Neural Plasticity in an Unconventional Animal System, the Songbird

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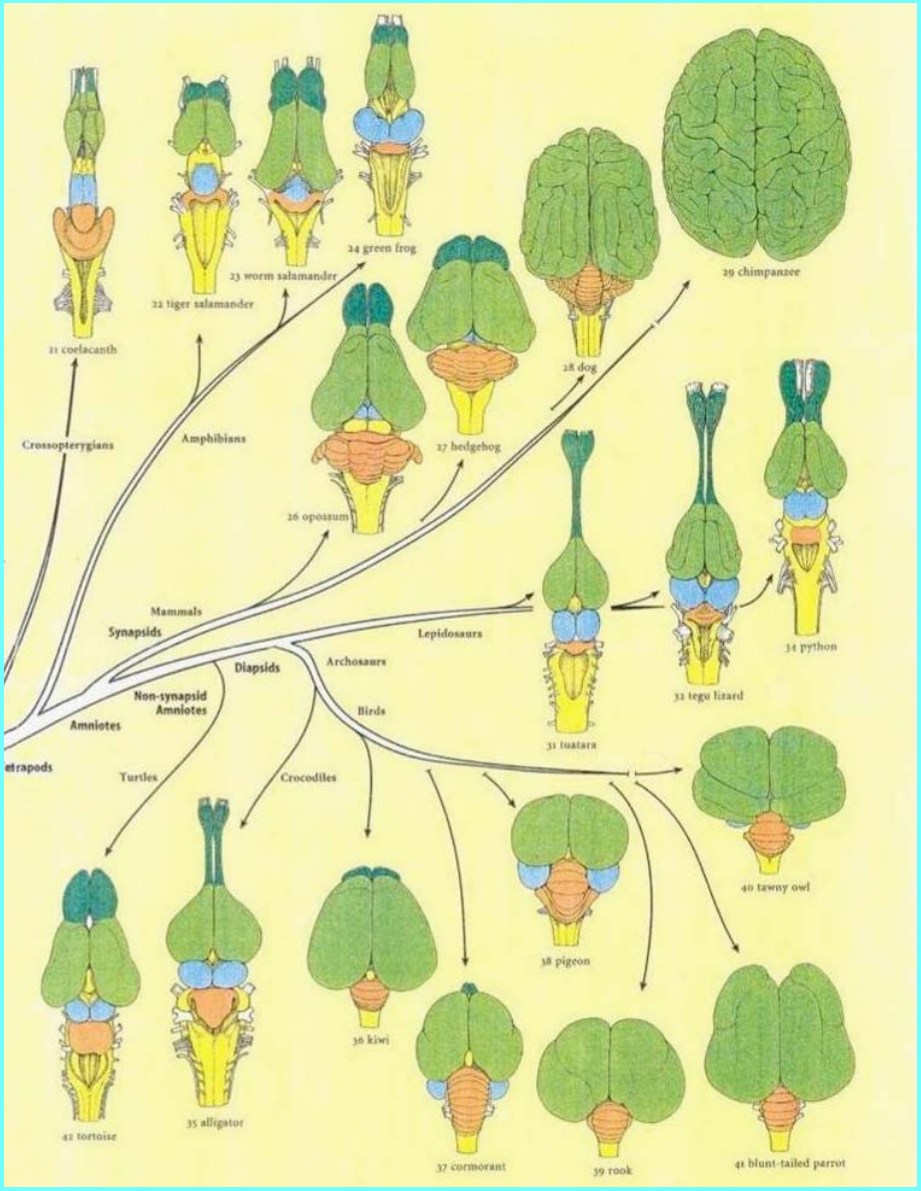
(Attempting to catch birds for research)

Why Study Birds?

1. Because what we learn can show us what our brains might do: birds as "a model system" for human biology.

Model System

- This seems unlikely:
  - Birds are not closely related to us
  - Their brains are very different
    - (nothing that looks like cortex
    - No corpus callosum
    - Different layout of other regions
  - Their activities also seem too different



Why Study Neurobiologyof Bird Song?

1. Because what we learn can show us what our brains might do: birds as "a model system" for human biology.

2. **To better understand the natural world--How does this domain of animal life work (and why)?**

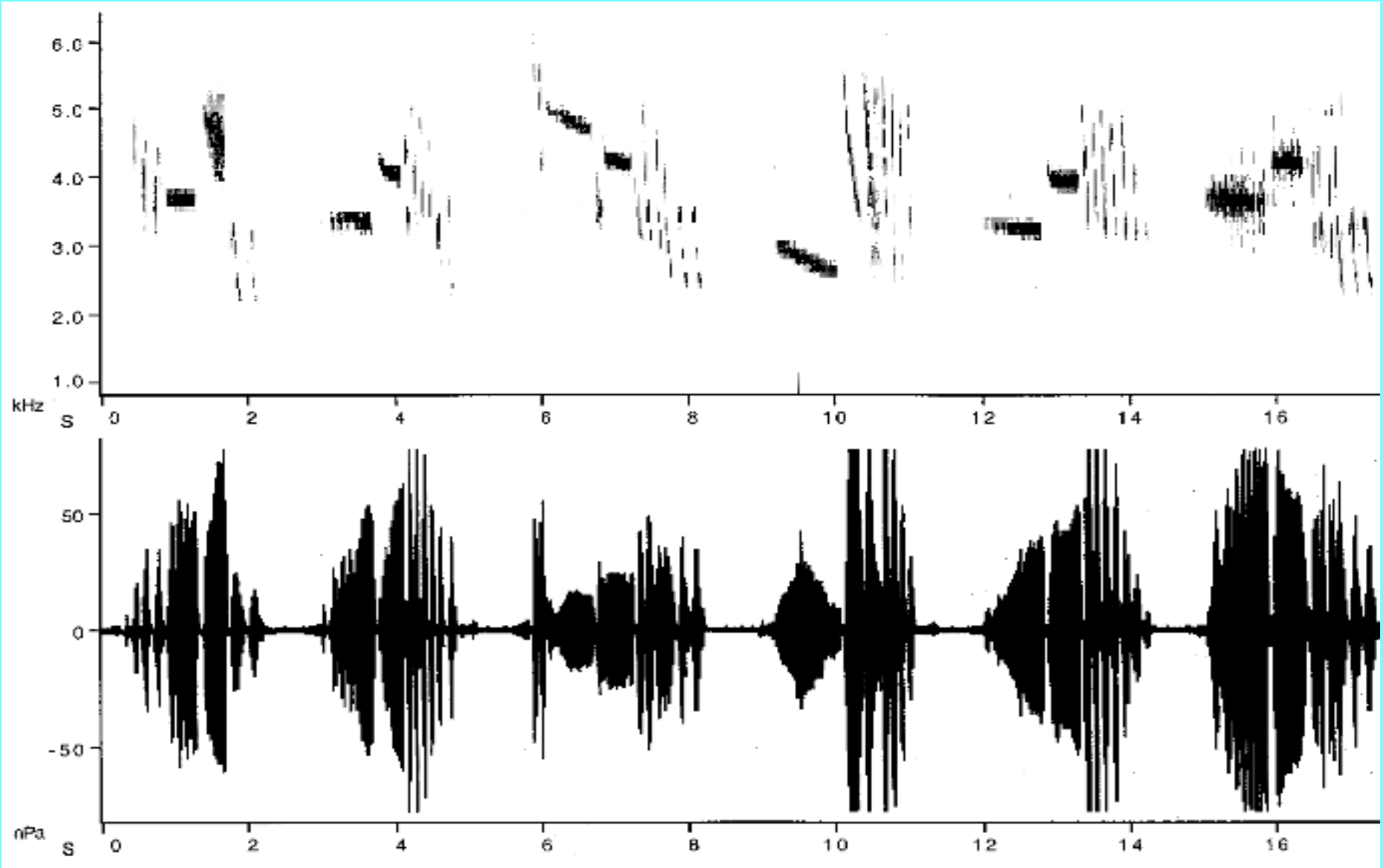
3. **To determine principles of brain construction and use**

The starting point: Song in songbirds is learned from auditory cues early in development

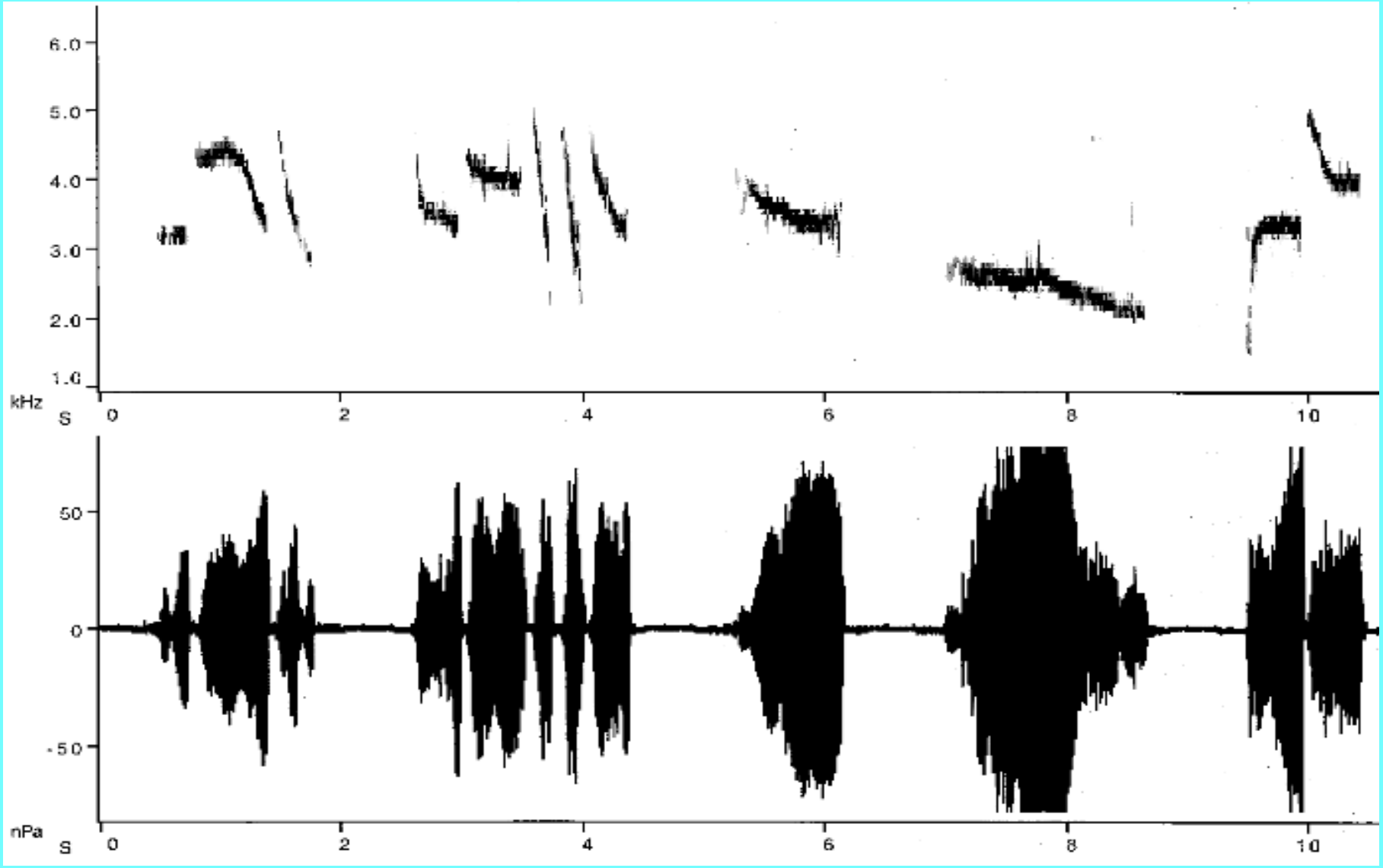
- Bring baby birds into the lab
- Evaluate influences on song by
  - Altering auditory or social experiences

Baby Songbirds are Altricial at Hatching

Songs of Normally Reared Sparrows



Songs of Sparrows Reared in Isolation



Problems:

1) Neural basis for innate song features

2) Neural sites and mechanisms of learning

3) Species differences in learning

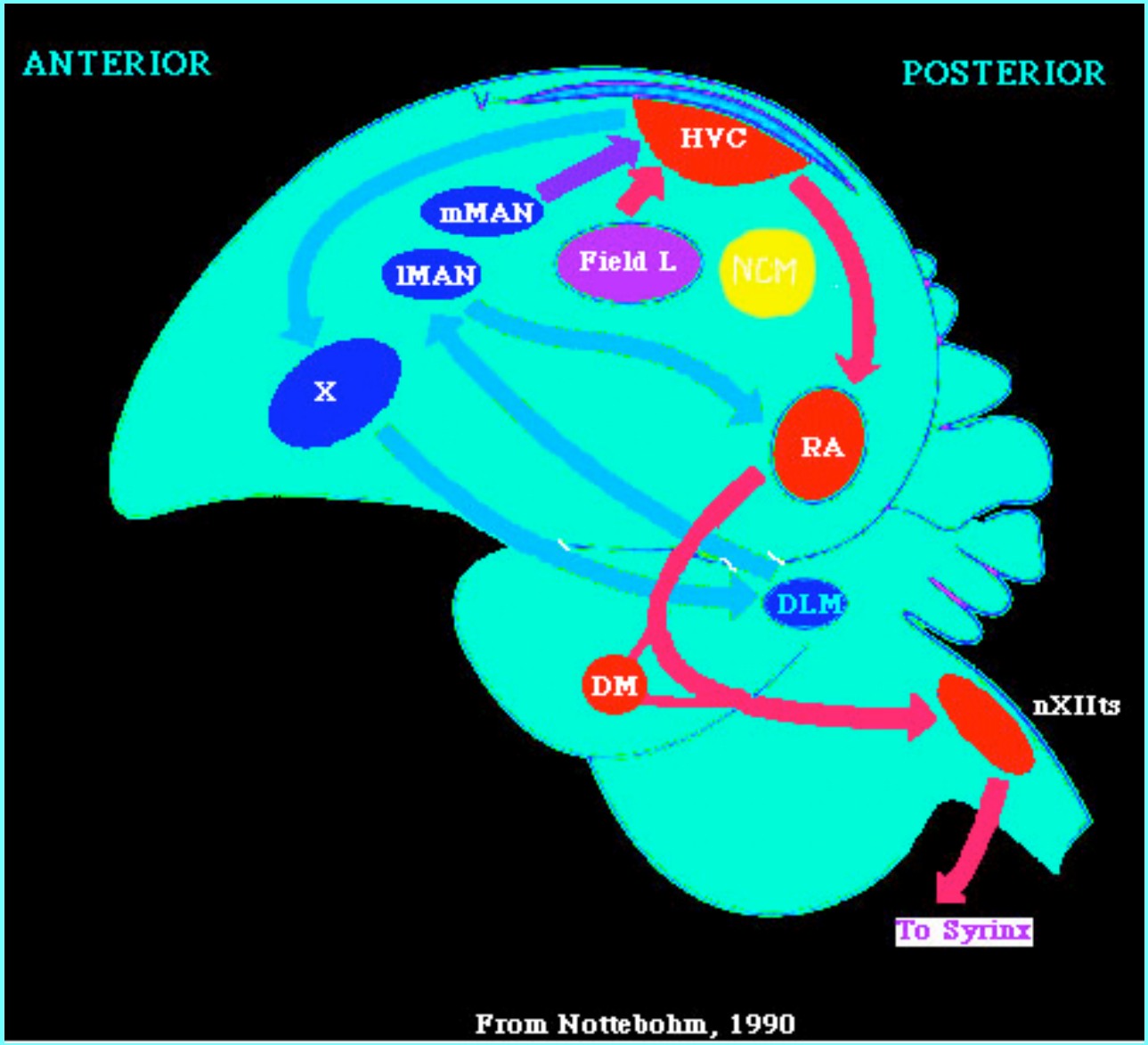
4) Sex differences in learning

More Song Facts

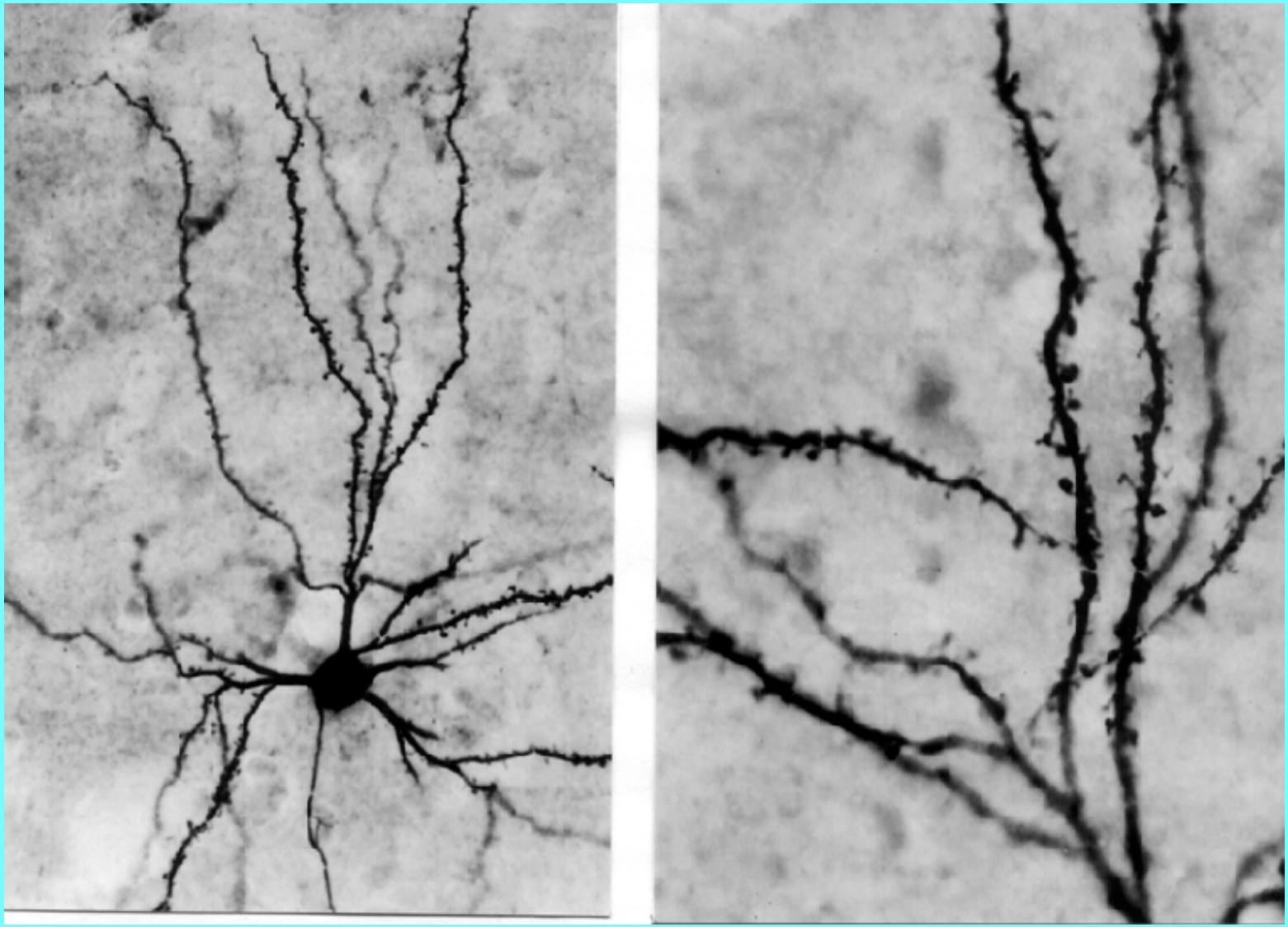
1. In most songbirds, males do all or most of the singing. Females sing little or not at all.
2. Young males **learn** their songs from adult males
3. As adults, males of many species attract females with song
4. For many species outside of the tropics, singing occurs with reproduction, which is seasonal
5. Different species vary in how complex a song they typically sing
6. For all but the simplest song types, males within a species also differ in song complexity

The Motor Song System consists of Production (red) and Regulatory Nuclei (blue)

[No obvious correspondence to mammal forebrain in general layout or in specific structures]

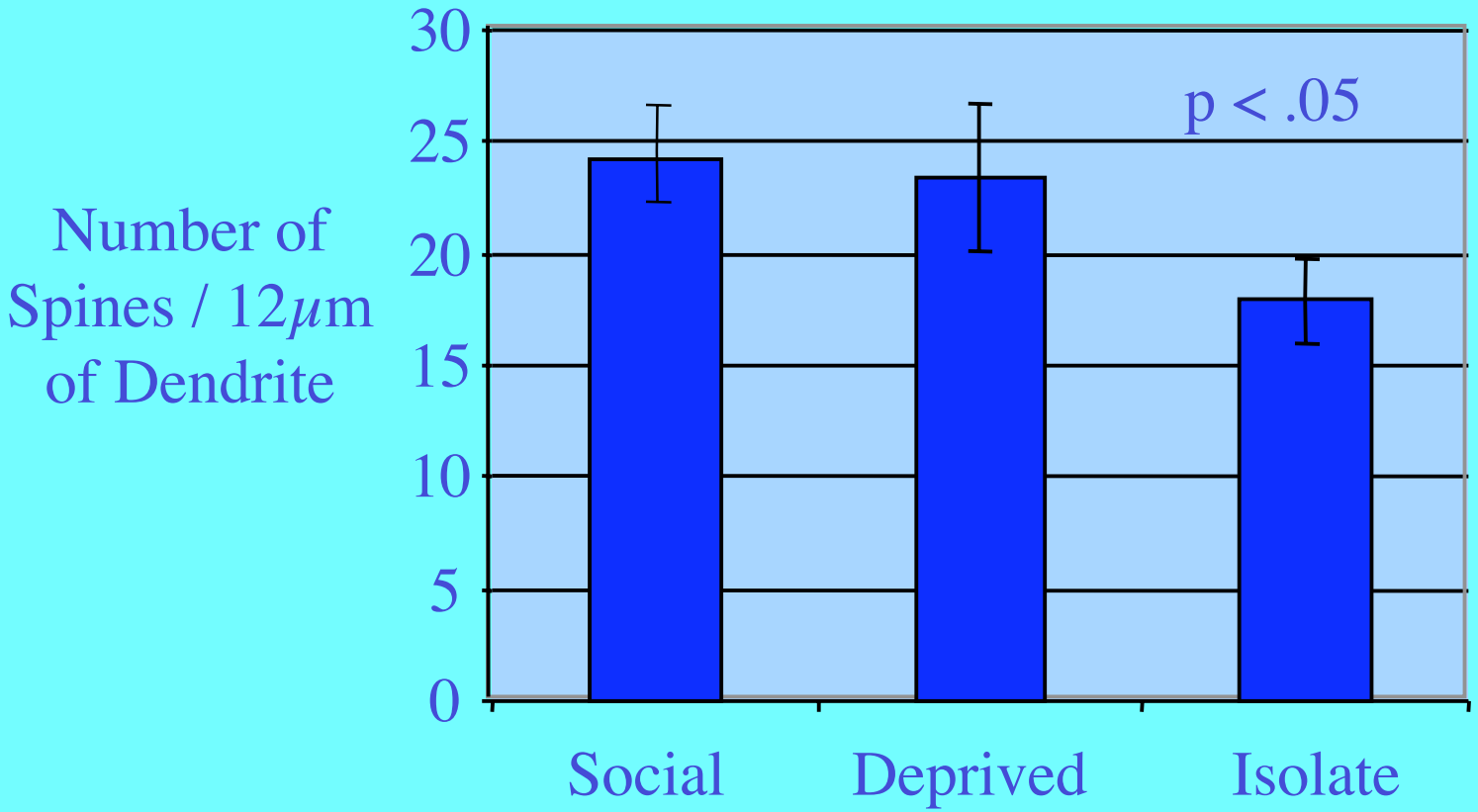


Dye-filled HVC Neuron, Showing Spines



Benton, Cardin & DeVoogd, ‘98

C. Manipulate Opportunity to Learn: Male Zebra Finches Reared in Isolation Have Abnormally Simple Song and Fewer Spine Synapses in HVC



Lauay, Komorowski & DeVoogd, 2005

What do we know of developmental mechanisms for learning?

For HVC, very little

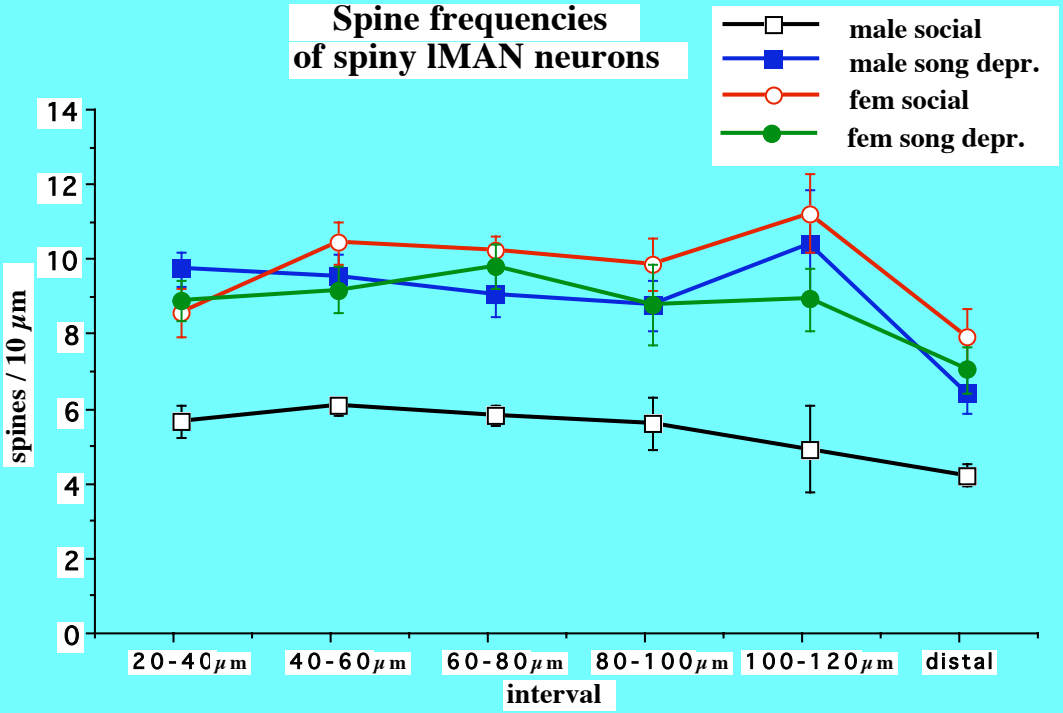
For l-MAN and Area X:

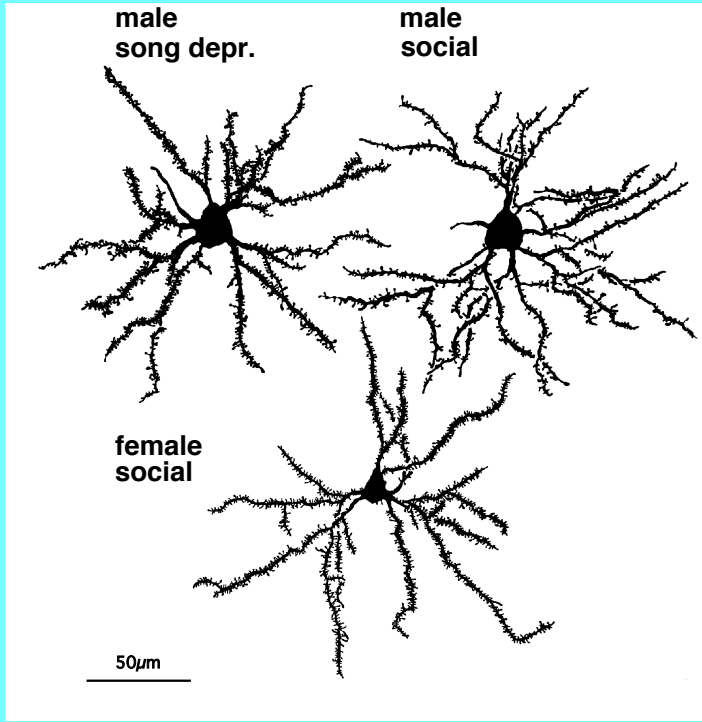
They must be intact for normal song acquisition

l-MAN must have working NMDA receptors

l-MAN synapses are lost during the time of normal song learning.

But, males without hearing song retain their extra spine synapses in l-MAN, at least until 55d

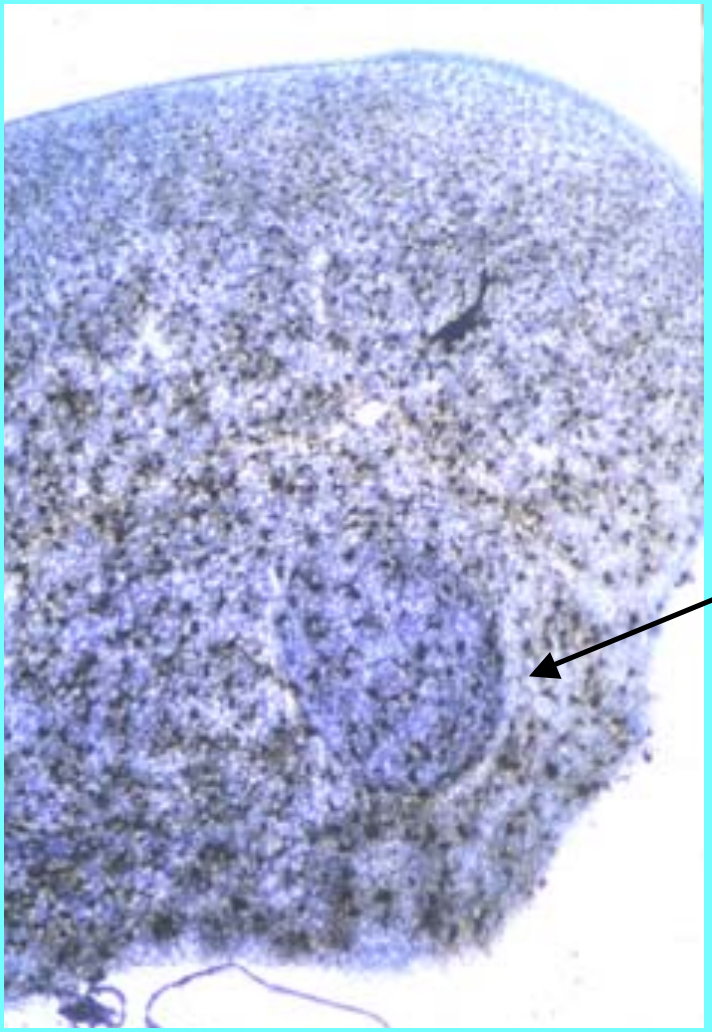




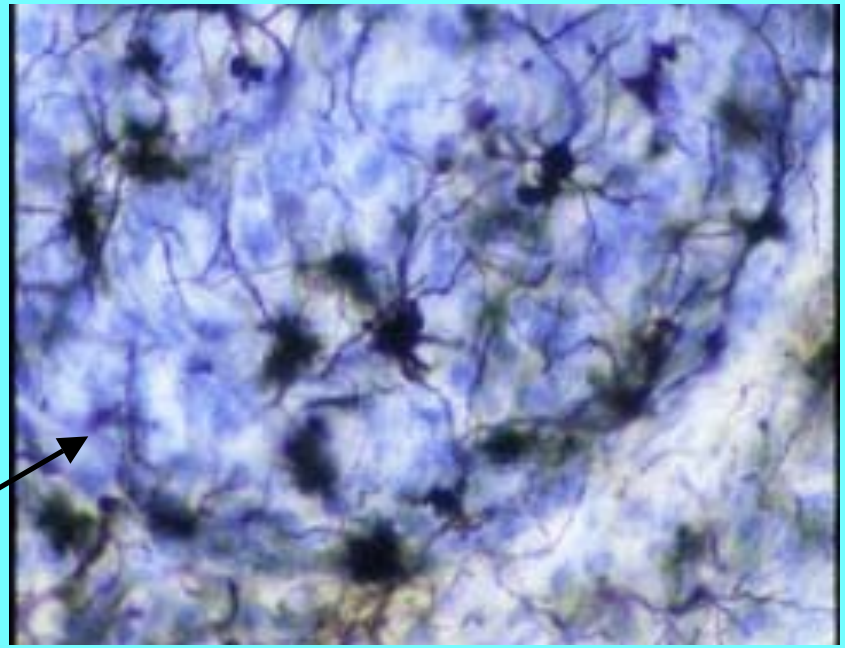
The song system continues to be plastic in adulthood in many species

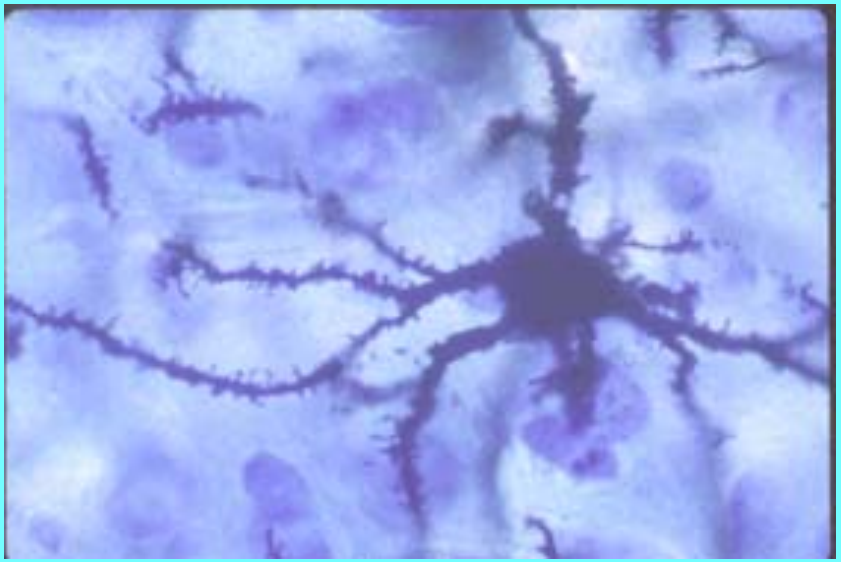
Both changing day length and changing steroid levels affect the song system and song

Song System: Golgi Stained RA Neurons

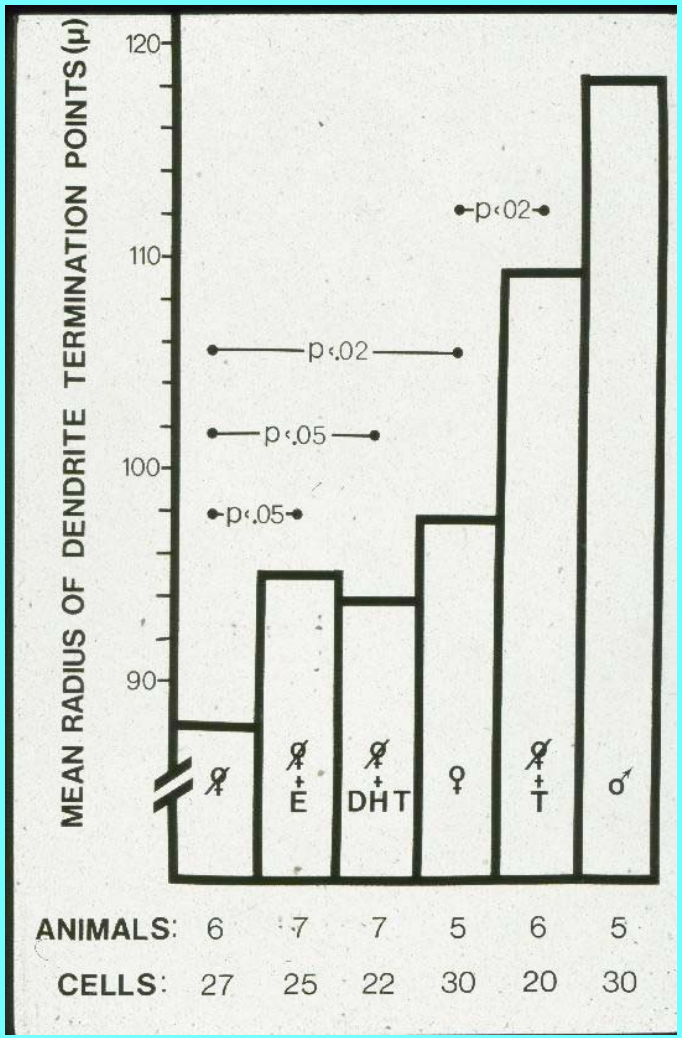


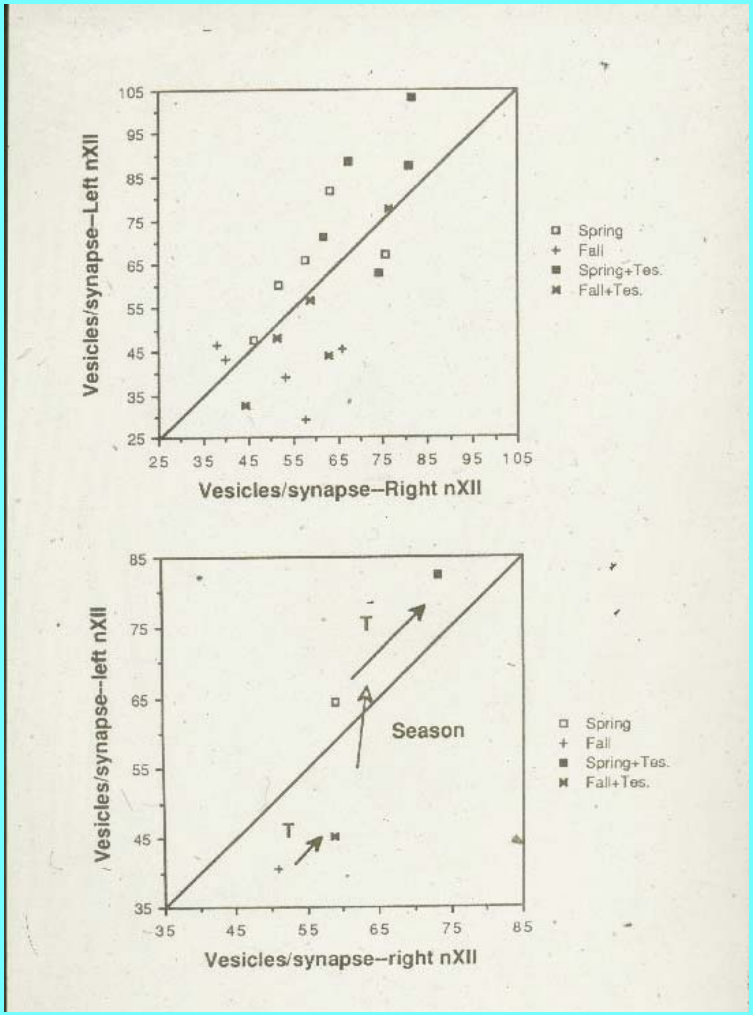
RA





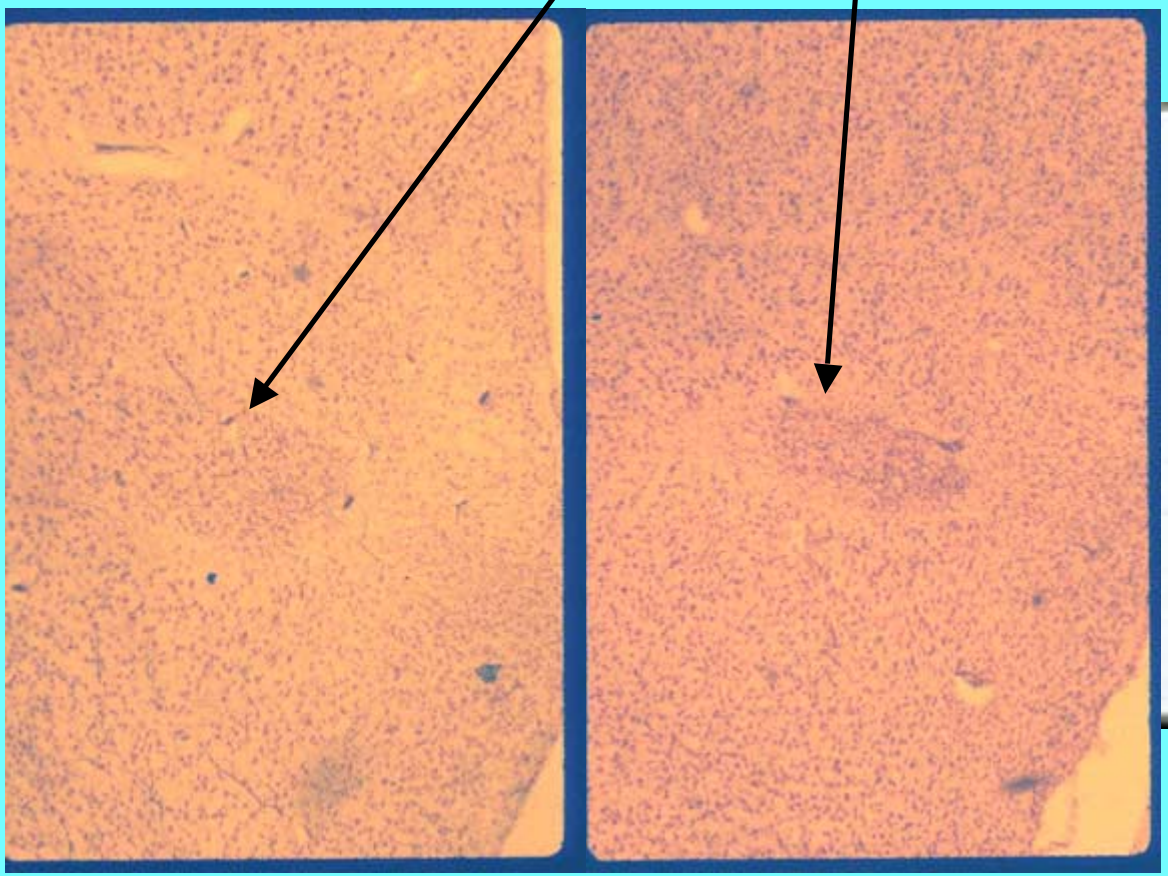
Song System Neurons Change Rapidly in Response to Steroids--Even in Adult Females



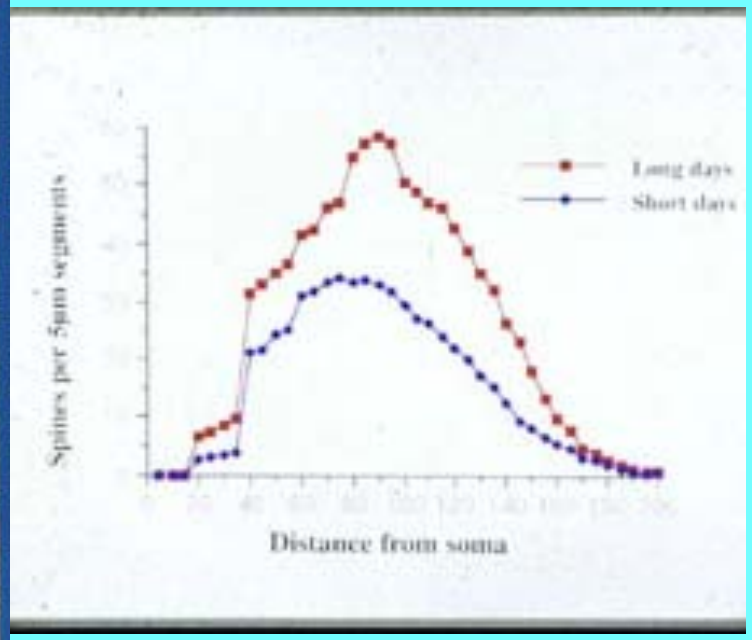


Anatomical Changes in the Song System Occur Seasonally in Adults--In phase with changes in singing

Spring Fall



Volume



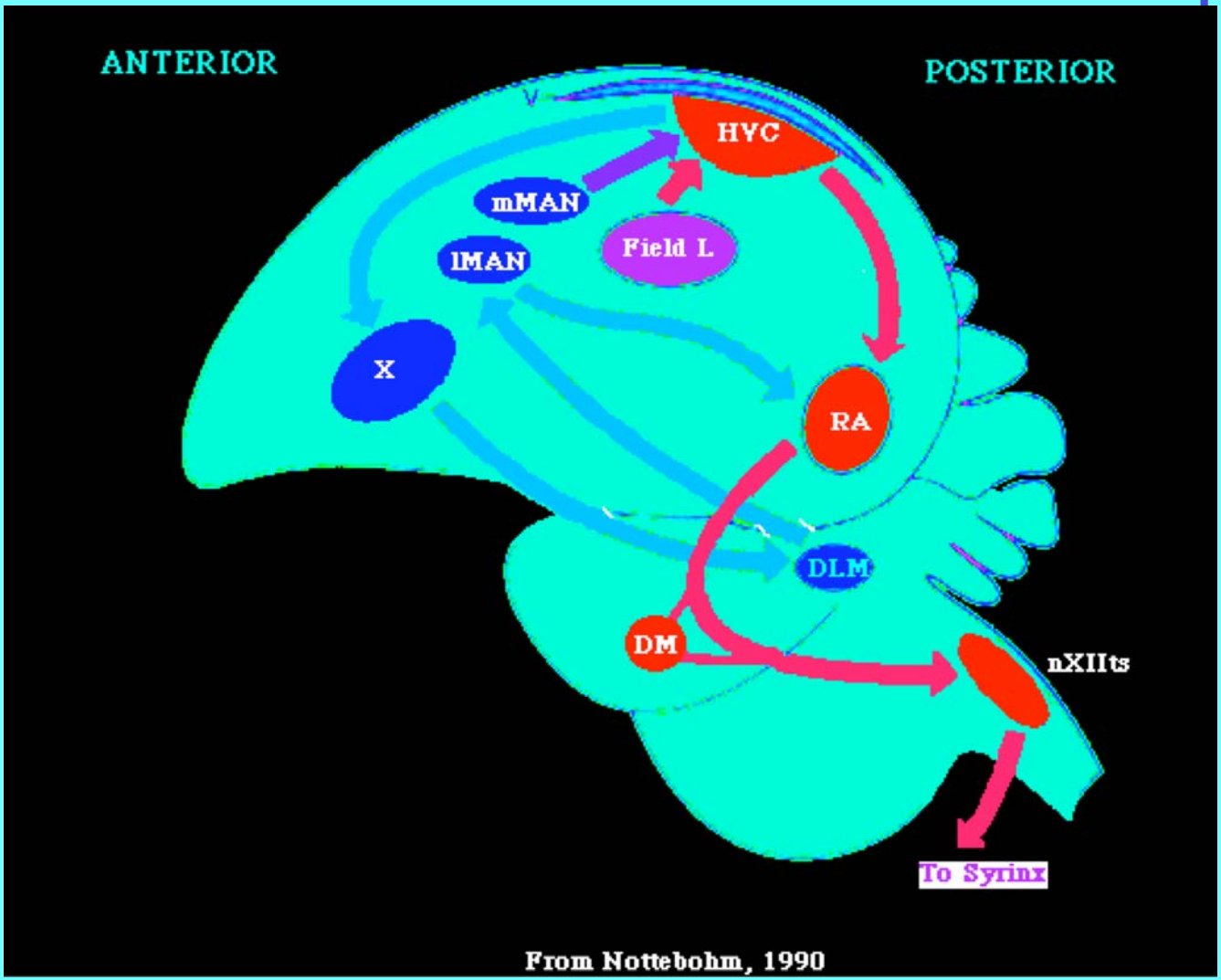
Number of Spine Synapses

Problem:

- How do you maintain song fidelity when massive numbers of synapses and even neurons turn over from one season to the next?
- Perhaps by phasic reference to an auditory memory, potentially using the same regulatory structures as in initial acquisition

Altering Influences on Song System Nuclei in Adults can Alter their Output

Normal Canary



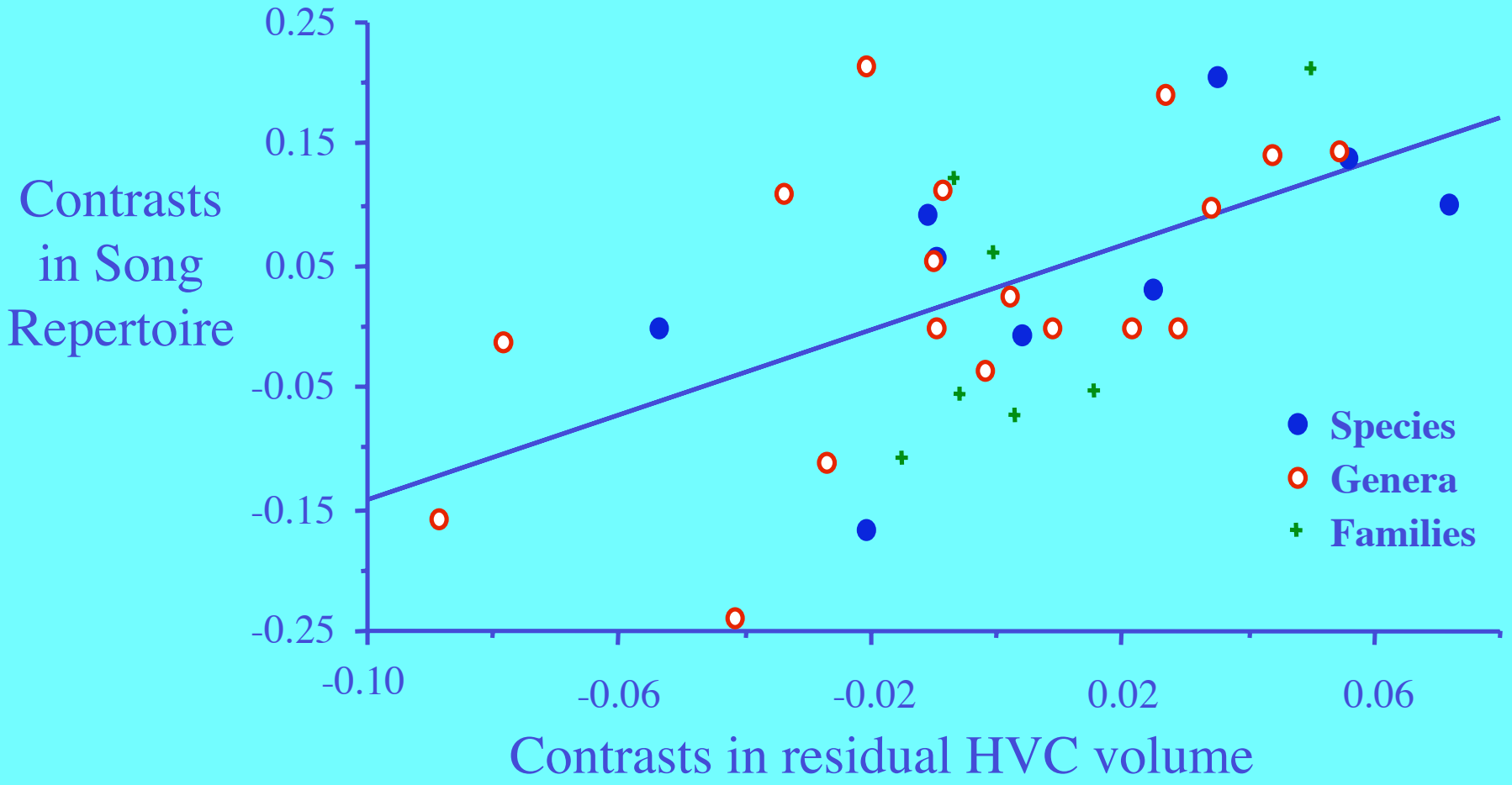
lMAN lesion

Kitko & DeVoogd, in prep.

Structure-Function Relations Within and Between Species

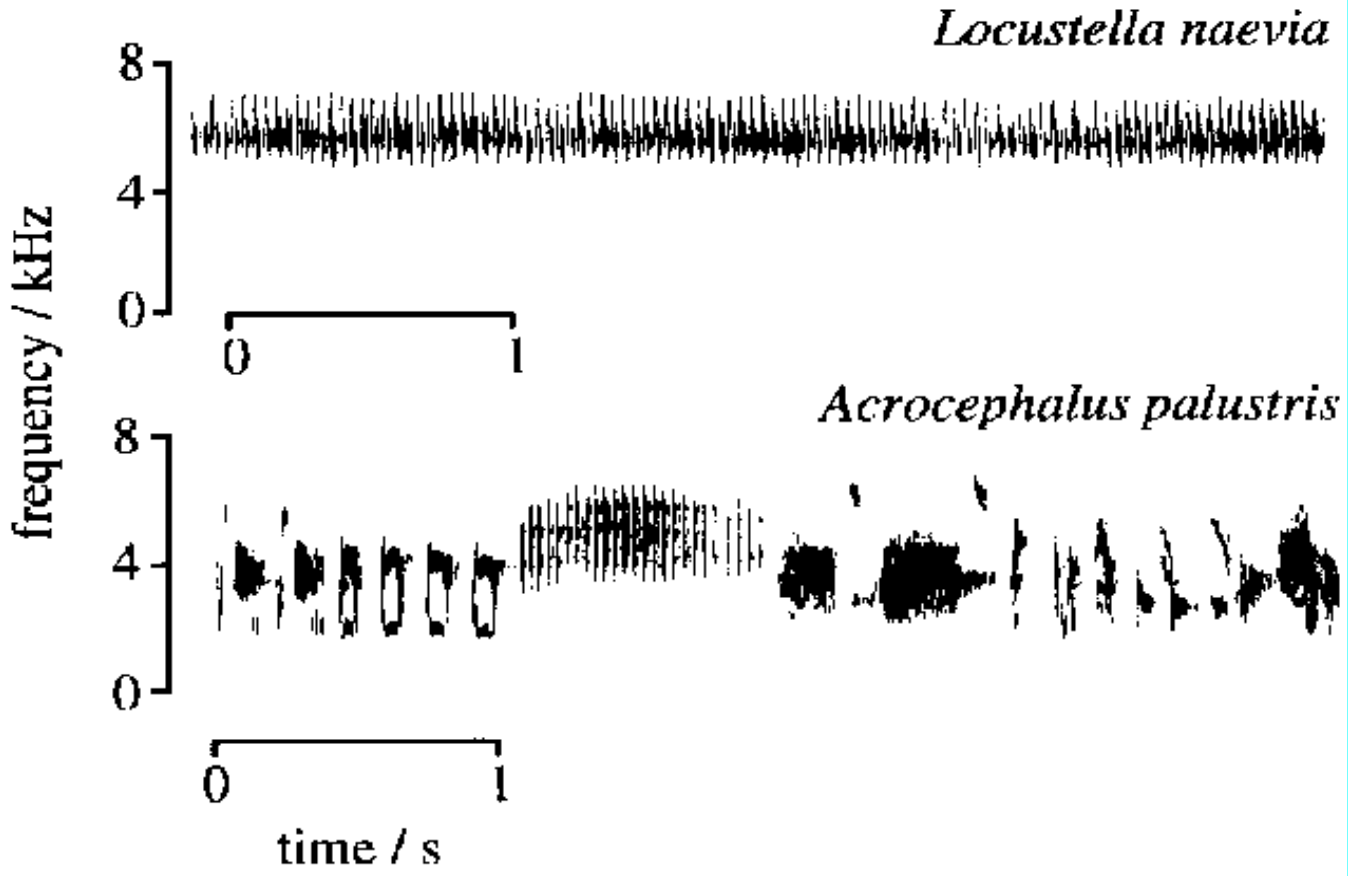
DeVoogd, Székely & Büki--part of the Hungarian work crew

HVC Volume is Related to Repertoire Across Songbird Species

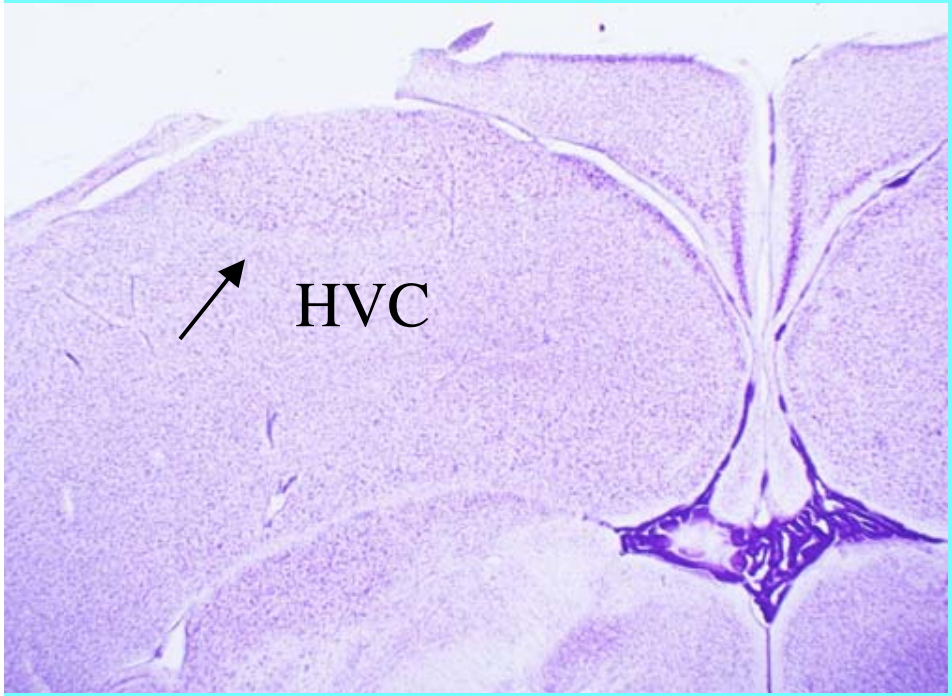


DeVoogd, Krebs, Healy & Purvis, '93

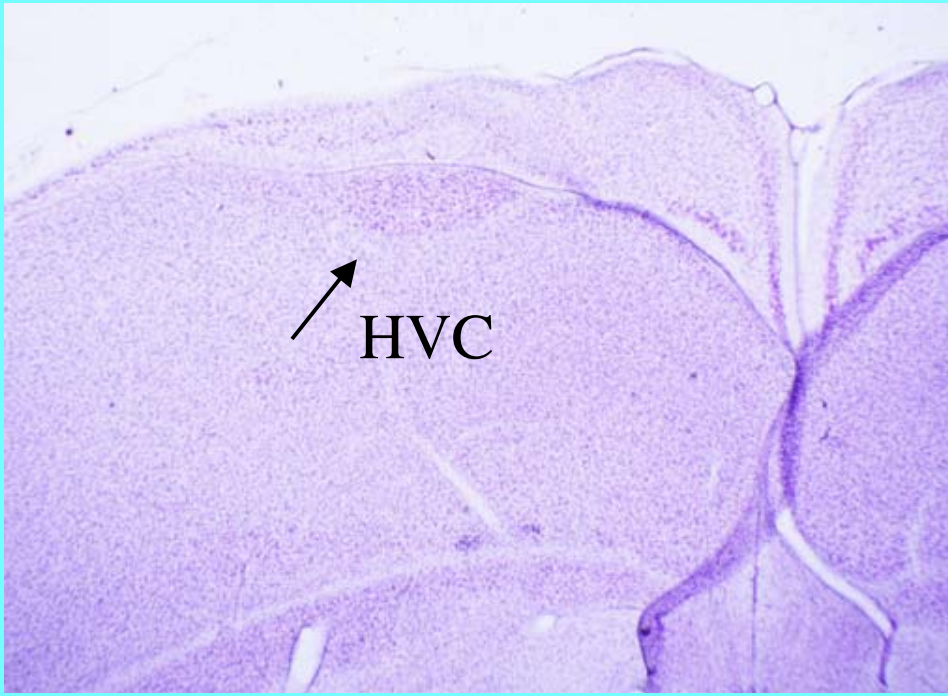
Syllable Repertoire can Vary by Nearly Two Orders of Magnitude Between Warbler Species



Differences in HVC Volume Across Species can be Striking



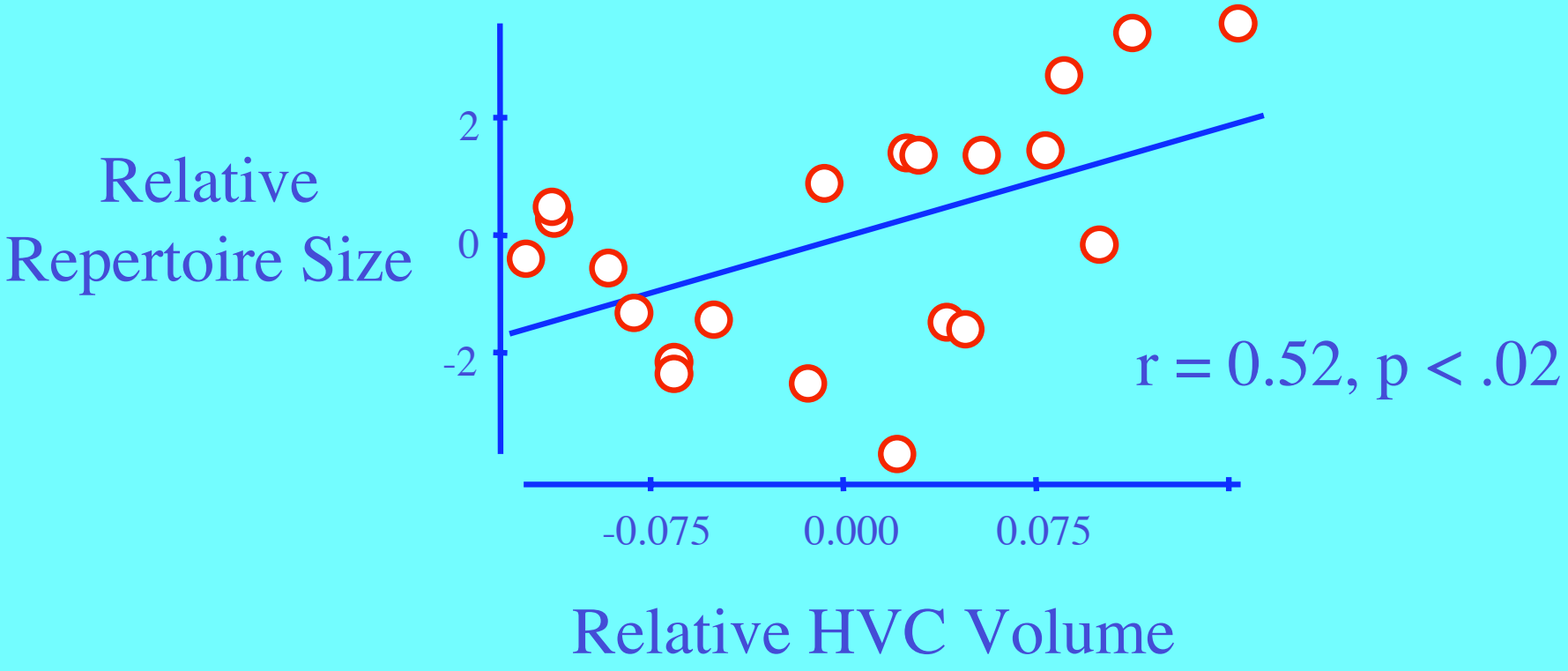
Marsh Warbler



River Warbler

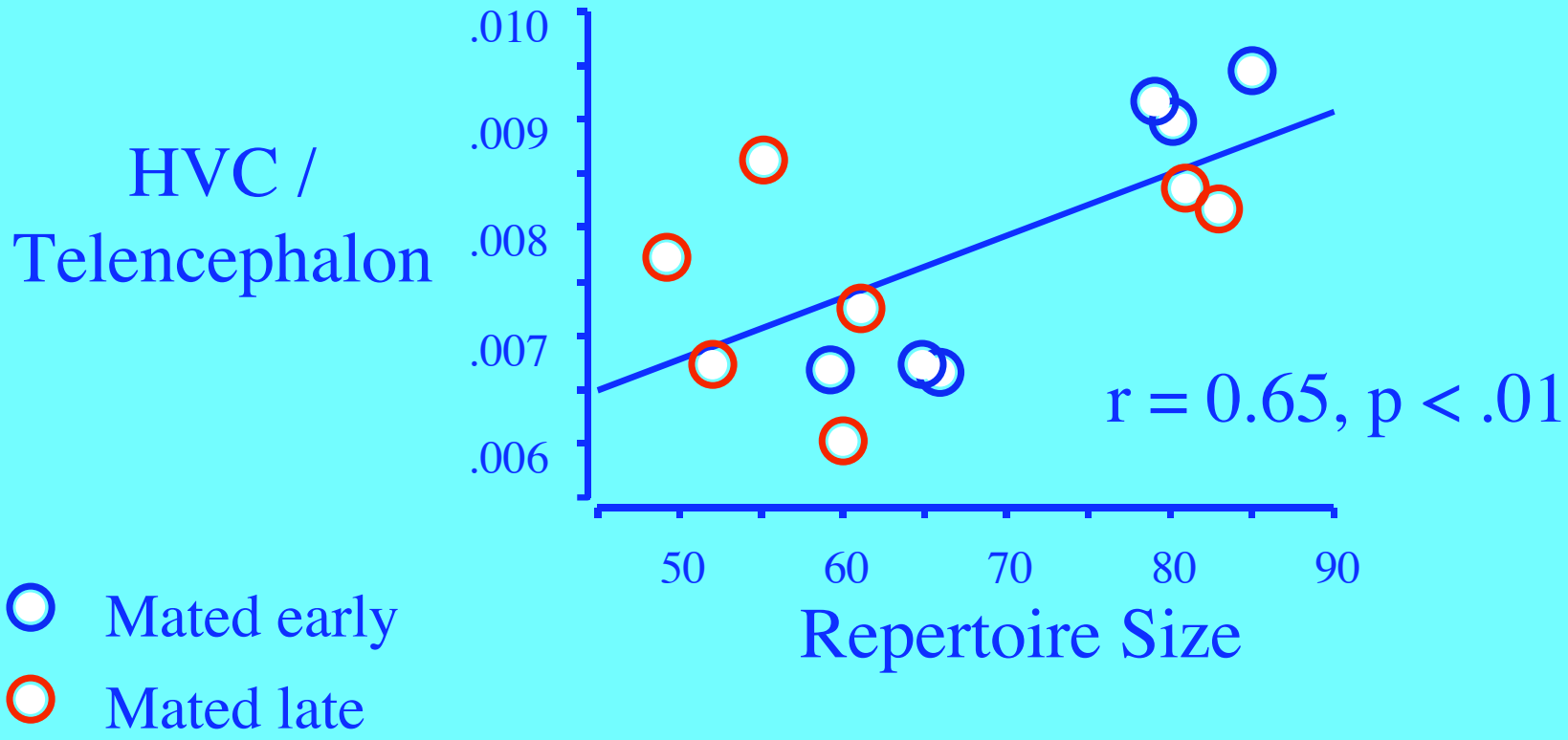
Székely et al., '96

HVC Volume and Repertoire Size are Positively Correlated in Zebra Finches



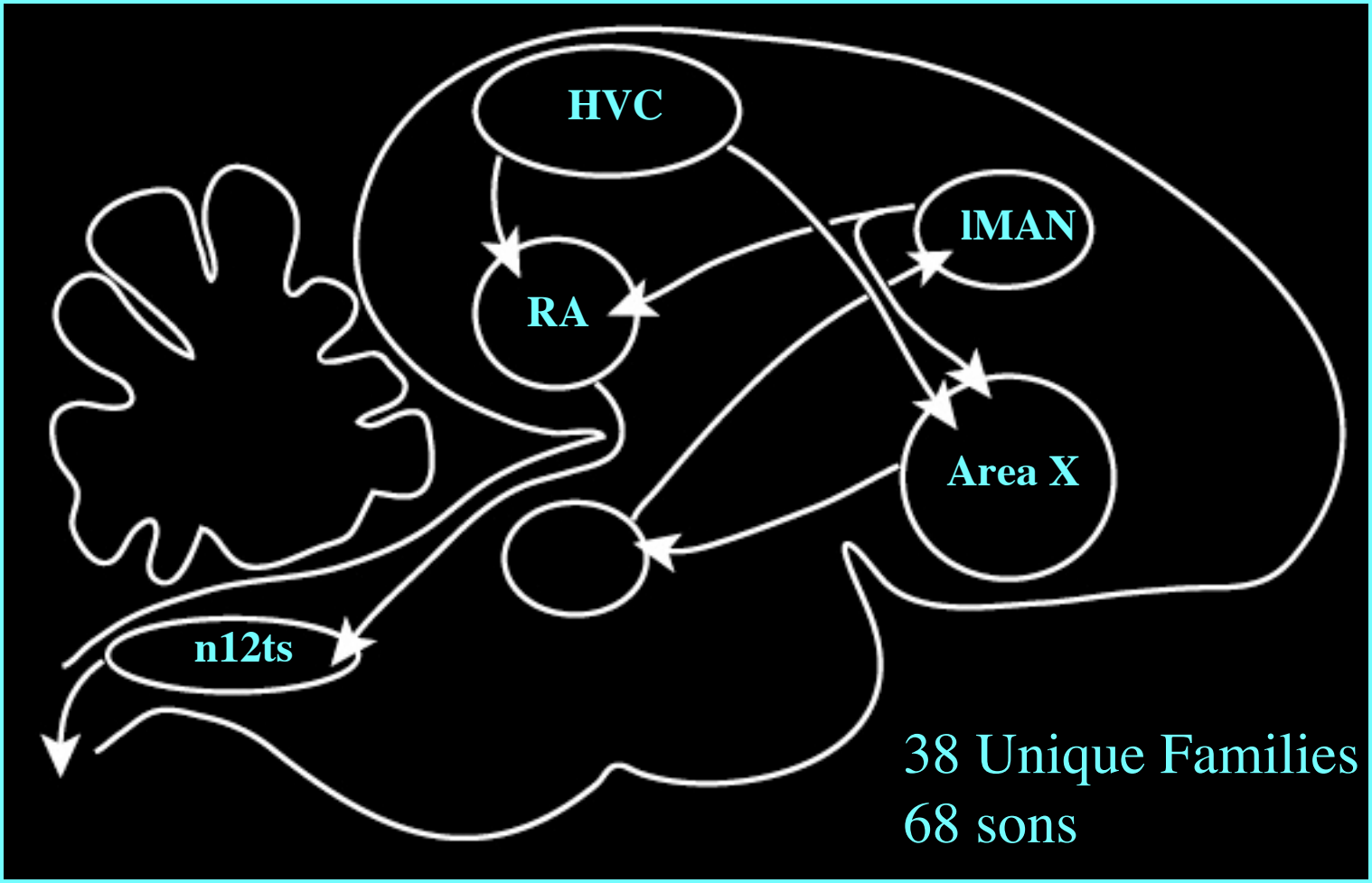
Airey & DeVoogd, '00

HVC Volume is Correlated with Repertoire Size in Sedge Warblers



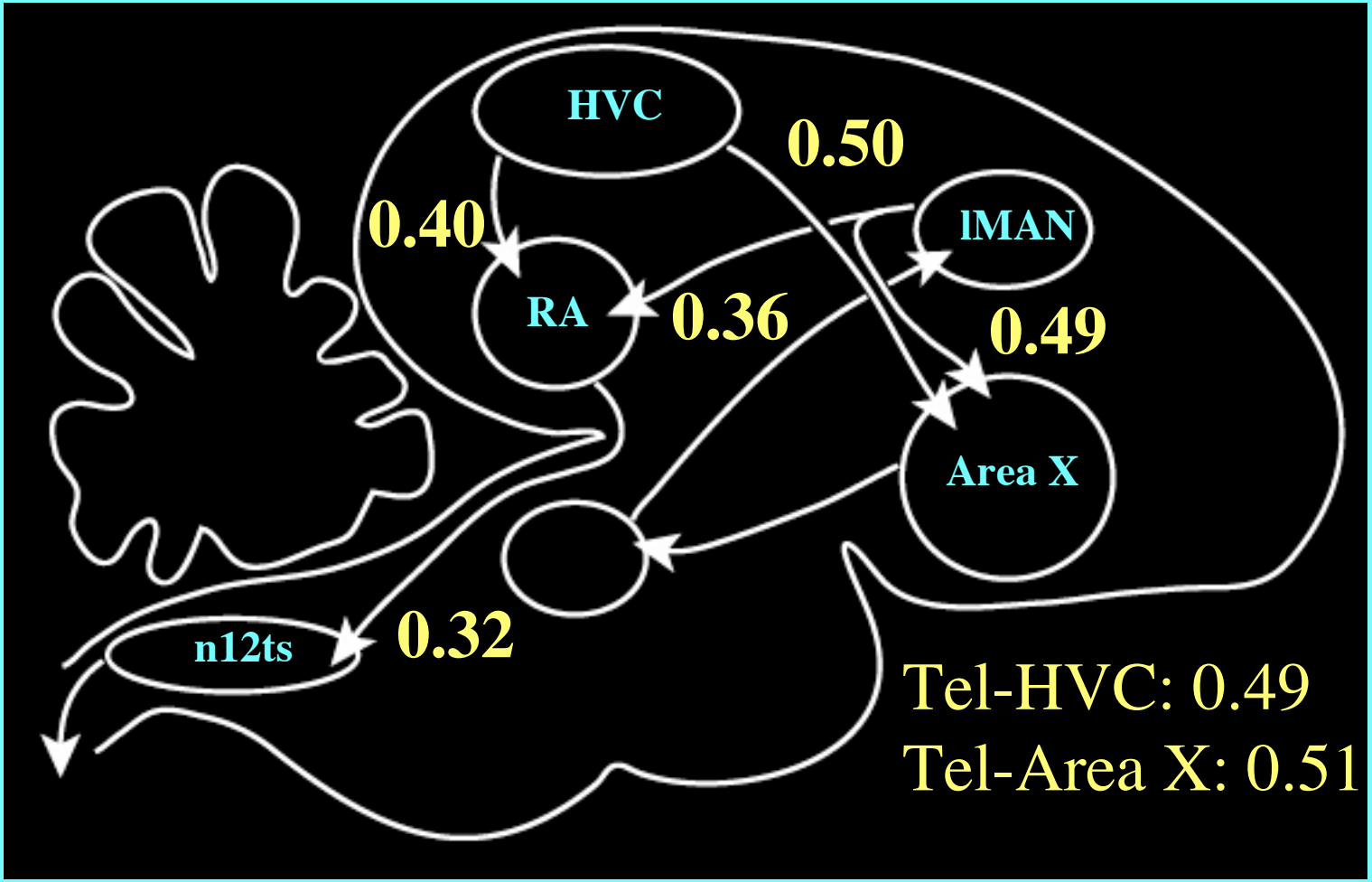
Airey, Buchanan, Szekely, Catchpole, & DeVoogd, '00

Individual differences in the Volumes of Song Nuclei are Heritable



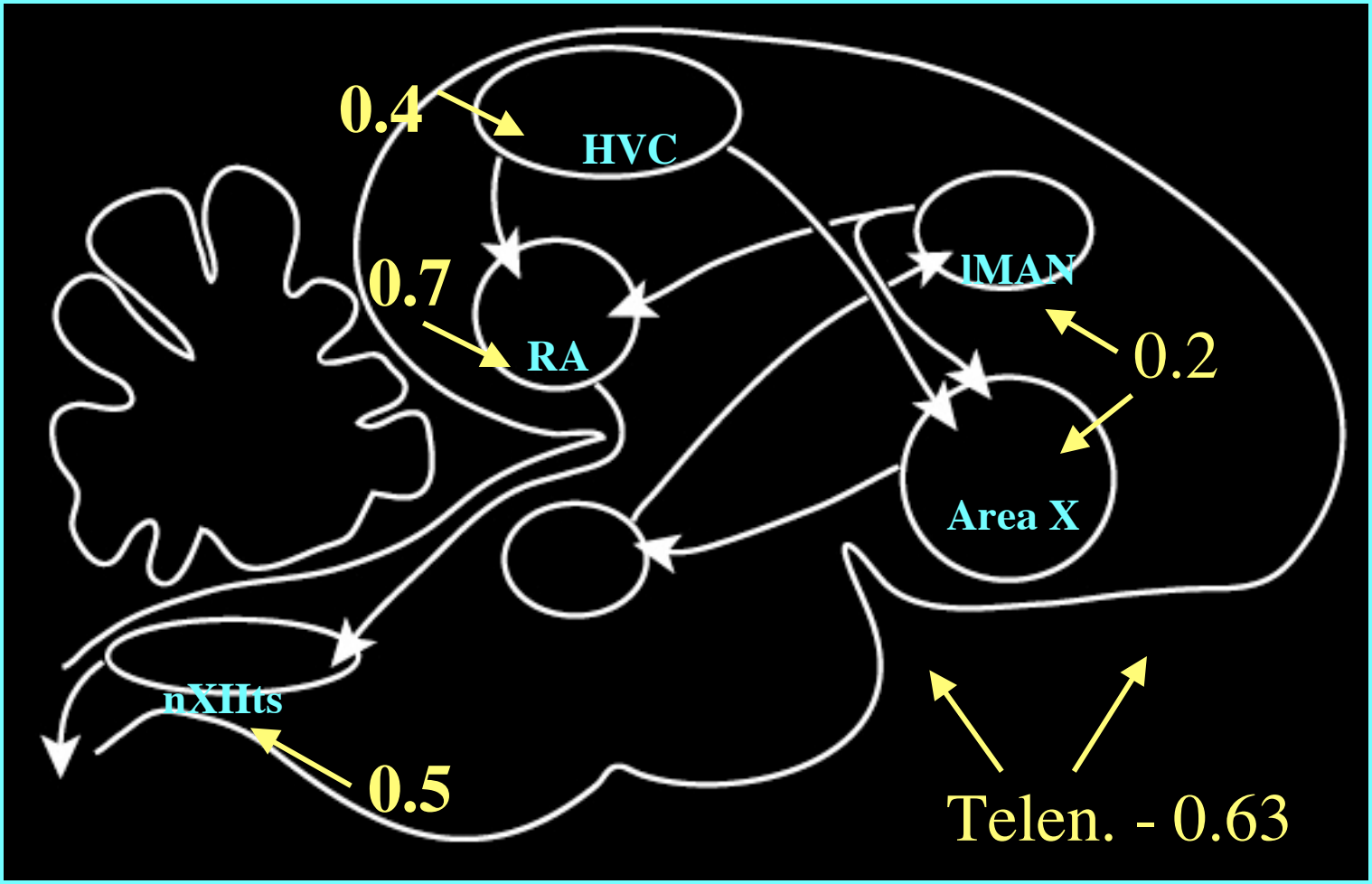
Airey, Castillo-Juarez, Casella, Pollak, & DeVoogd, '00

Volumes of Song Nuclei Within Individuals are Correlated with the Telencephalon and Each Other



Airey, Castillo-Juarez, Casella, Pollak, & DeVoogd, '00

Variation in the Volumes of Song Production Nuclei is Heritable



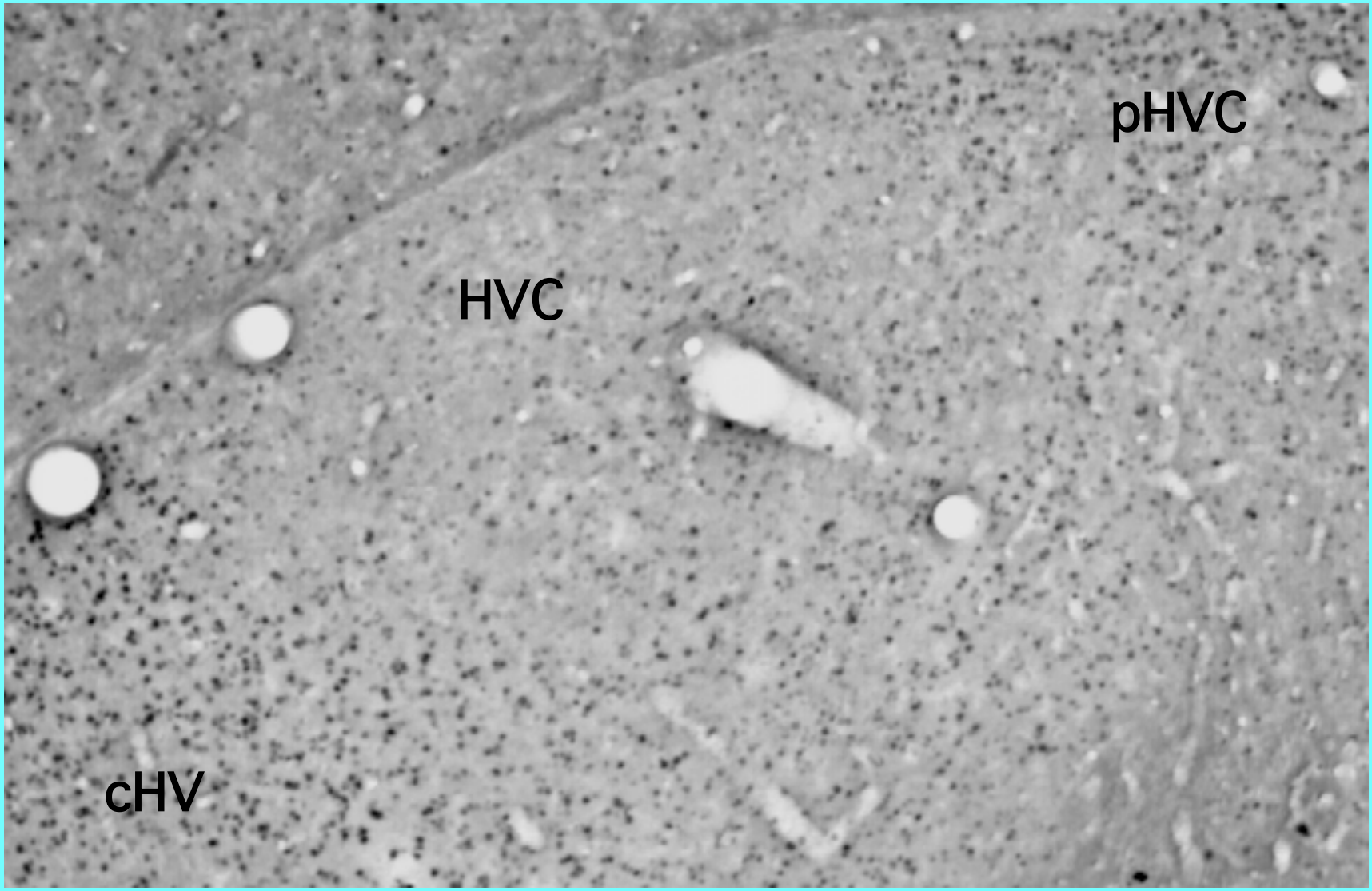
Airey, Castillo-Juarez, Casella, Pollak, & DeVoogd, '00

Song is interactive:
Accurate decoding is as important
as accurate production.
Thus, if a male is encoding complexity
and is singing to a female,
the female must be able to assess
the complexity.

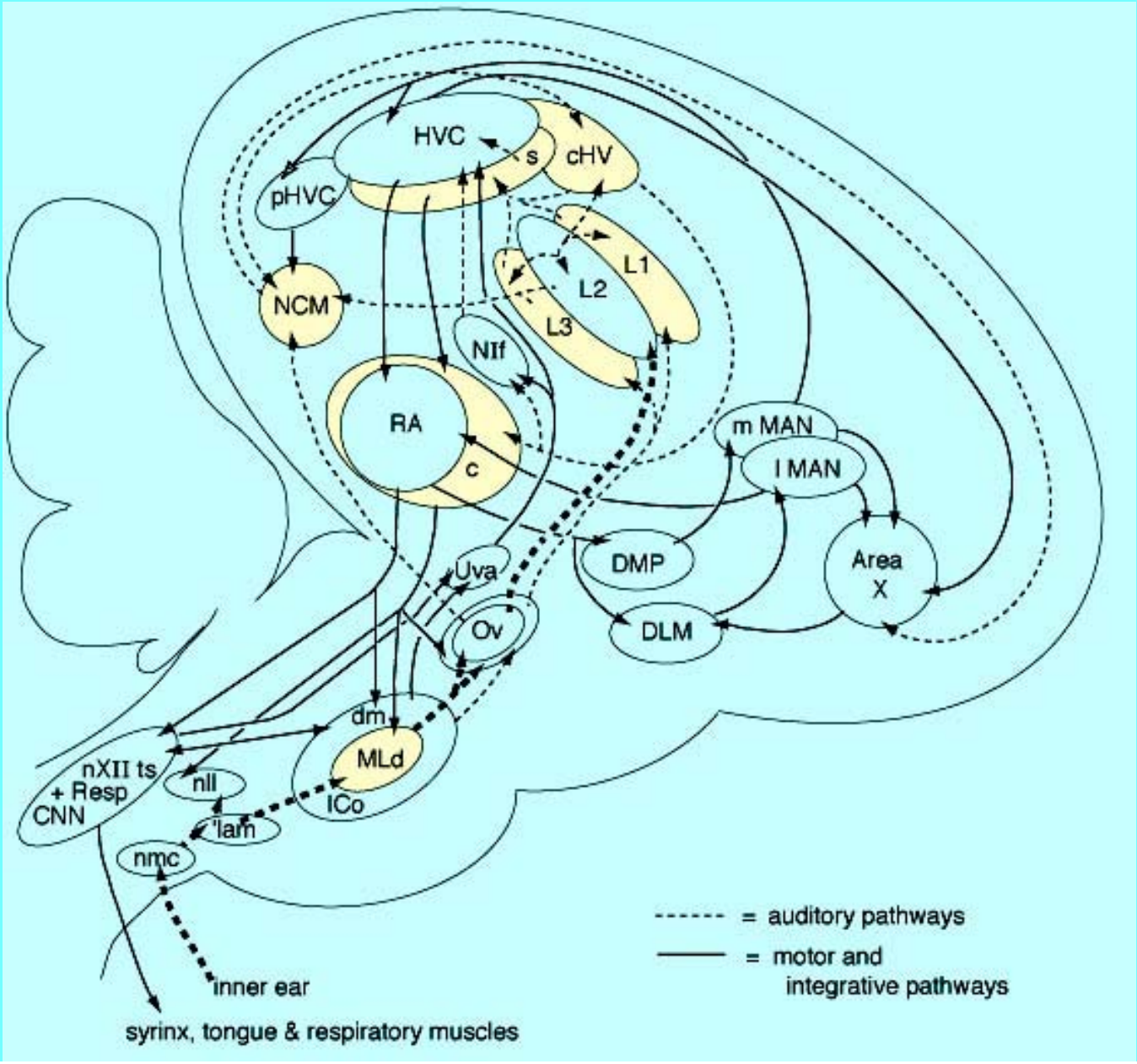
Females Monitor Male Song and Use it in Selecting Mates

Bensch & Hasselquist, ‘92

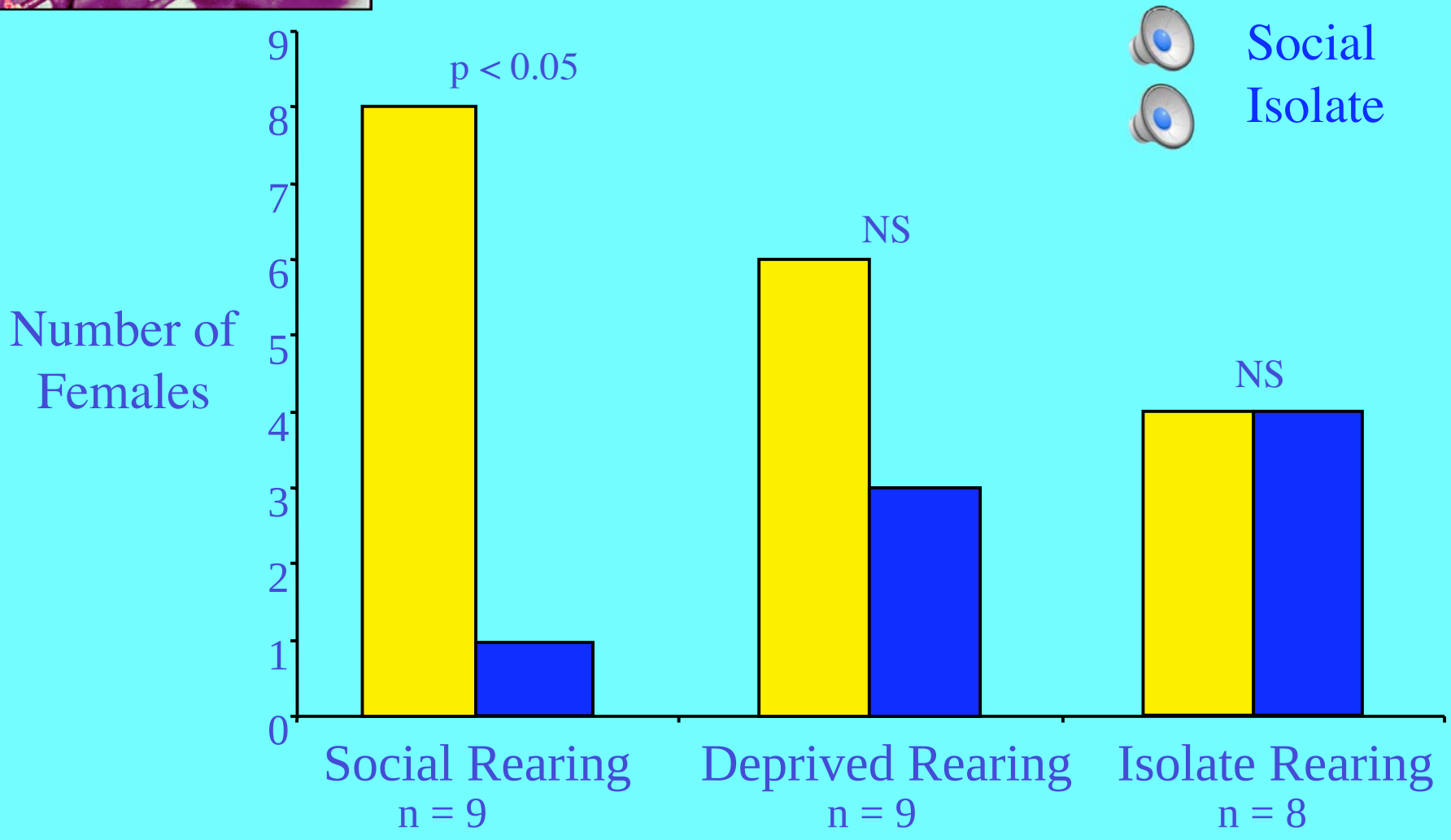
Hearing Song Increases Production of IEG Protein in Areas Near HVC



Hearing Song Activates Novel Brain Regions

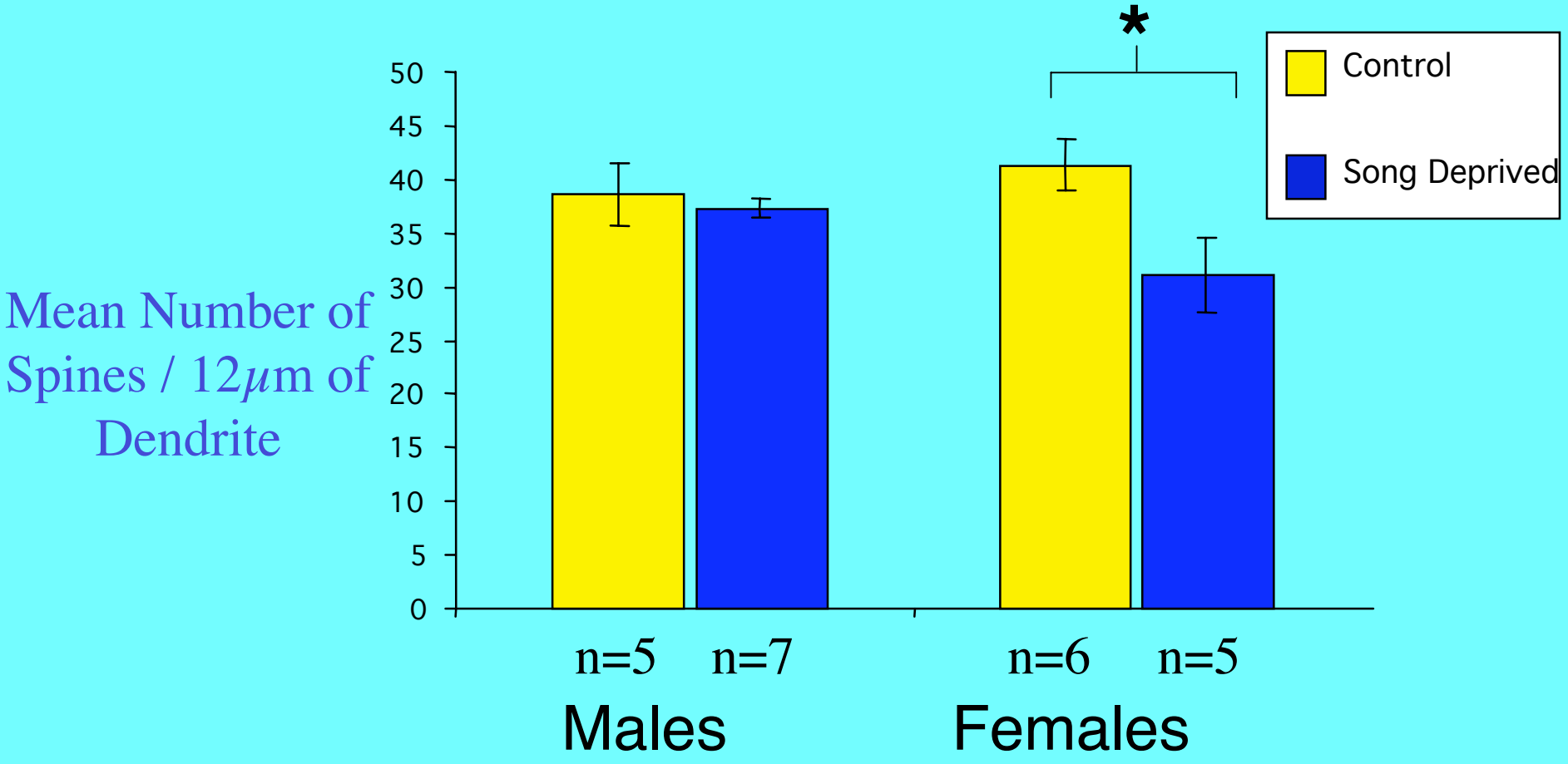


Female Zebra Finches Learn Song Discrimination



Lauay et al., 2004

Female Finches Reared in Isolation Have Fewer Spine Synapses in NCM



Lauay, Komorowski & DeVoogd, 2006

1) Preventing motor learning impairs formation of synapses in a brain area like motor cortex.

2) Preventing auditory learning impairs formation of synapses in a brain area like auditory cortex.

3) Coordinating the two involves synaptic selection

4) Across species, amount of song learning possible is set by the number of neurons devoted to the task.

5) Natural variation between species and between individuals within species sets limits to the amount of learning

6) Auditory learning laters the circuitry of NCM, and motor learning alters HVC

7) Perhaps selection for large song system structures is restrained by developmental constraints--one brain component cannot be made larger without altering related components