Adult Neurogenesis in the Hippocampus and Septum of Food-Storing Birds

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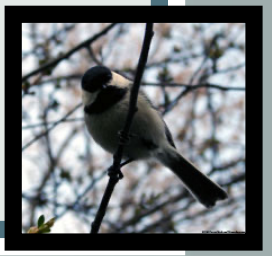
OVERVIEW

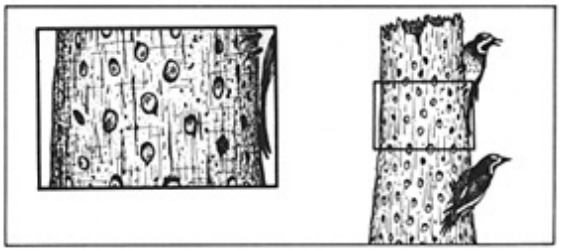
- Why study neurogenesis in food-storing birds
  - History a la Nottebohm
- What is food-storing?
- Avian Hippocampus & Septum
  - Structure, Function, Homology
- Adult Avian Neurogenesis
  - Innate Neurogenesis
  - Injury-Induced Neurogenesis
- Article Discussion
  - Barnea & Nottebohm (1994)
  - Law et al. (2009)
  - Gardner et al. (In Submission)

WHY STUDY NEUROGENESIS IN FOOD-STORING BIRDS?

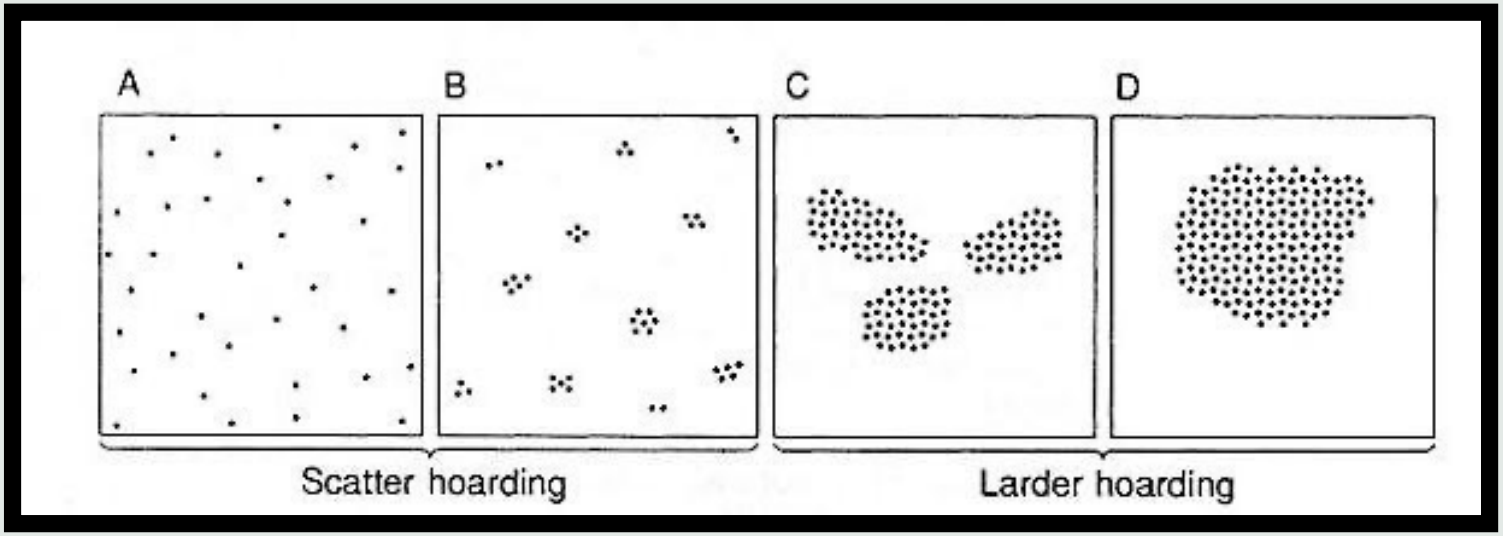
- Early 1980s: Nottebohm studies seasonal neurogenesis and volumetric changes of song nuclei in canaries
  - http://www.fi.edu/winners/2006/NottebohmWeb.mp4
- Late 1980s: Largest studies examining volumetric changes in the avian hippocampus
  - Krebs examined 35 European species of passerines
  - Sherry examined 13 North American species of passerines
  - Both demonstrate: HP Food-storers > HP non-storers
- Early 1990s: Nottebohm extends his research to study seasonal changes of hippocampus in food-storing birds.

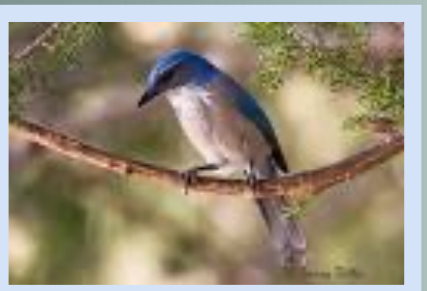


FOOD-STORING BEHAVIOR



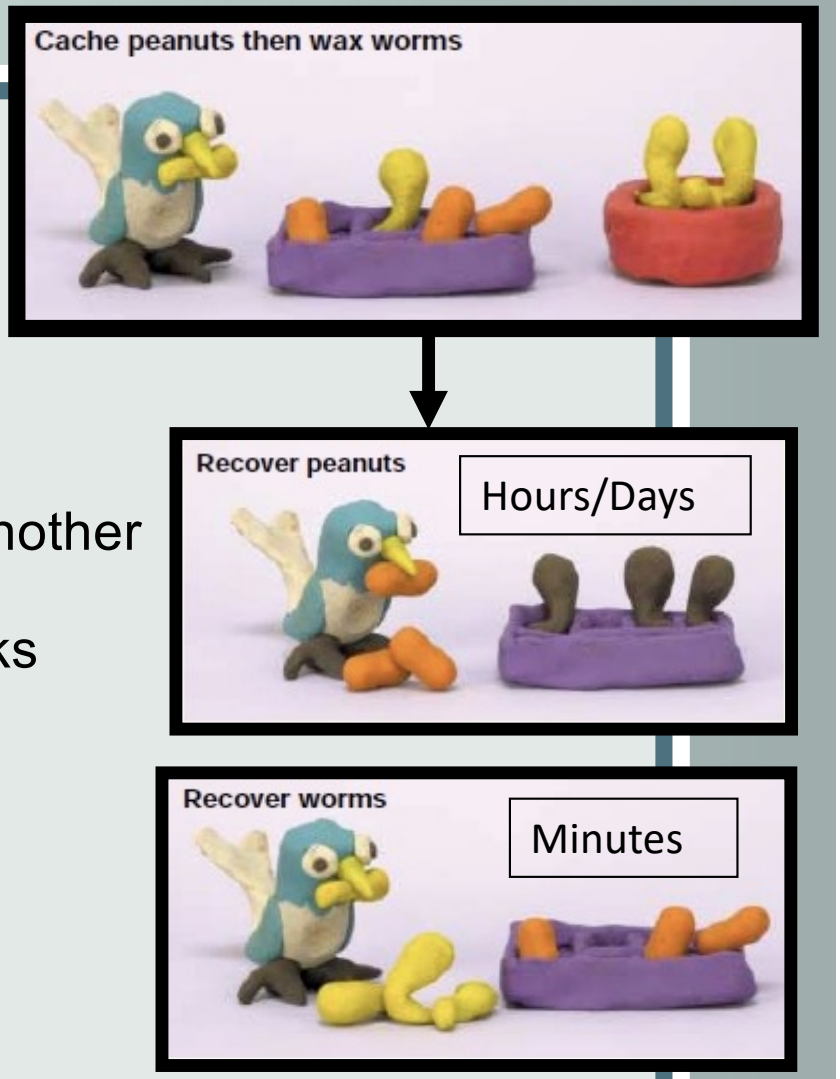
- Food-Storing: Manipulation of food for future consumption
  - Consumption of food is deferred
  - Food is manipulated in order to deter other organisms from consuming it
- Cache: Stored food
- Scatter-Hoarding: Food is stored in a variety of locations (A&B)
- Larder-Hoarding: Food is stored in one or a few locations (C&D)





FOOD-STORING BEHAVIOR

- Cache Recovery:
  - Spatial memory
  - Recall by a number of variables
    - Time of storage (***When***)
    - Type of food stored (***What***)
    - Relationship of one stored cache to another (***Where***)
    - Map territory by reference to landmarks (***Where***)
    - Position of sun (***Where***)
    - Learn vectors (***Where***)
  - Do not use: scent, position rules, fixed paths, snapshots, random search, mark cache site



http://www.youtube.com/watch?v=TmkKFTGGD1k&feature=related (~5:31)

AVIAN FOOD-STORERS

9,000 Seeds

3,000 Locations

25 km

9 month retention

Parvorder Corvidae aka Corvids (Crows, Jays, Nutcrackers)

Parvorder Paridae aka Parvids (Chickadees)

Hundreds of seeds

28 day retention

Suborder Passeri aka Passerine (Song Birds)

Parvorder Sittidae (Nuthatches)

Order Passeriformes (Perching Birds)

EVOLUTION OF FOOD-STORING

- The adaptive value of learning
- Adaptive Specialization: Animals develop more specialized cognitive abilities and skills that are appropriate for the environments in which they live.
  - Certain features of memory (e.g., duration, capacity, discrimination) have become modified during evolution in response to the selective advantage of retrieval of stored food.
  - Explains differences within various storing species and between storers and non-storers.

EVIDENCE SUPPORTING AN ADAPTIVE SPECIALIZATION IN FOOD-STORERS

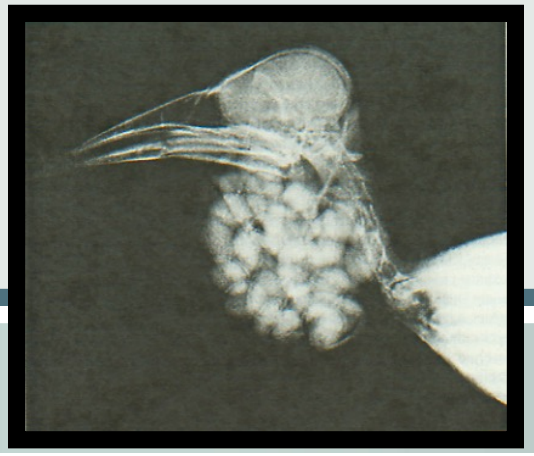
- Power of prediction:
  - ***Observation****:* Food-storers solve the problem of interrupted food-supply during the winter by recovering thousands of separately stored caches.
  - ***Question****:* To accurately recover the food, food-storers should evolve cognitive/behavioral and physiological mechanisms with what properties?
  - ***Predictions****: Suggestions anyone?* ☺ Don't cheat by looking in the notes!

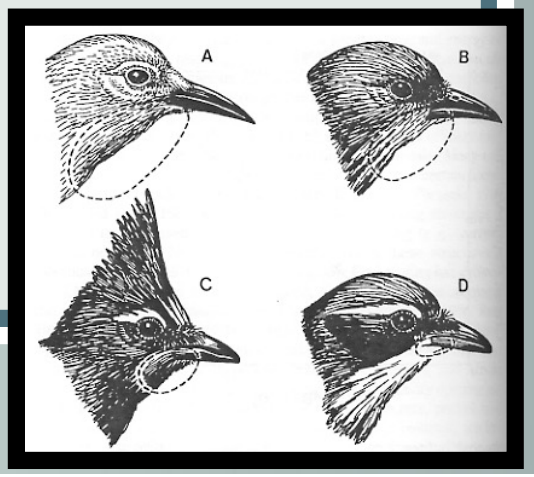
EVIDENCE SUPPORTING AN ADAPTIVE SPECIALIZATION IN FOOD-STORERS

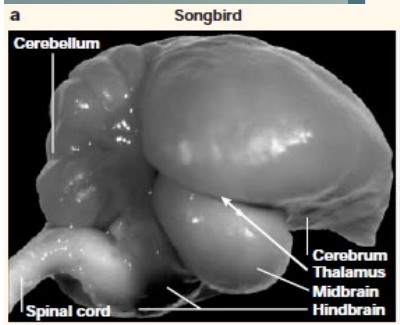
- Storing birds should have superior spatial memory capacity than non-storers
- Storing birds should perform equal to non-storers on tasks of non-spatial memory (color)
- Heavy-cache dependent storers should outperform light-cache dependent storers on spatial memory tasks
- For storing birds, the HP should be involved in cache recovery.
- Storing birds should have larger HP volume than non-storing birds

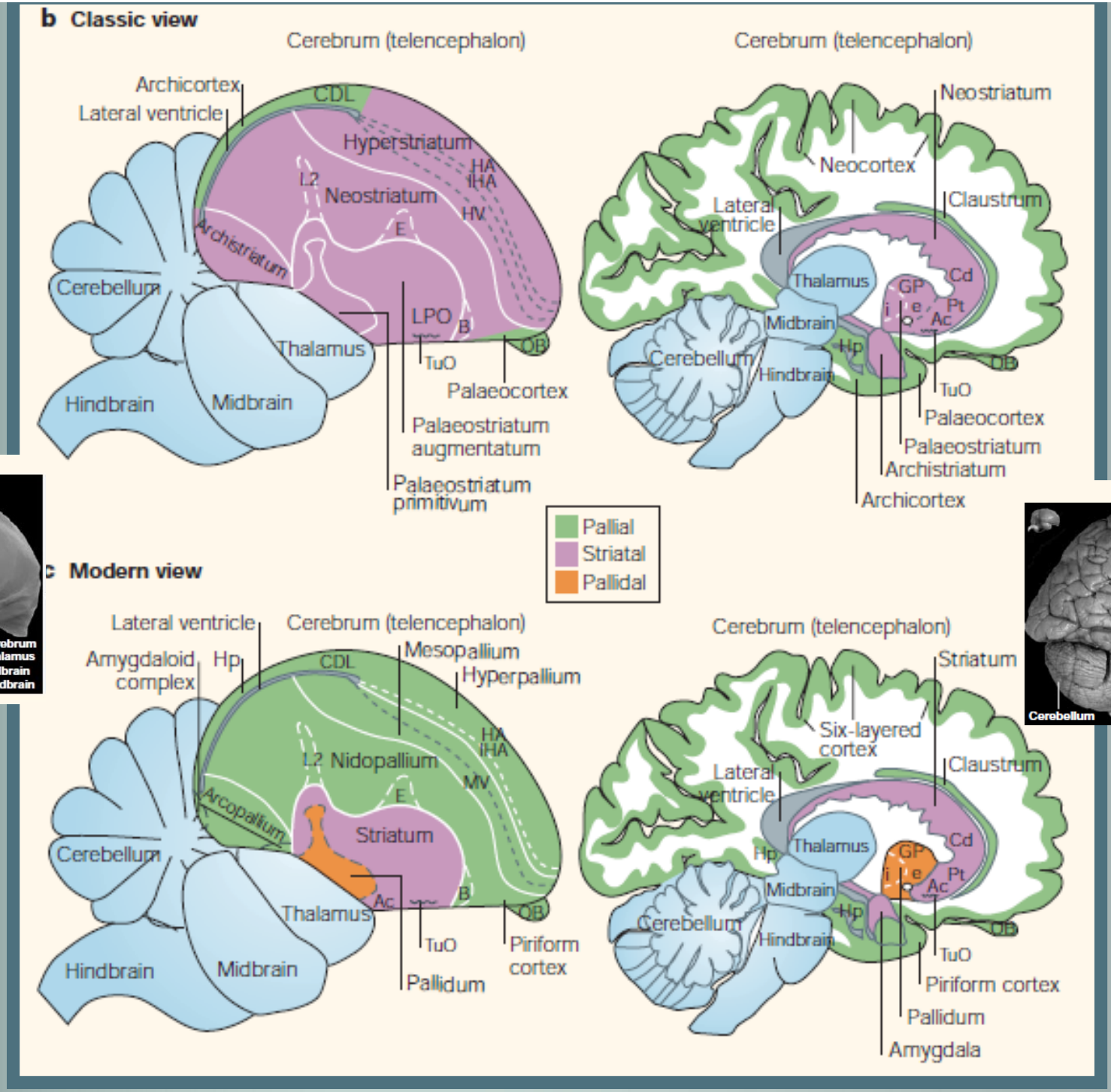
EVIDENCE SUPPORTING AN ADAPTIVE SPECIALIZATION IN FOOD-STORERS

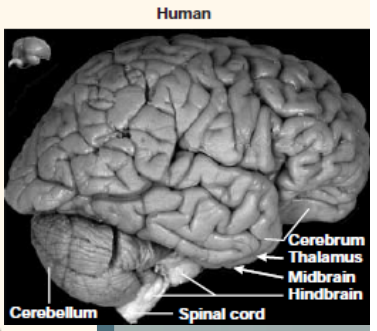
- Storing birds should have more HP neurogenesis than non-storing birds
- Storing birds should have larger HP volumes during the fall vs spring
- Storing birds should have more HP neurogenesis during the fall vs spring
- Non-storing birds should show no seasonal differences in HP neurogenesis
- Storers should have morphological specializations







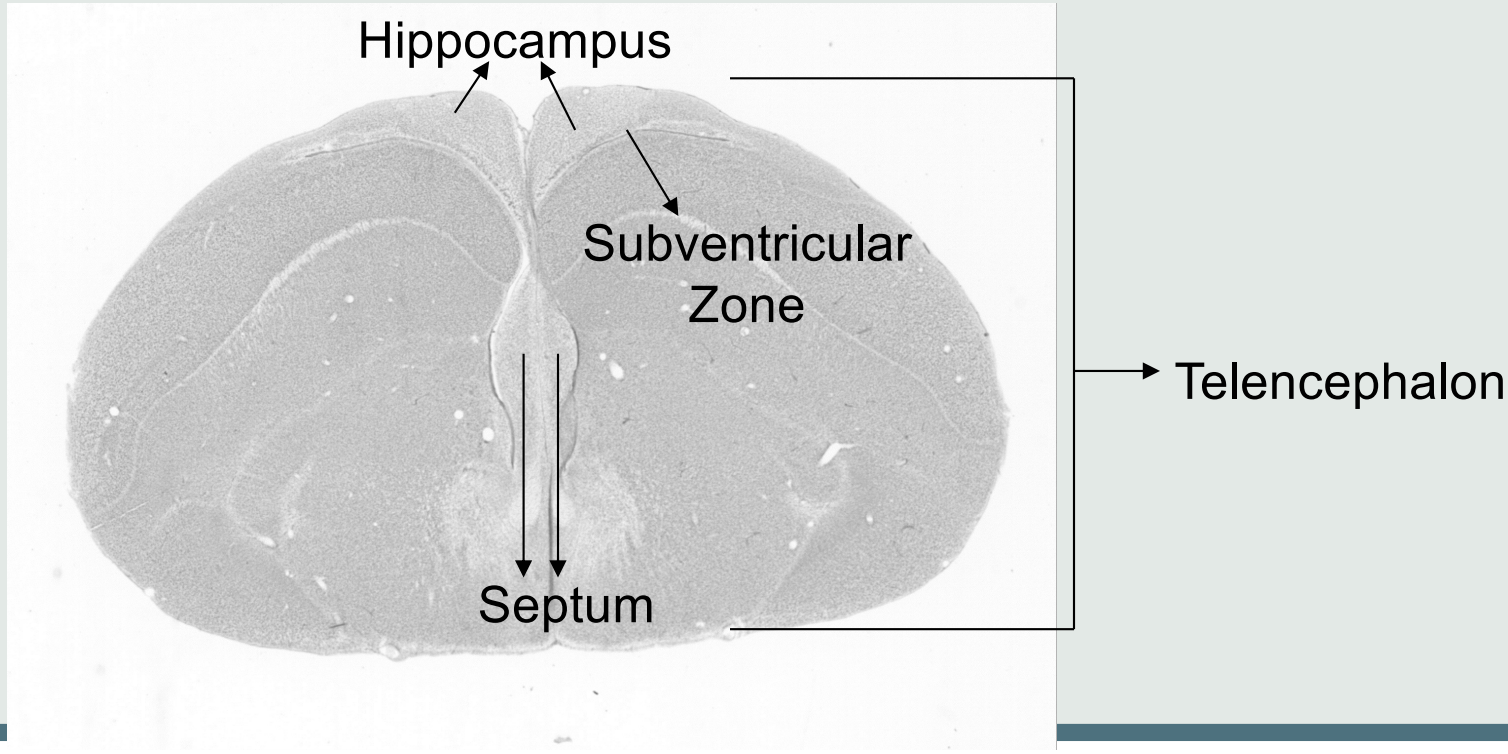




http://www.youtube.com/watch?v=b7iPOwFmMbg&feature=related

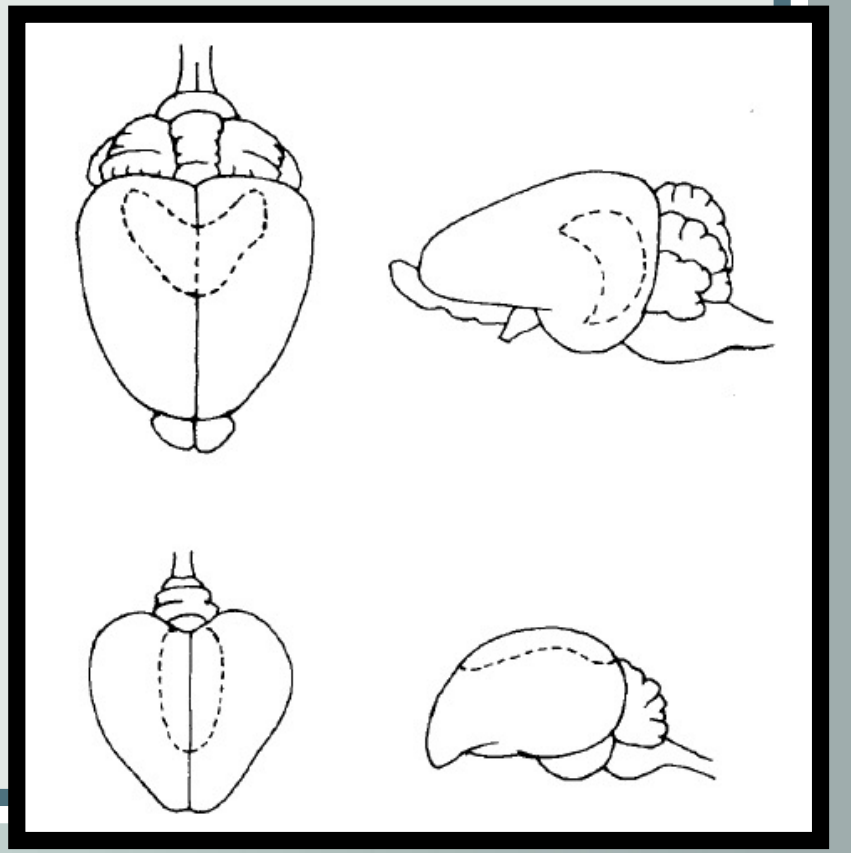
AVIAN HIPPOCAMPUS

- Processes spatial memory
- Is part of the telencephalon and is located in the dorsomedial cortex
- Covers 67% of A-P axis
- Is closely located to the subventricular zone (stem-cell region)

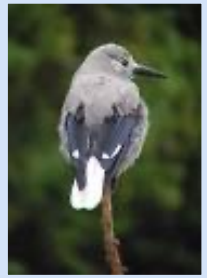


AVIAN HIPPOCAMPUS

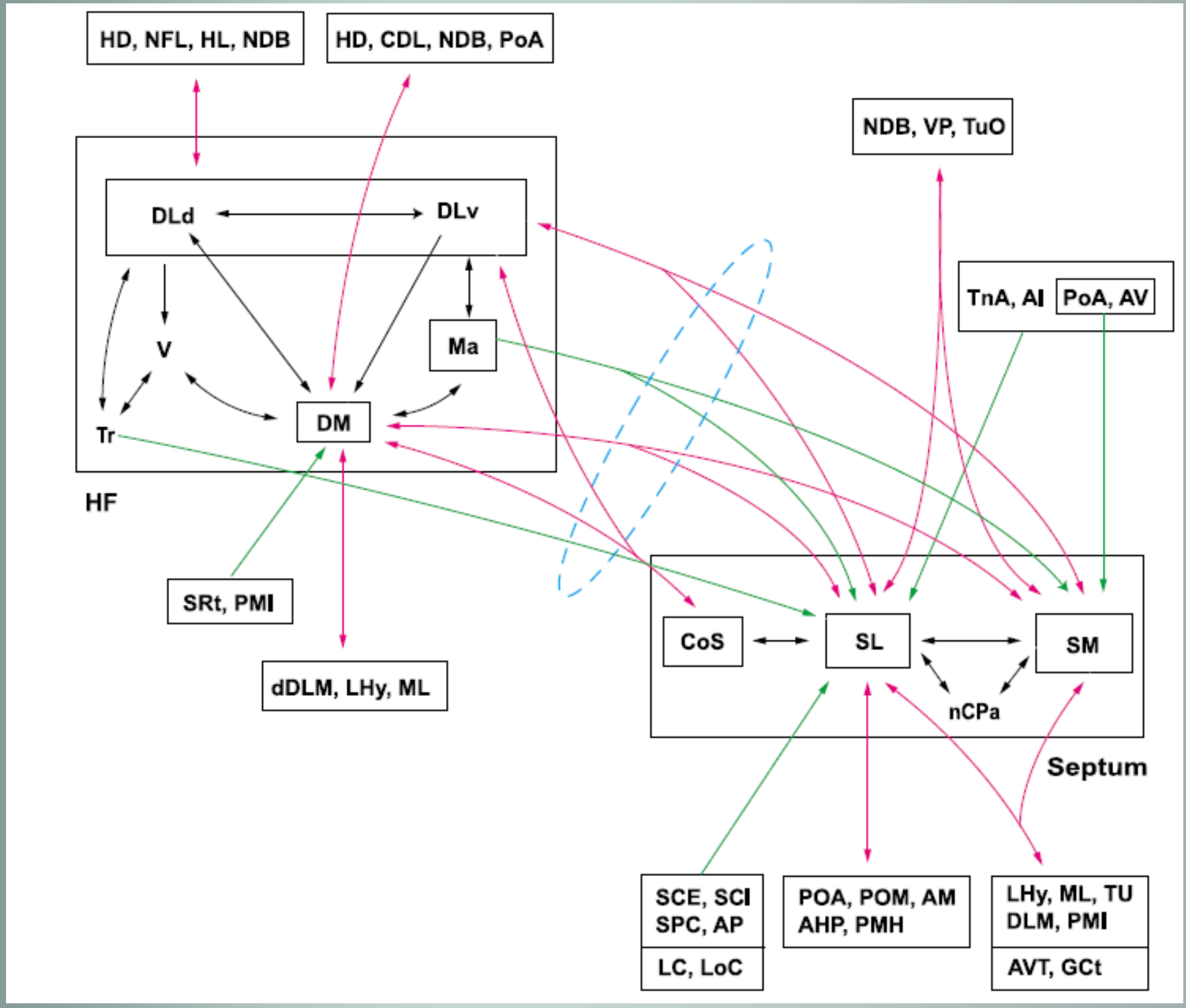
- Embryological, anatomical, physiological, and neurochemical evidence suggest that the avian and mammalian hippocampi are homologous.
- Both the mammalian and avian hippocampi show topological similarities. However, throughout evolution the avian hippocampus remained in its original position, while the mammalian hippocampus changed locations.



AVIAN SEPTUM



- Avian and mammalian septum demonstrate structural and neurochemical homology
- The avian hippocampus shares reciprocal, bilateral projections to the septum
- Septum also projects to: brain stem, hypothalamus, & basal ganglia
- Septum also receives input from: amygdala, preoptic area, & basal ganglia
- Neurochemical homology: vasotocin, corticotrophin-releasing factor, substance P, choline acetyltransferase, & tyrosine hydroxylase
- In mammals, septum is involved in spatial memory. In birds, social behaviors (maybe food-storing?)

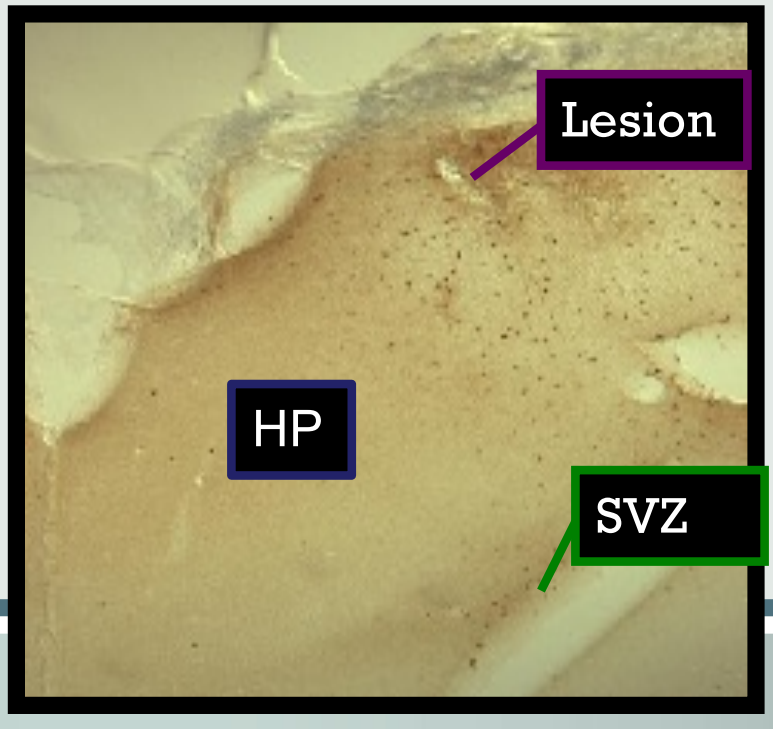

HD, NFL, HL, NDB
HD, CDL, NDB, PoA
NDB, VP, TuO
DLd
DLv
TnA, AI
PoA, AV
V
Ma
Tr
DM
HF
SRt, PMI
dDLM, LHy, ML
CoS
SL
SM
nCPa
Septum
SCE, SCI
SPC, AP
LC, LoC
POA, POM, AM
AHP, PMH
LHy, ML, TU
DLM, PMI
AVT, GCt

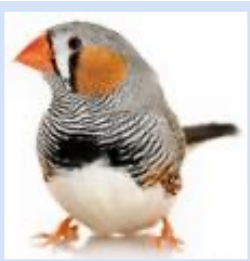
AVIAN SEPTUM

- Why do we care about the septum of storers?
  - HP of storers is “special” (volume, neurogenesis)
  - HP shares reciprocal, bilateral connections w/septum
  - In mammals, septum is involved in spatial memory
  - Septum storers > Septum non-storers
  - Fall septum storers > Spring septum storers
- In mammals, septal input regulates adult hippocampal neurogenesis
  - Lesions to the medial septum decrease adult hippocampal neurogenesis by about 40%

ADULT AVIAN NEUROGENESIS

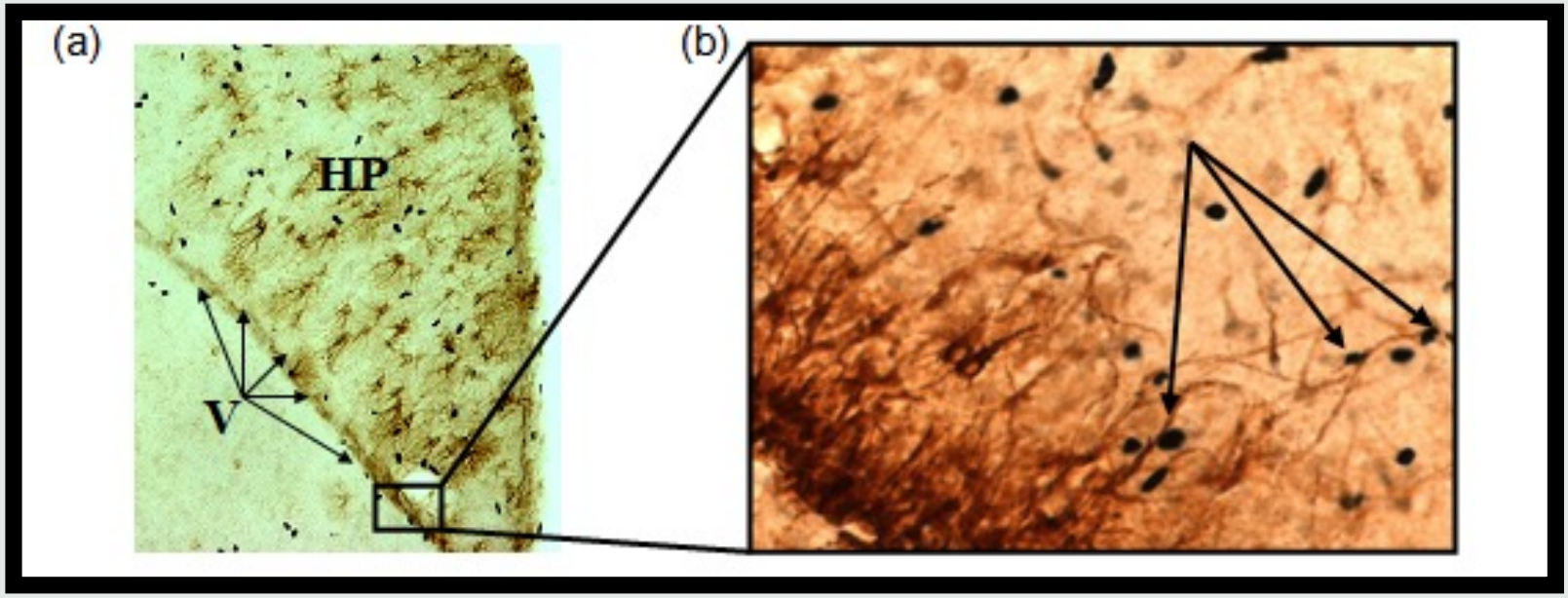
- Innate Neurogenesis:
  - No dentate gyrus
  - Stem cell zone: SVZ
- Injury-Induced Neurogenesis:
  - Zebra Finches: Hippocampal **injury** results in cell proliferation in the **hippocampus** & **SVZ**
  - Septum too!





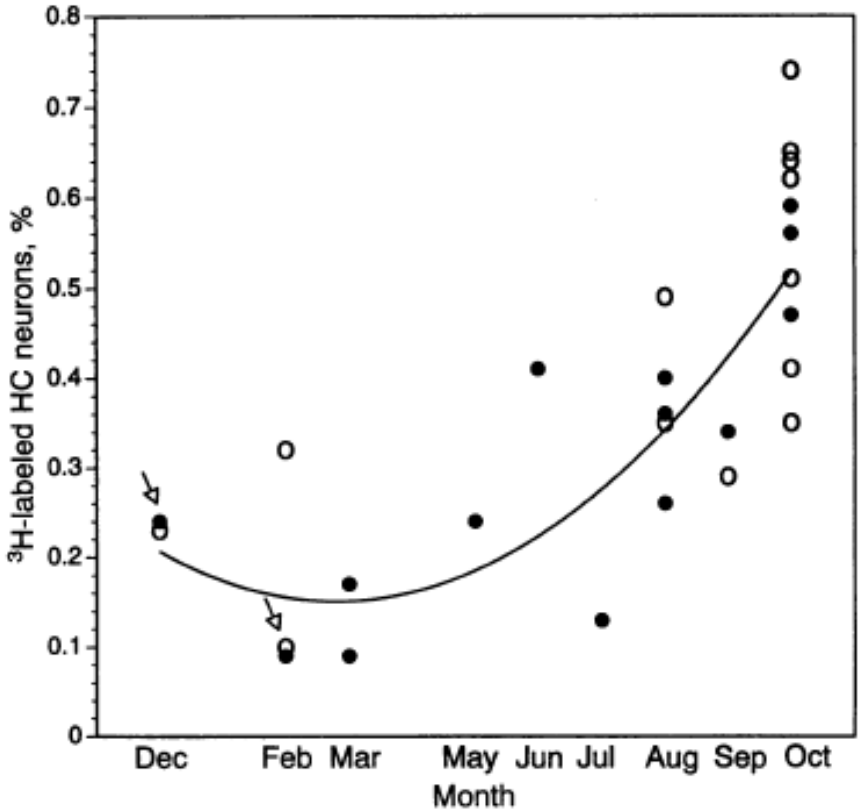
ADULT AVIAN NEUROGENESIS

- Zebra Finches: Hippocampal injury results in upregulation of aromatase in reactive astrocytes & glia (Peterson et al., 2004; 2007; Lee et al., 2007)
  - Somas of adult radial cells are anchored in SVZ & their processes extend out toward the injury



NEUROGENESIS IN FOOD-STORERS

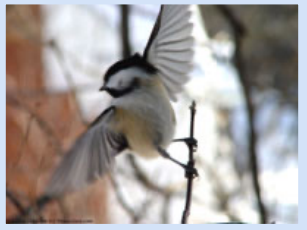
- Barnea & Nottebohm (1994)
  - Wild black-capped chickadees caught at various times throughout the year
  - Injected with [^{3}H]thymidine
  - Some birds released, some held captive
  - Recaptured wild-birds 6 weeks later (or longer)
  - Peak HP neurogenesis during fall
  - Distances of labeled neurons from SVZ was similar at 6 weeks & longer survival times.



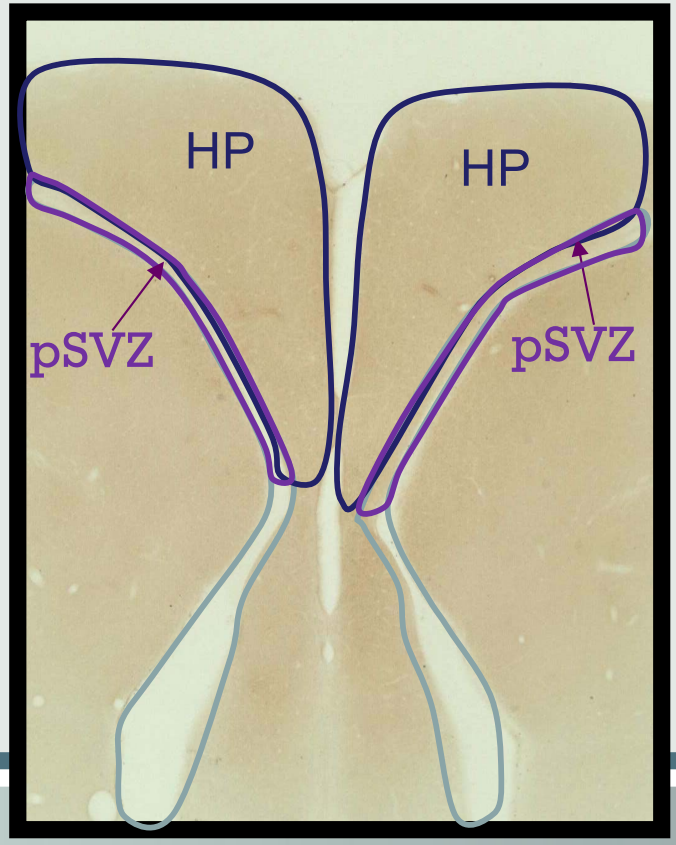
NEUROGENESIS IN FOOD-STORERS

- Law et al. (2009)
  - Examined innate & injury-induced cell proliferation in wild-caught food-storing black-capped chickadees & non-storing dark-eyed juncos during the fall at the CSC
  - Birds received either no lesion or a unilateral lesion to the right hippocampus
  - 24 hours later, all birds received an injection of the mitotic marker BrdU
  - 7 days later, all birds were perfused
  - DV: Density of BrdU-immunoreactive cells (cells/mm2) in the hippocampus & SVZ

NEUROGENESIS IN FOOD-STORERS



- Law et al. (2009)
  - BrdU-IR cells were counted in the hippocampus & SVZ
  - SVZ divided based on proximity to hippocampus
    - Proximal SVZ (pSVZ): Adjacent to HP



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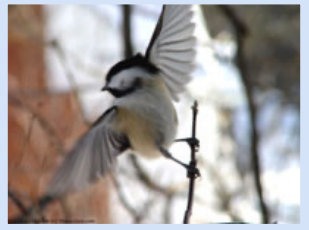
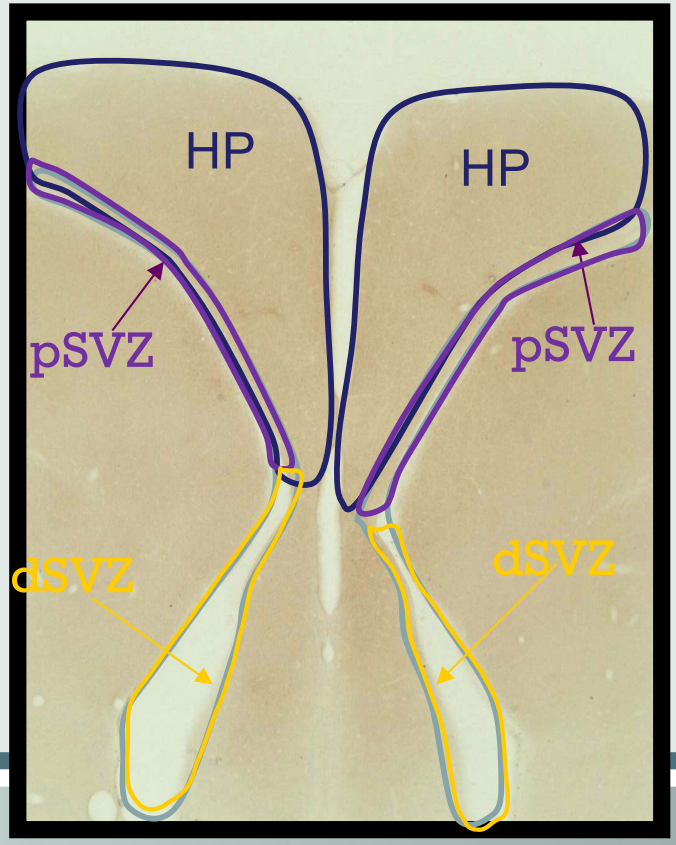
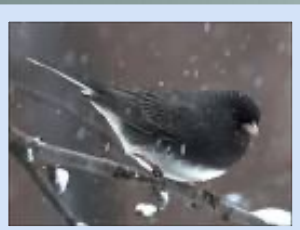
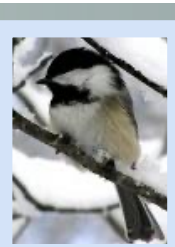


- Law et al. (2009)
  - BrdU-IR cells were counted in the hippocampus & SVZ
  - SVZ divided based on proximity to hippocampus
    - Proximal SVZ (pSVZ): Adjacent to HP
    - Distal SVZ (dSVZ): Non-adjacent to HP

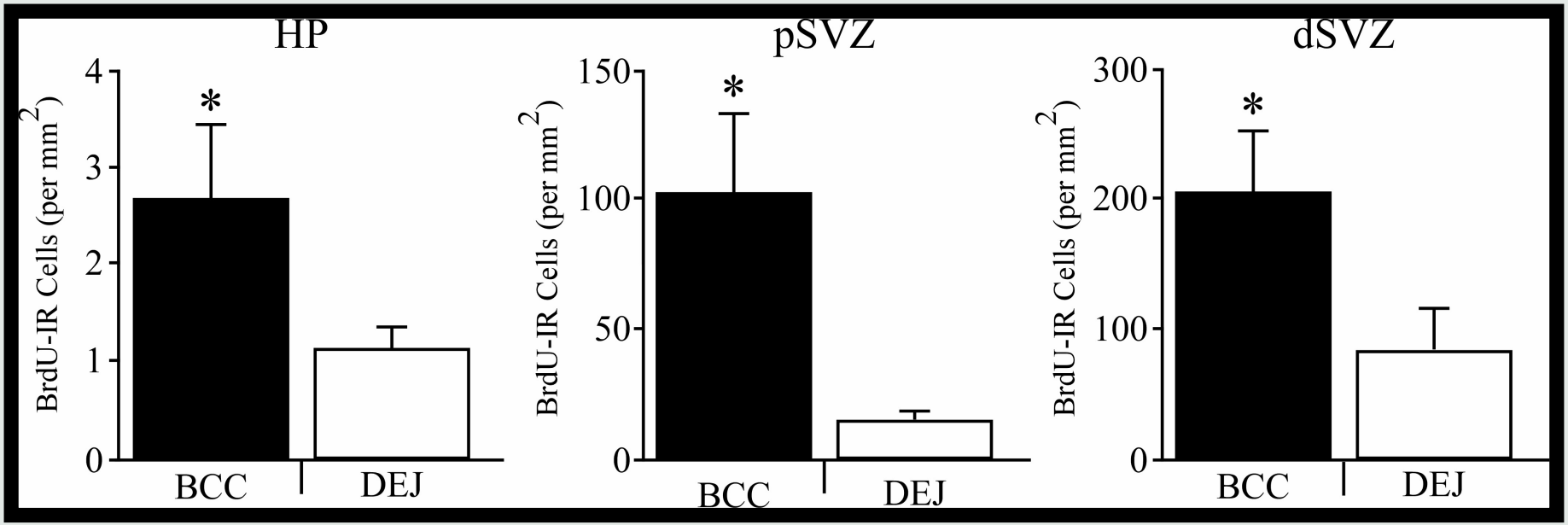


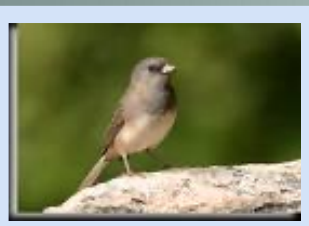


NEUROGENESIS IN FOOD-STORERS



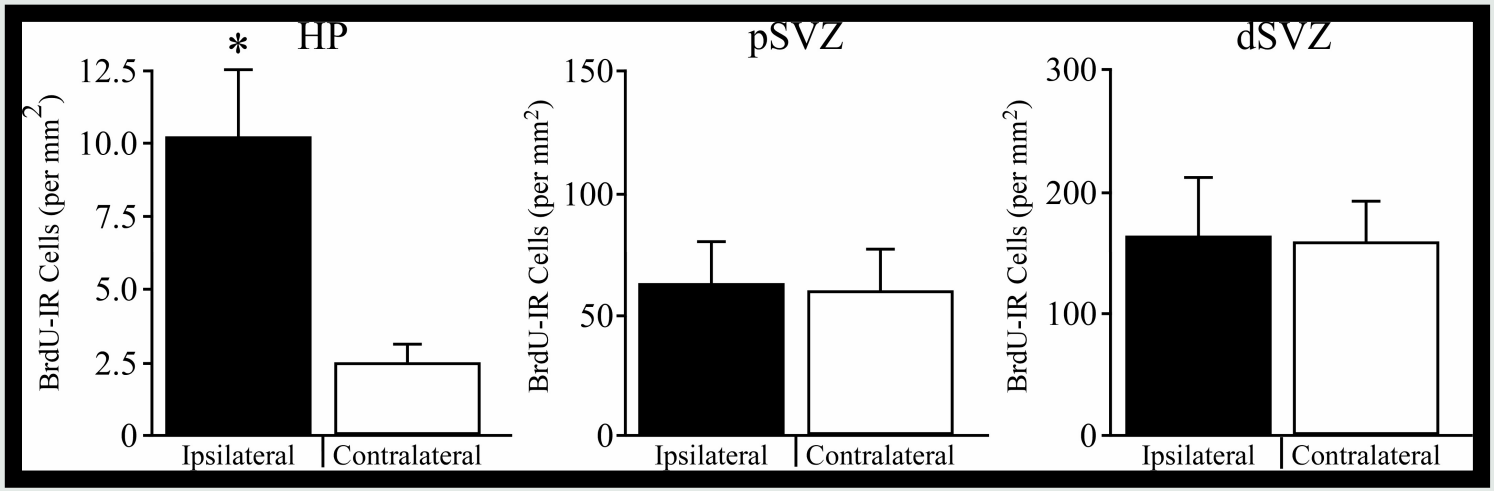
- Law et al. (2009):
  - Innate cell proliferation: Chickadee > Junco

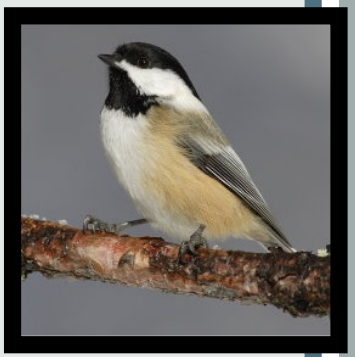


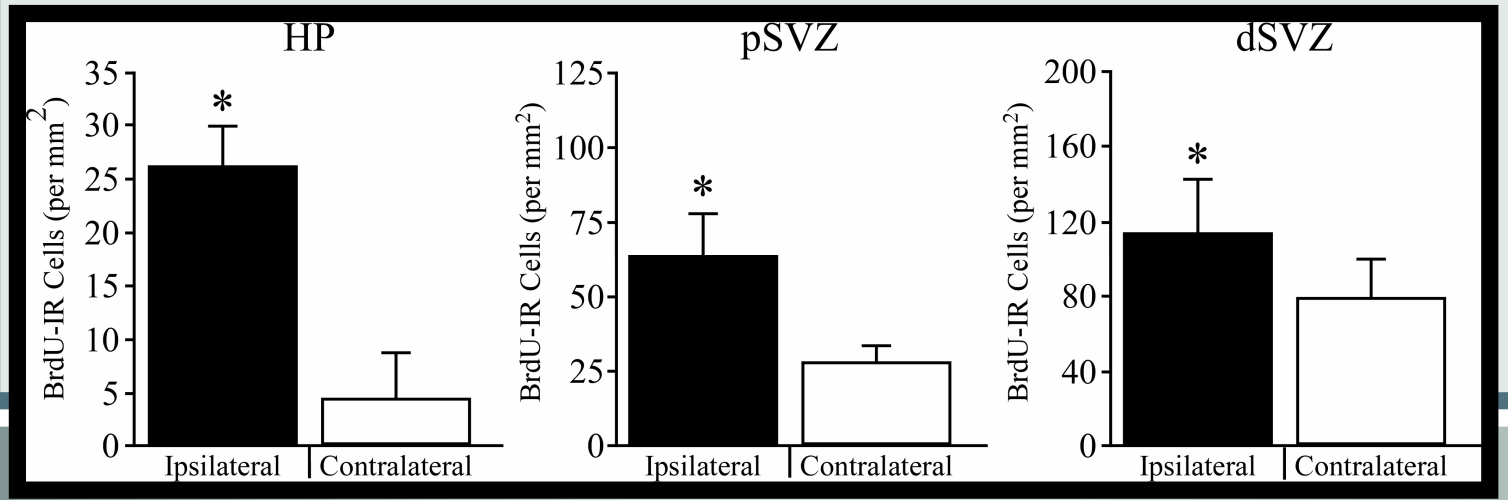


NEUROGENESIS IN FOOD-STORERS

- Law et al. (2009):
  - Injury-Induced Cell Proliferation: Junco > Chickadee

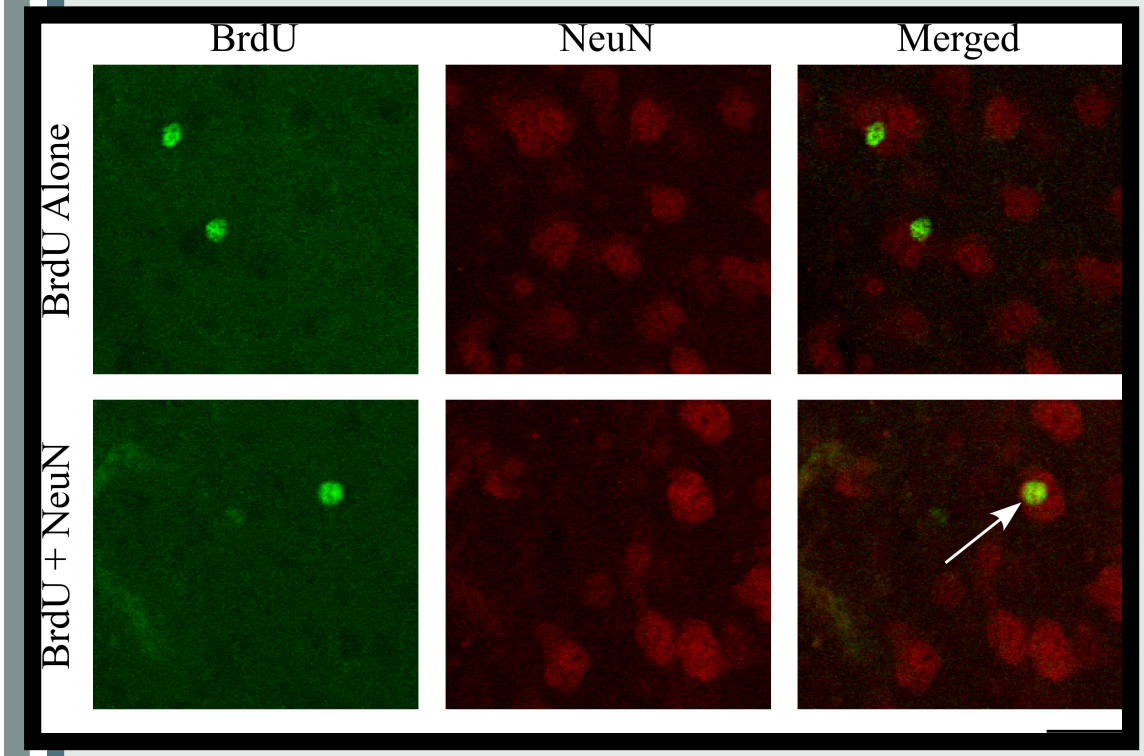






NEUROGENESIS IN FOOD-STORERS

- Law et al. (2009):
  - Injury-Induced Neurogenesis: Chickadee > Junco



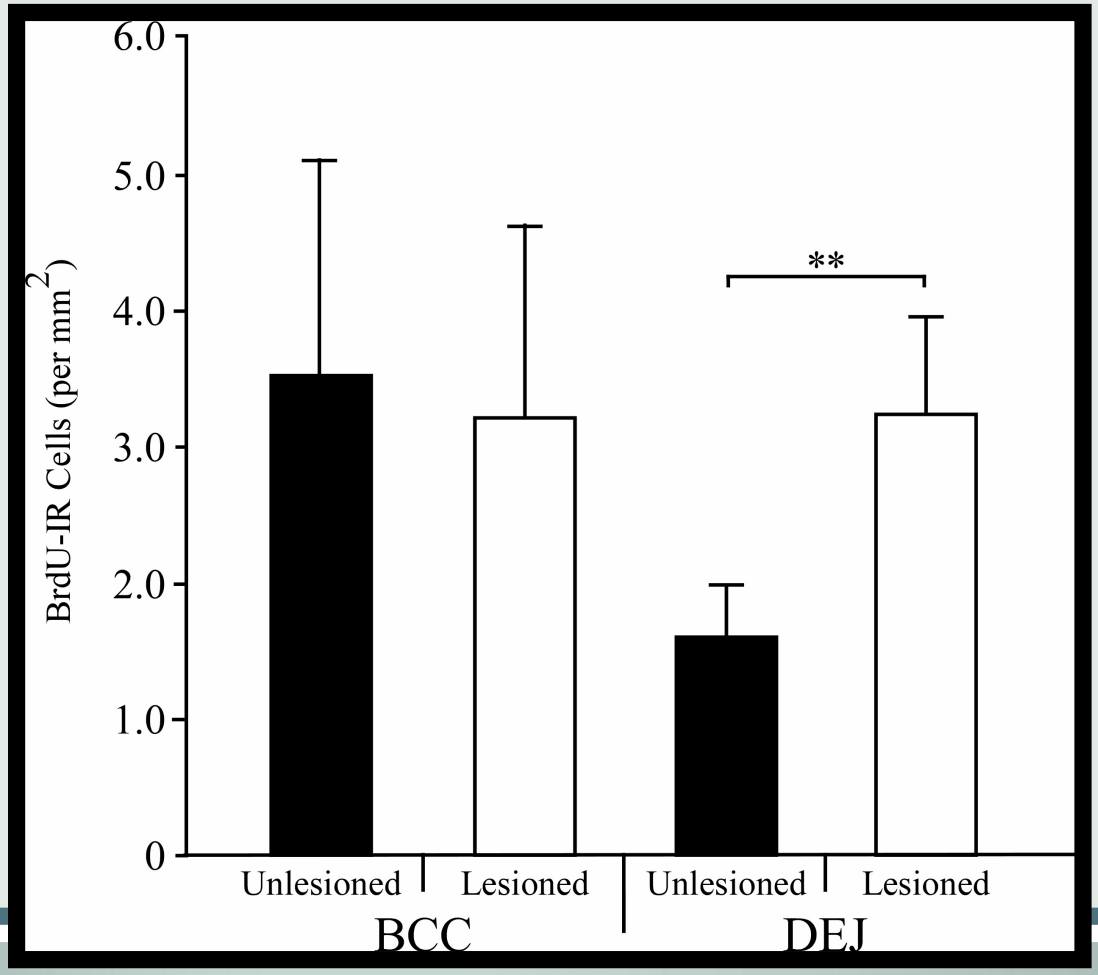
	Brain Region		
Species	HP (%)	pSVZ (%)	dSVZ (%)
BCC	37	7	<1
DEJ	17	0	0

NEUROGENESIS IN FOOD-STORERS

- Gardner et al. (In Submission)
  - Examined injury-induced cell proliferation in wild-caught storing chickadees & non-storing juncos during the fall at the CSC
  - Same birds used by Law et al. (2009)
  - DV: Density of BrdU-IR cells (cells/mm2) in the Septum

NEUROGENESIS IN FOOD-STORERS

- Gardner et al. (In Submission)
  - Injury-induced Cell Proliferation: Junco > Chickadee

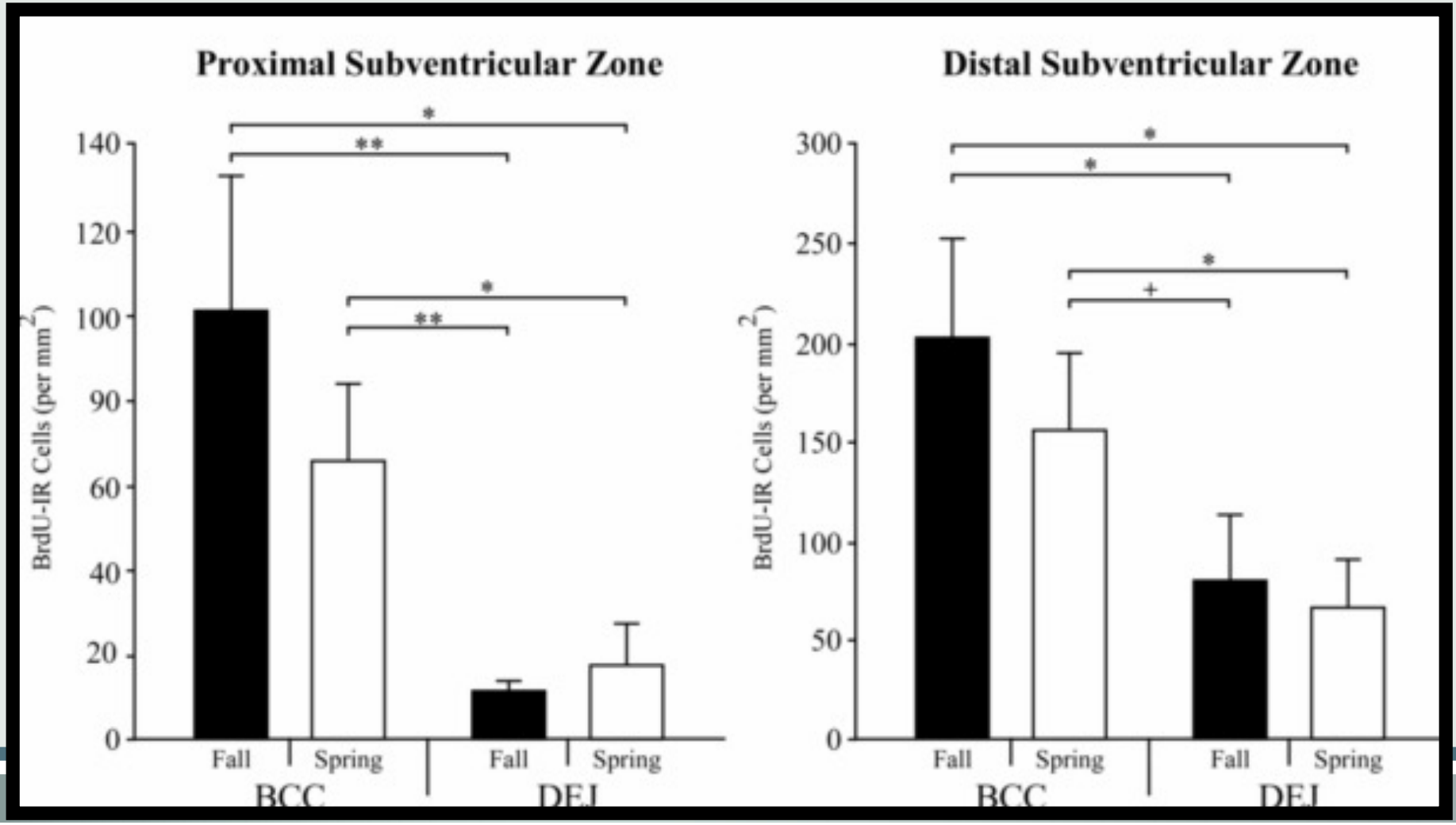


NEUROGENESIS IN FOOD-STORERS

- Gardner et al. (In Submission):
  - Seasonal fluctuations in septal or SVZ cell proliferation?
  - Examined innate (unlesioned) cell proliferation in wild-caught storing chickadees & non-storing juncos during the fall & spring at the CSC
  - 48 hours after capture, all birds received an injection BrdU
  - 7 days later, all birds were perfused
  - DV: Density of BrdU-IR cells (cells/mm2) in the hippocampus, septum, pSVZ, & dSVZ

NEUROGENESIS IN FOOD-STORERS

- Gardner et al. (In Submission):
  - No seasonal changes in SVZ



NEUROGENESIS IN FOOD-STORERS

- Both the hippocampus & septum have peak rates of cell proliferation during the fall in chickadees but not juncos
- There are no seasonal effects in the SVZ in either species
- Lesioned chickadees only show injury-induced cell proliferation in the hippocampus
- Lesioned juncos show injury-induced cell proliferation in the hippocampus, septum, pSVZ, & dSVZ (similar to zebra finches)
- Lesioned chickadees had fewer newly born hippocampal cells following injury compared to juncos
- Lesioned chickadees had a higher percentage of newly born neurons compared to juncos

NEUROGENESIS IN FOOD-STORERS

- Innate cell proliferation:
  - Is enhanced in storers, especially during the fall?
  - Selective advantage in the brain designed to meet the cognitive demands of food-storing?
- Injury-Induced cell proliferation:
  - Spread of injury restricted in storers?
  - Storers demonstrate a much faster cellular turnover than nonstorers?

THANK YOU!

QUESTIONS?
COMMENTS?
CRITIQUES?

If you have time, check out the videos of the 2009 World Science Festival on Avian Einsteins! ☺

Info at:
http://www.worldsciencefestival.com/2009/avian-einsteins

Videos at YouTube (Parts 1-11), starting at:
http://www.youtube.com/watch?v=fG5sbhREefU

Note: The interviewer is *slightly* annoying, sorry!