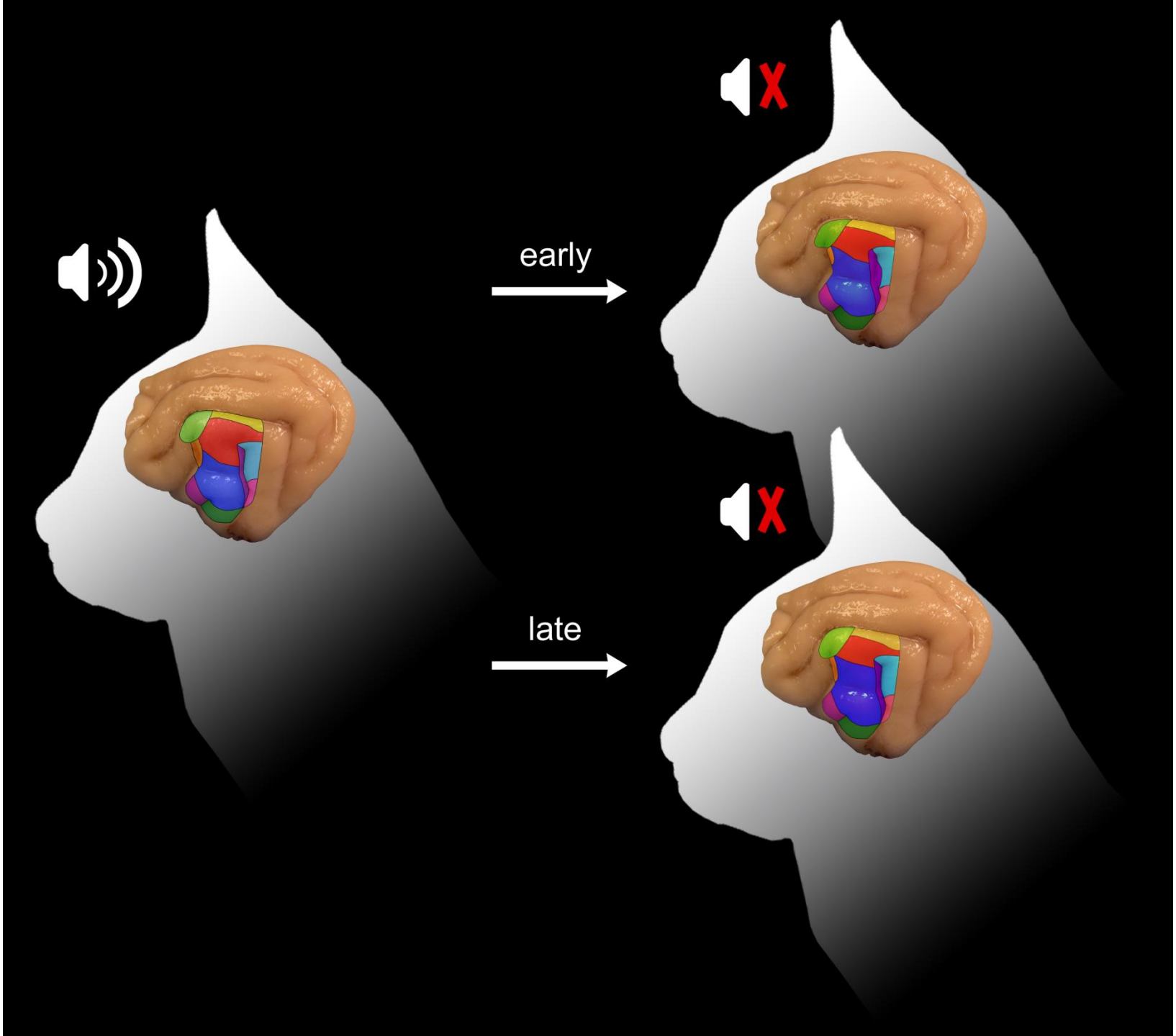
cerebral systems laboratory

Western
The Brain and Mind Institute

Western
National Centre for Audiology

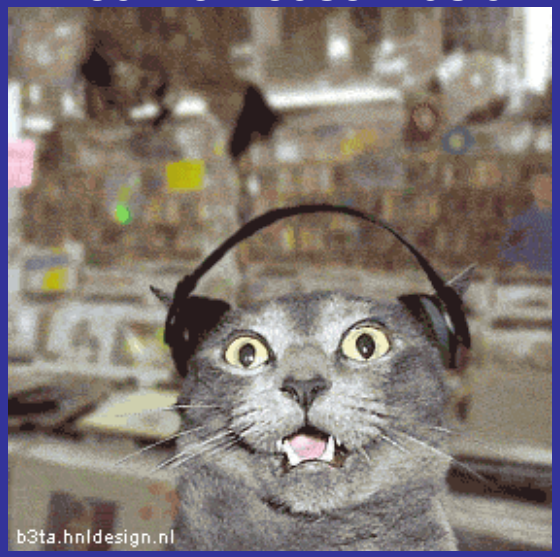

early
late

Feline Acoustic Stimulation

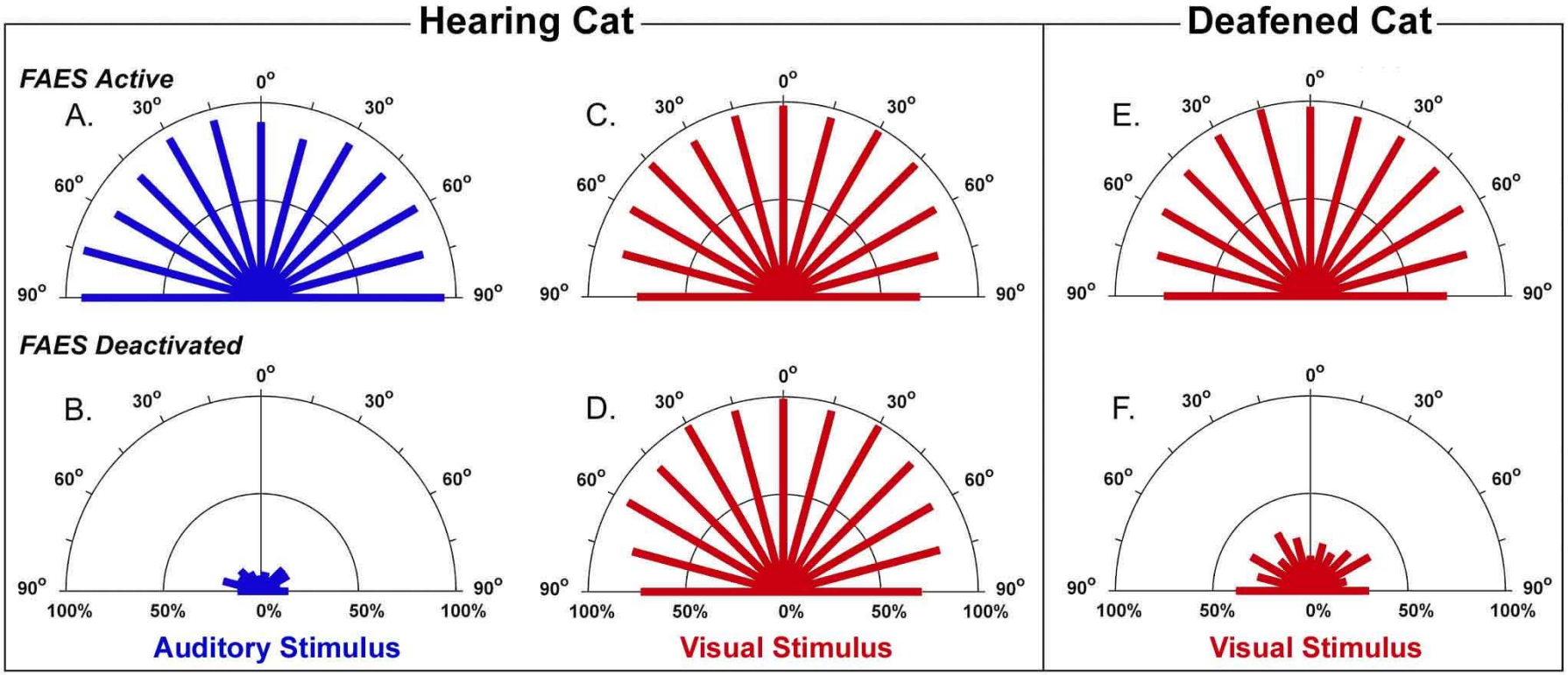
Stevie Wonder

Techno House Music

Hip-Hop



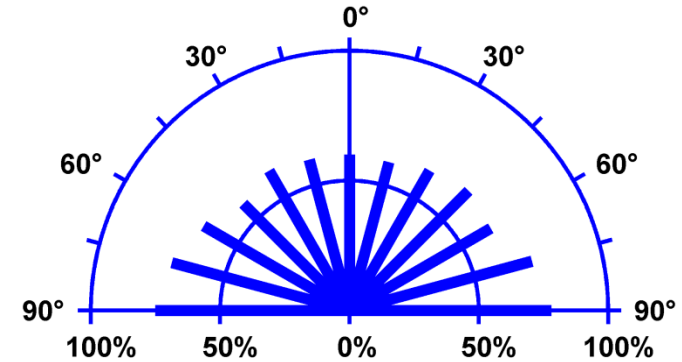
Metallica on Ecstasy


Hearing Cat
Deafened Cat
FAES Active
FAES Deactivated
A.
B.
C.
D.
E.
F.
0°
30°
60°
90°
100%
50%
0%
Auditory Stimulus
Visual Stimulus
Visual Stimulus

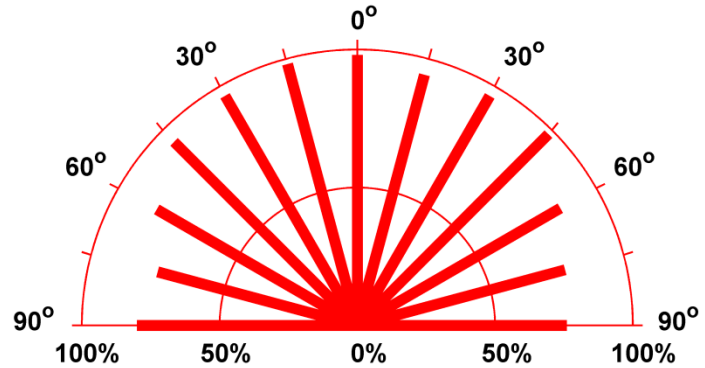
Deaf Cat w/CIs

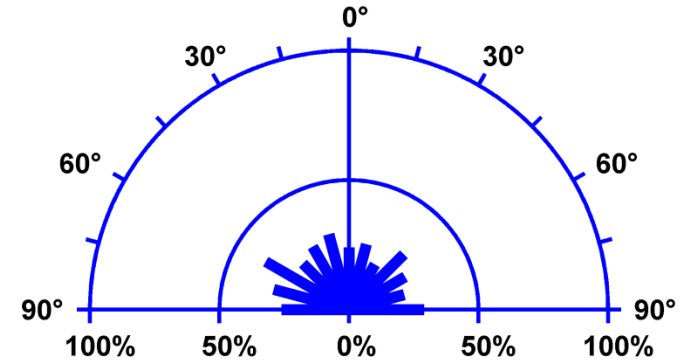
Acoustic Stimulus

Visual Stimulus

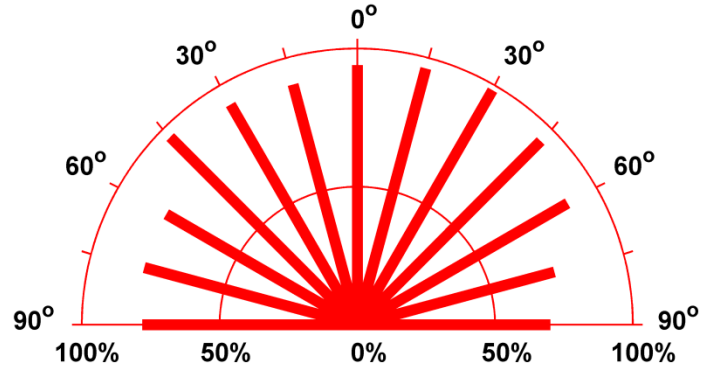


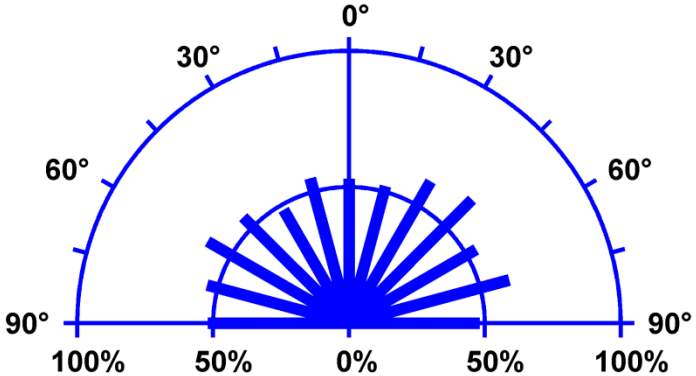
Control



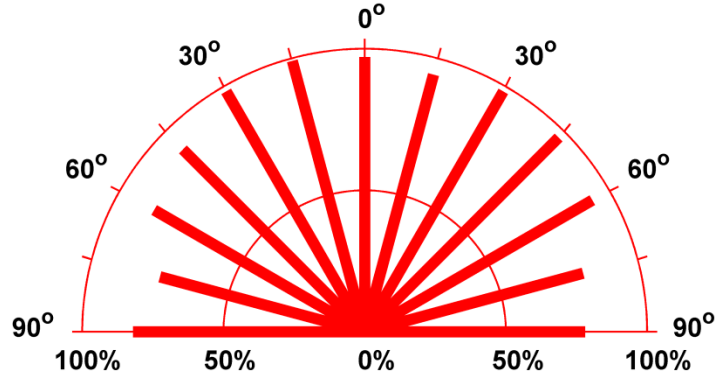


FAES Deactivated



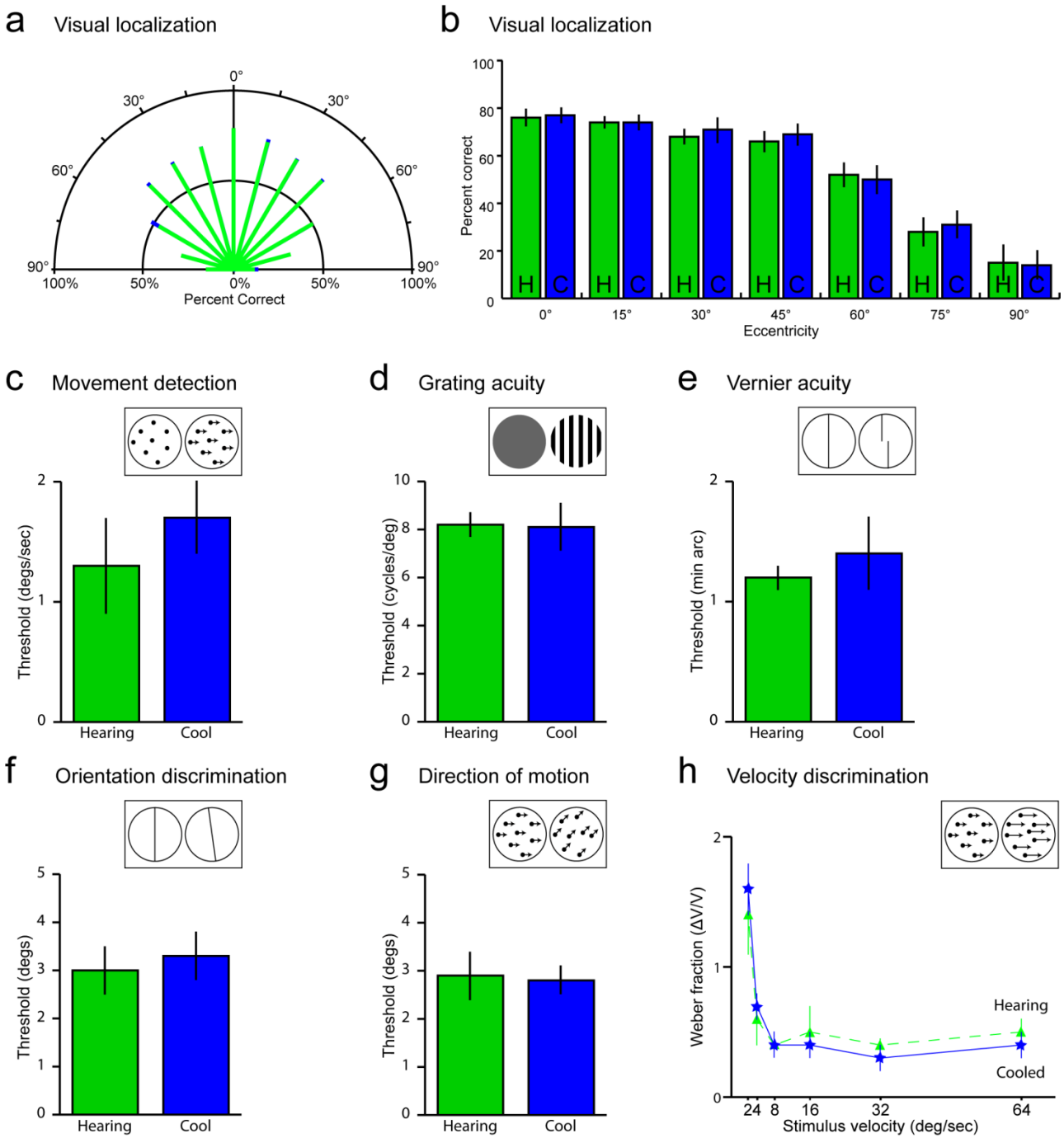


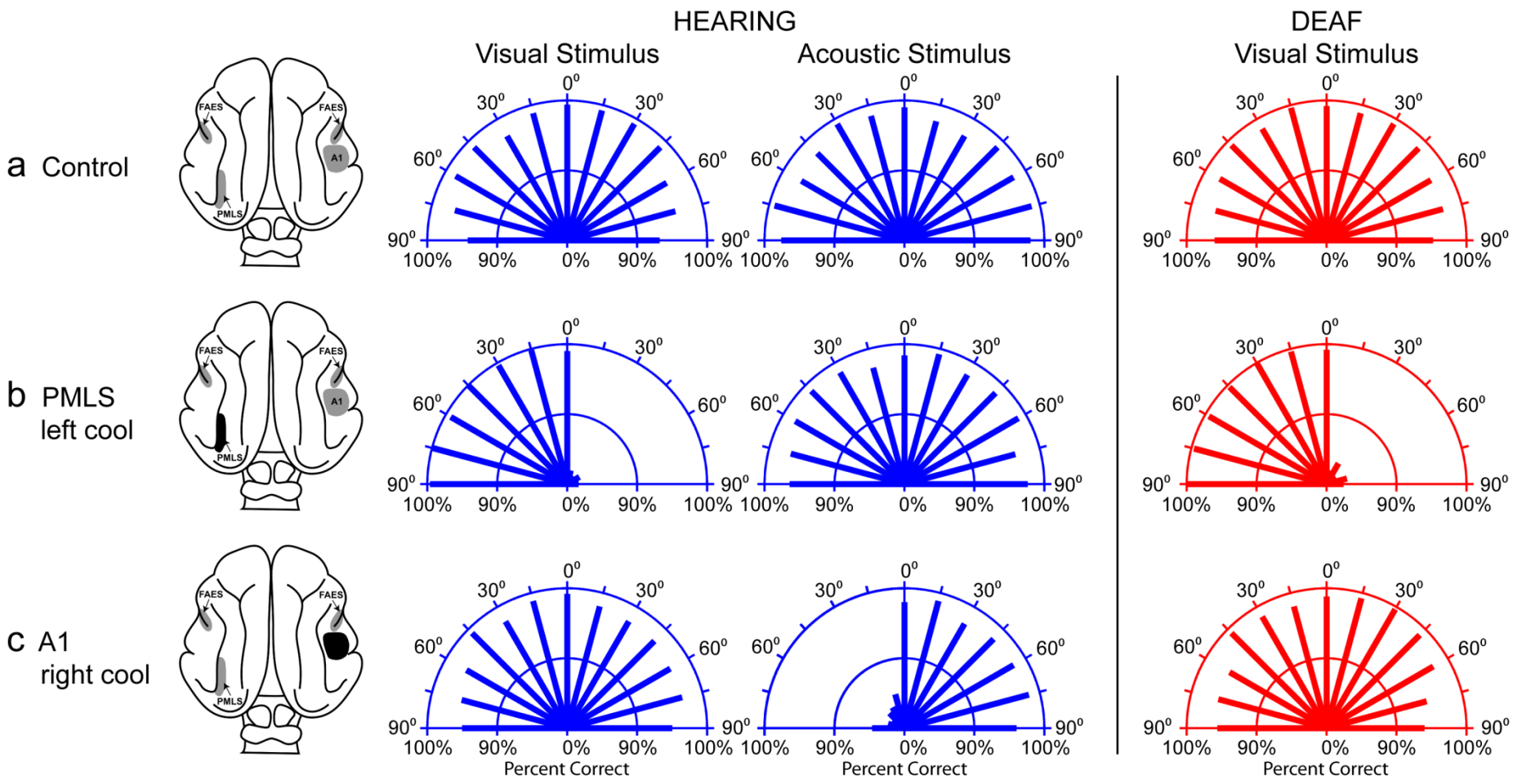
A1 Deactivated



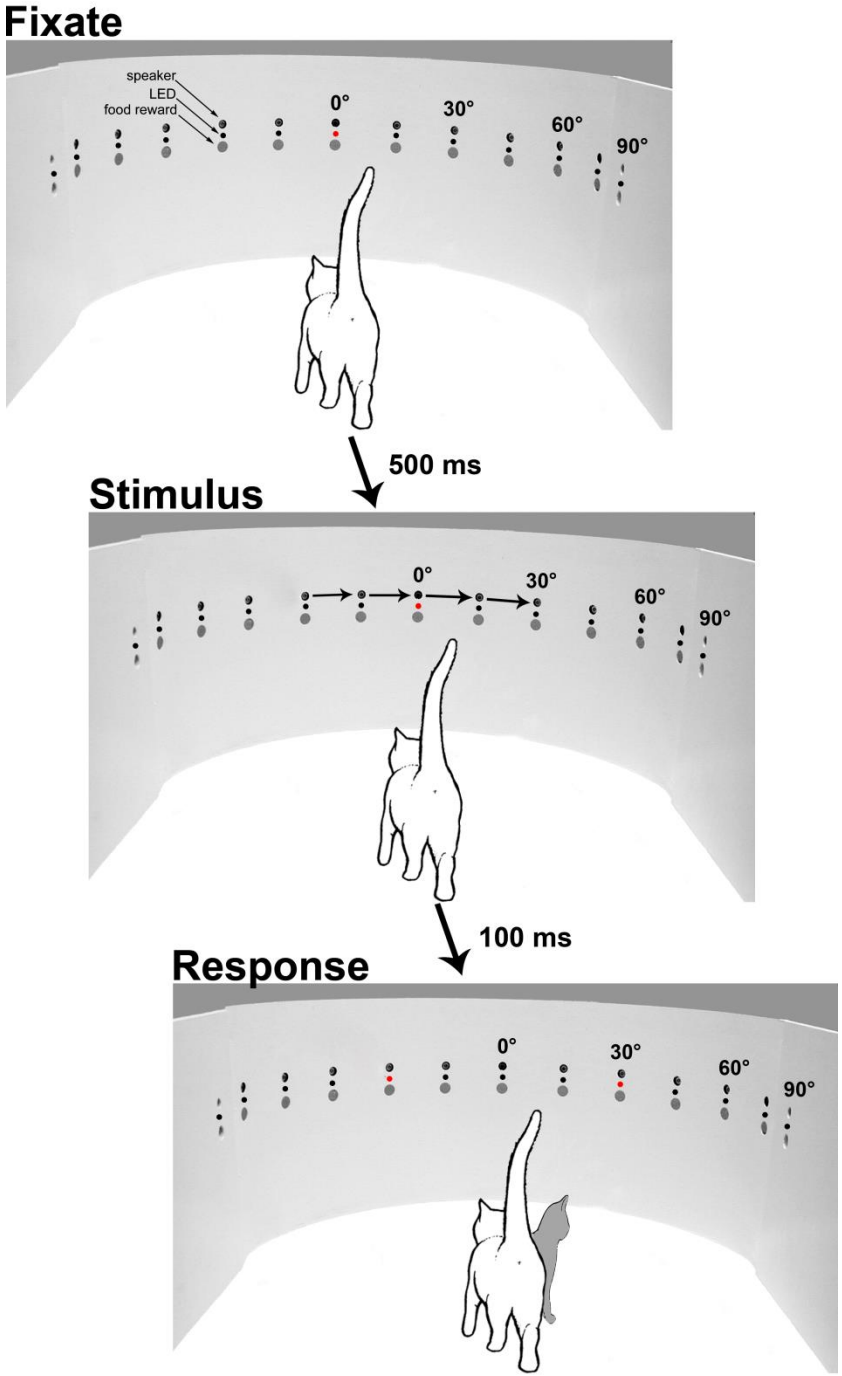
Summary of Visual and Acoustic Orienting Deficits

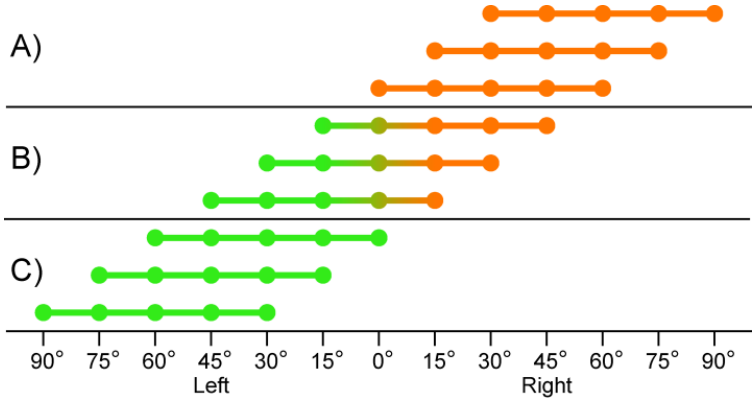
	Hearing Cat	Deaf Cat	Deaf Cat w/CI
Deactivate FAES	Acoustic Deficit	Visual Deficit	Acoustic Deficit*
Deactivate A1	Acoustic Deficit	No Orienting Deficits	Acoustic Deficit*


a
Visual localization
0°
30°
30°
60°
60°
90°
90°
100%
50%
0%
50%
100%
Percent Correct
b
Visual localization
Percent correct
100
80
60
40
20
0
H
C
0°
15°
30°
45°
60°
75°
90°
Eccentricity
c
Movement detection
Threshold (degs/sec)
2
1
0
Hearing
Cool
d
Grating acuity
Threshold (cycles/deg)
10
8
6
4
2
0
Hearing
Cool
e
Vernier acuity
Threshold (min arc)
2
1
0
Hearing
Cool
f
Orientation discrimination
Threshold (degs)
5
4
3
2
1
0
Hearing
Cool
g
Direction of motion
Threshold (degs)
5
4
3
2
1
0
Hearing
Cool
h
Velocity discrimination
Weber fraction (ΔV/V)
2
1
0
Hearing
Cooled
24
8
16
32
64
Stimulus velocity (deg/sec)


HEARING
Visual Stimulus
Acoustic Stimulus
DEAF
Visual Stimulus
a Control
b PMLS
left cool
c A1
right cool
FAES
A1
PMLS
0°
30°
60°
90°
100%
90%
0%
Percent Correct

Direction of Motion Discrimination

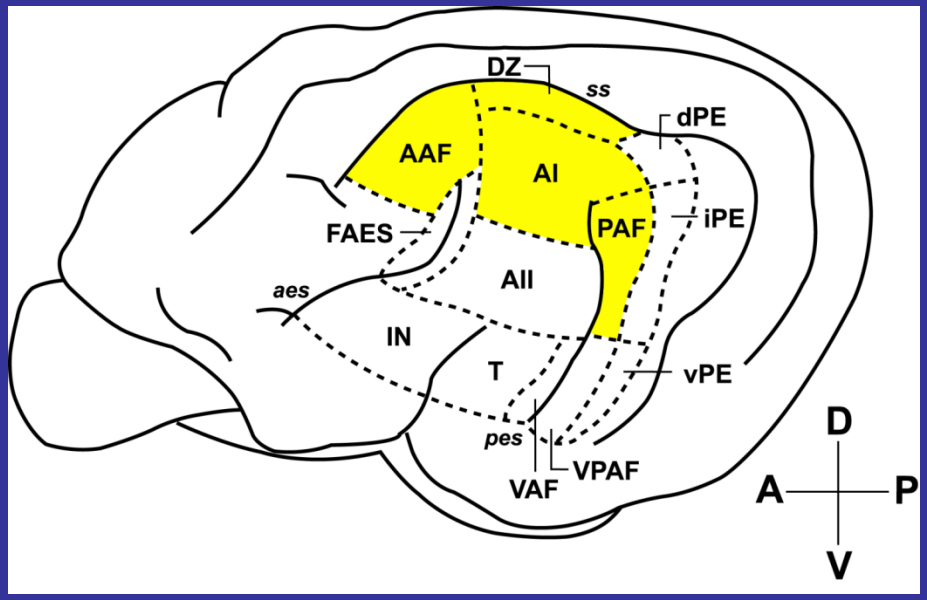


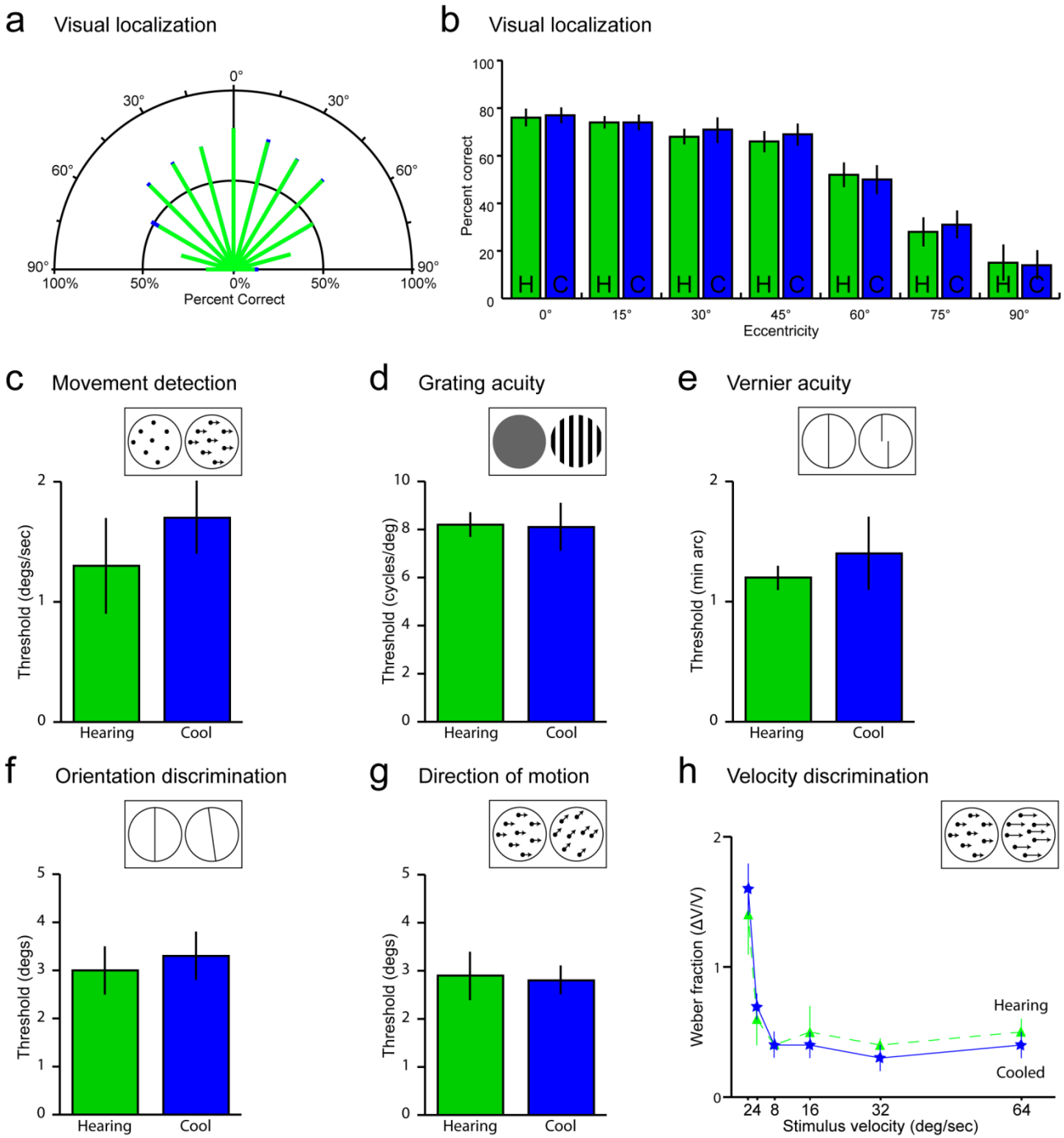


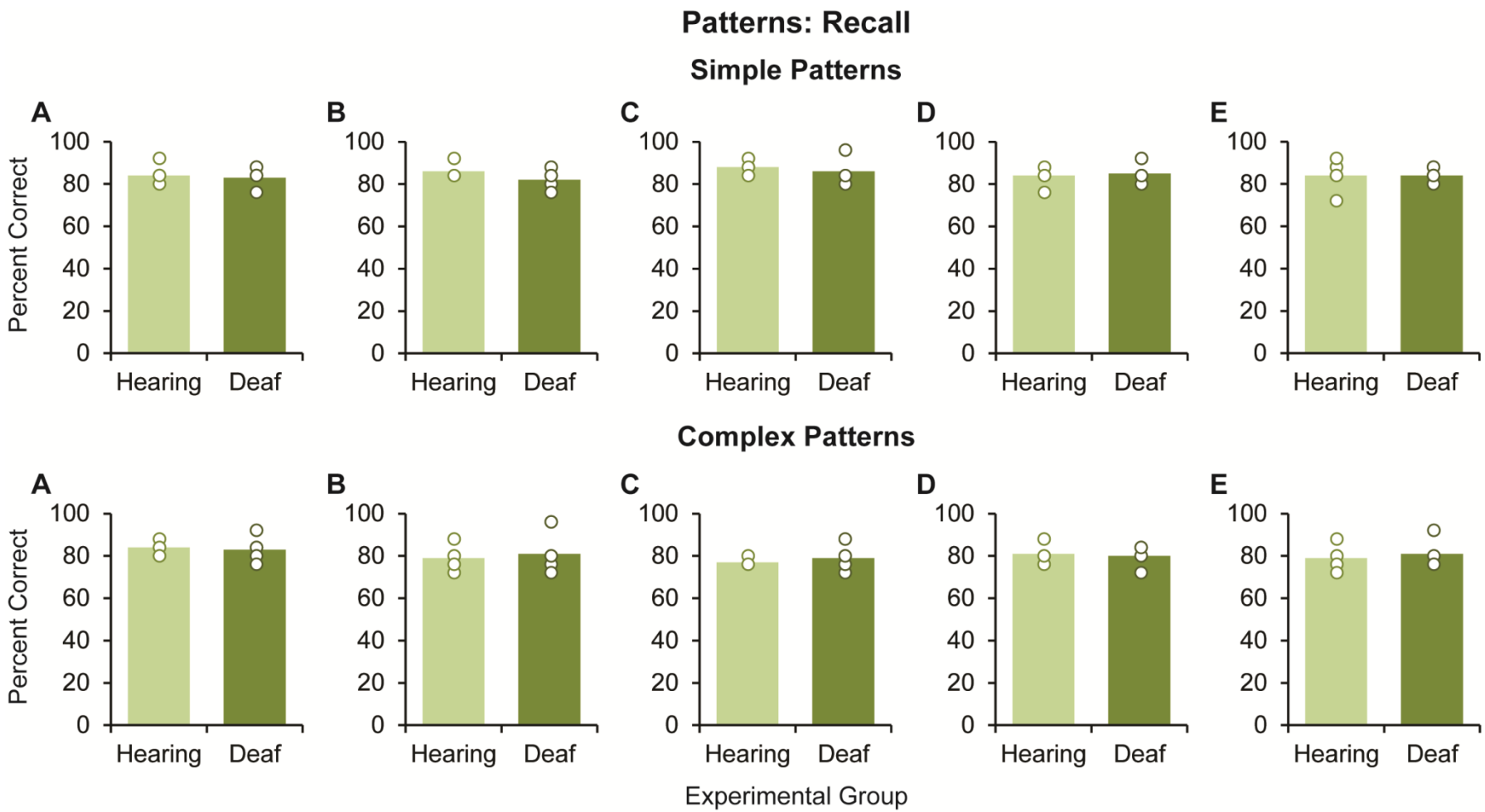
<u>Stimulus:</u>
Sweeping Broadband noise burst
(800-5,000 Hz)
90 deg/sec
667 ms duration
78 dB SPL

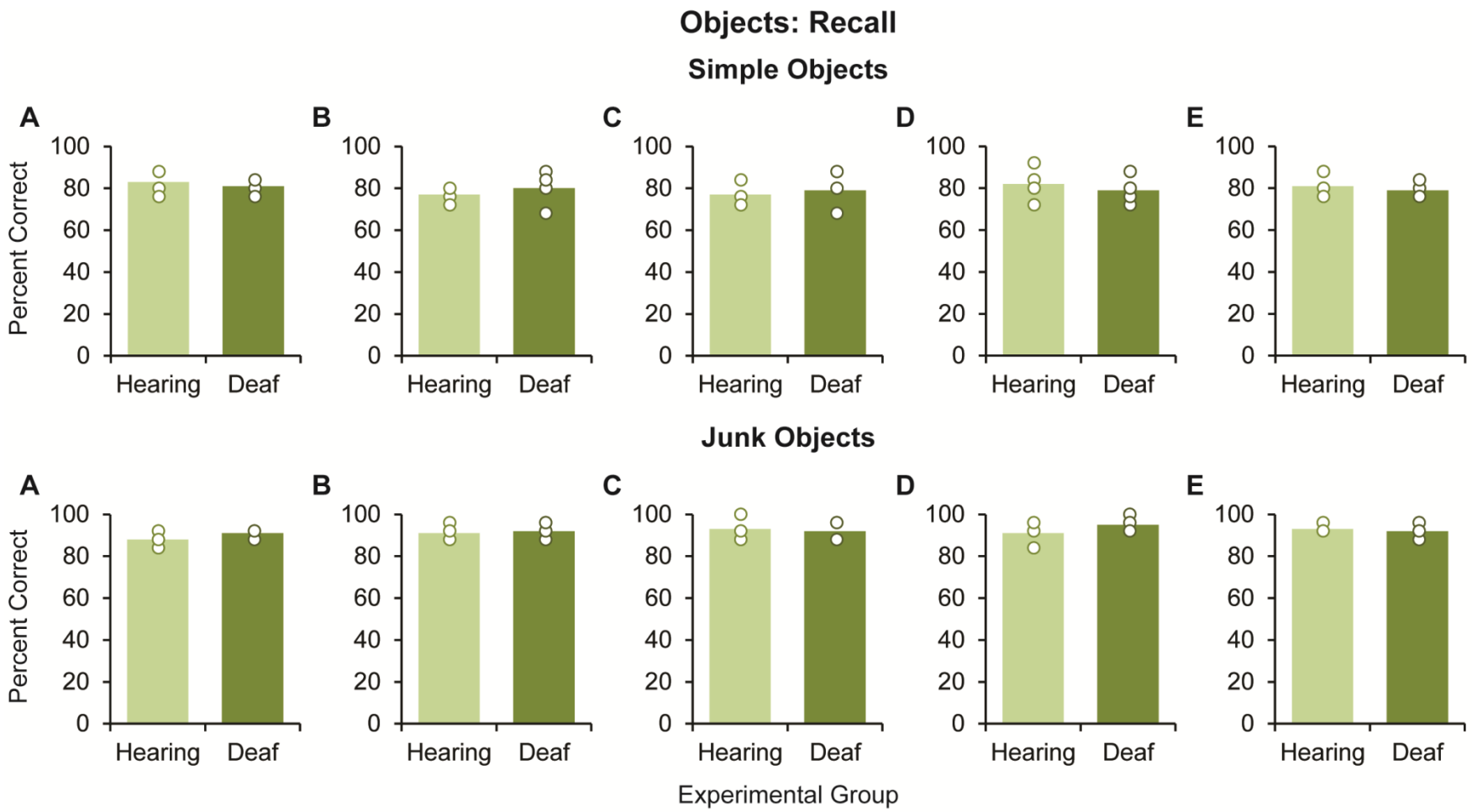
Control - Hearing Cats

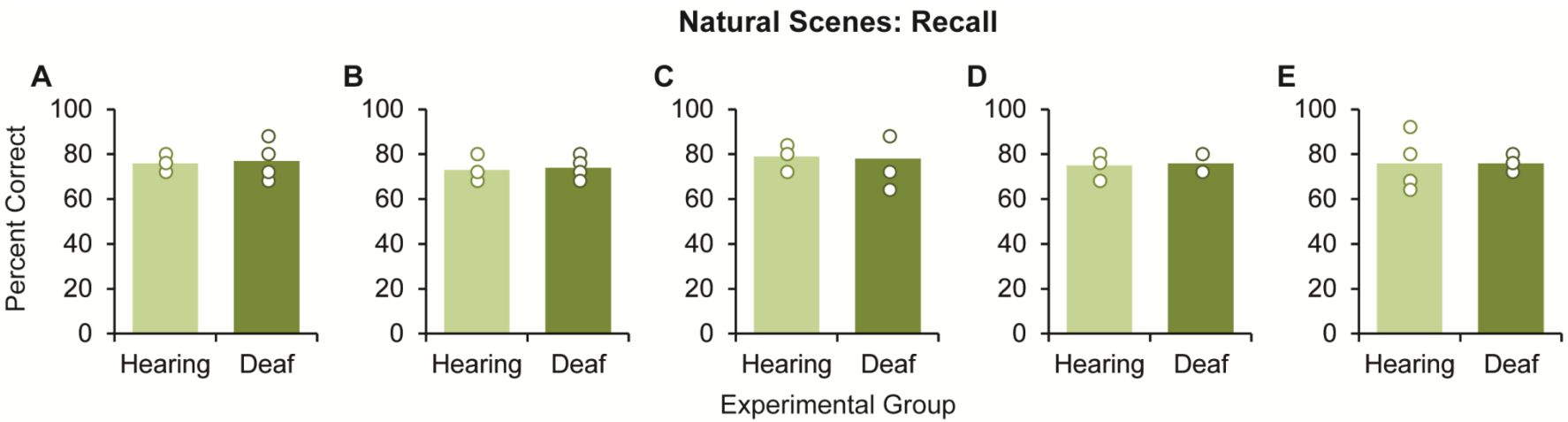
Reversible deactivation of none of the four regions of auditory cortex resulted in any impairments on any of the seven visual tasks examined.

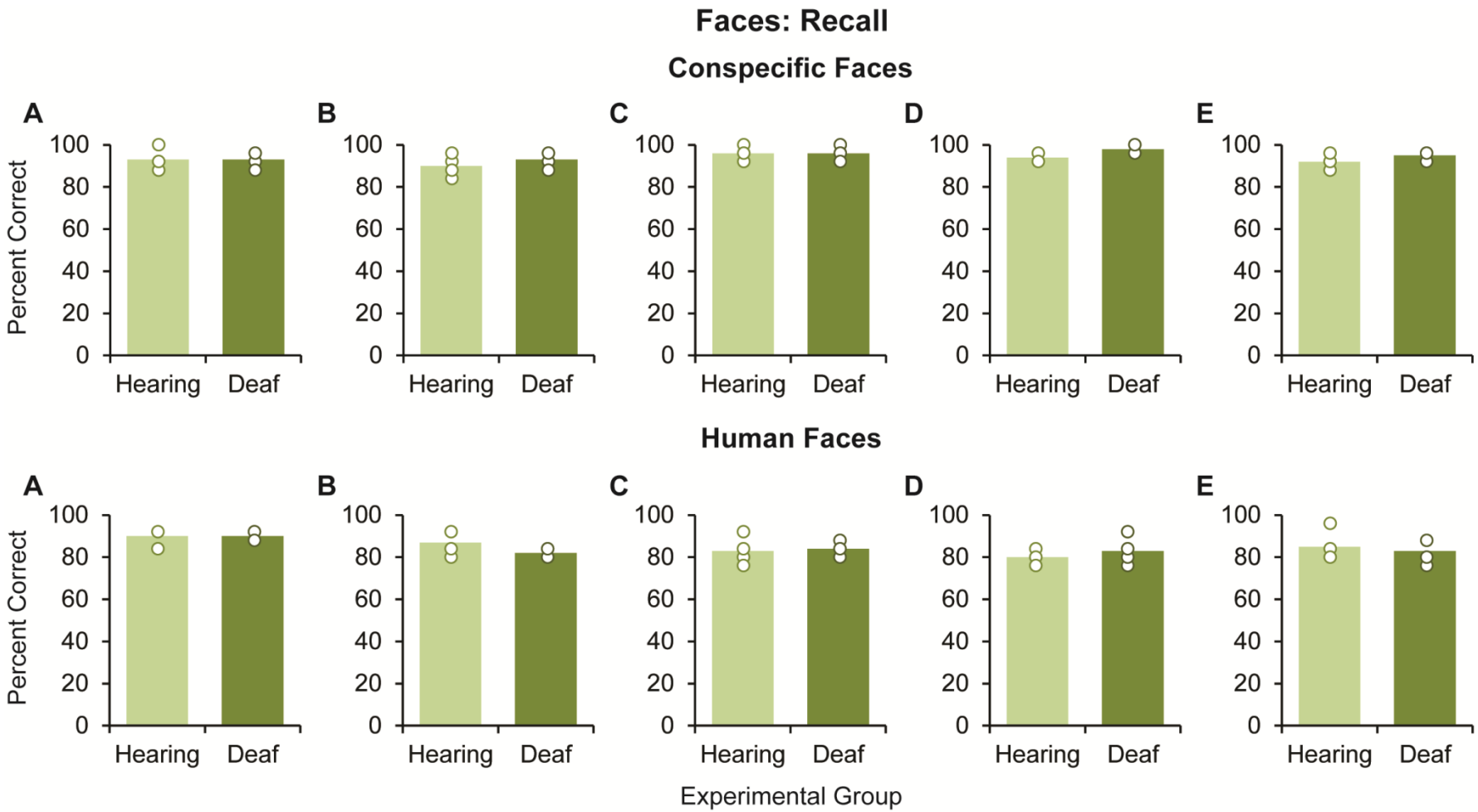



a
Visual localization
0°
30°
30°
60°
60°
90°
90°
100%
50%
0%
50%
100%
Percent Correct
b
Visual localization
Percent correct
100
80
60
40
20
0
H
C
0°
15°
30°
45°
60°
75°
90°
Eccentricity
c
Movement detection
Threshold (degs/sec)
2
1
0
Hearing
Cool
d
Grating acuity
Threshold (cycles/deg)
10
8
6
4
2
0
Hearing
Cool
e
Vernier acuity
Threshold (min arc)
2
1
0
Hearing
Cool
f
Orientation discrimination
Threshold (degs)
5
4
3
2
1
0
Hearing
Cool
g
Direction of motion
Threshold (degs)
5
4
3
2
1
0
Hearing
Cool
h
Velocity discrimination
Weber fraction (ΔV/V)
2
1
0
Hearing
Cooled
24
8
16
32
64
Stimulus velocity (deg/sec)


Patterns: Recall
Simple Patterns
A
B
C
D
E
Percent Correct
100
80
60
40
20
0
Hearing
Deaf
Complex Patterns
Experimental Group


Objects: Recall
Simple Objects
A
B
C
D
E
Percent Correct
100
80
60
40
20
0
Hearing
Deaf
Junk Objects
Experimental Group


Natural Scenes: Recall
A
B
C
D
E
Percent Correct
100
80
60
40
20
0
Hearing
Deaf
Experimental Group


Faces: Recall
Conspecific Faces
A
B
C
D
E
Percent Correct
100
80
60
40
20
0
Hearing
Deaf
Human Faces
Experimental Group