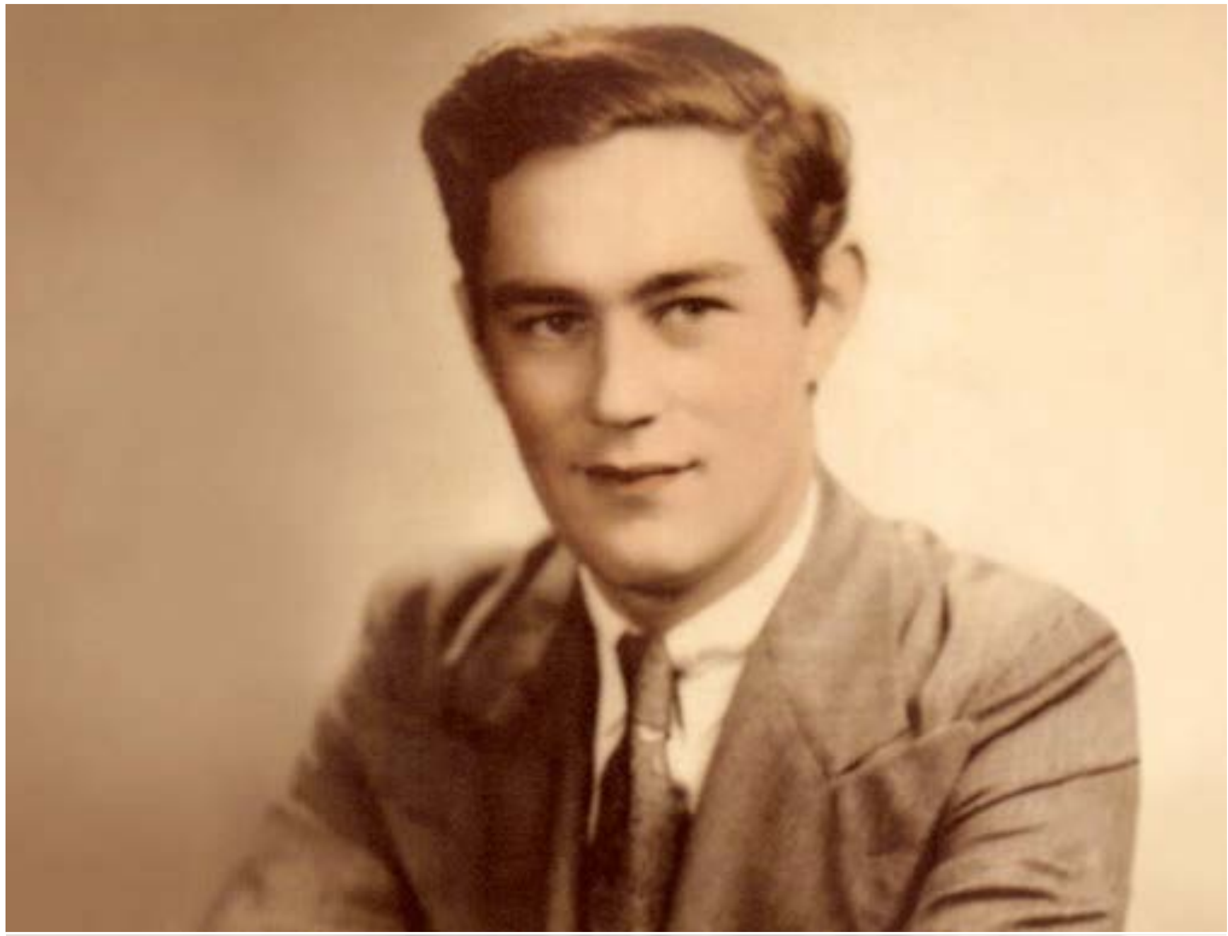
DECLARATIVE, EPISODIC, AND SEMANTIC MEMORY

Norbert Fortin, PhD



NB209: Behavioral Neuroscience

MULTIPLE MEMORY SYSTEMS

DIFFERENT BRAIN SYSTEMS FOR DIFFERENT TYPES OF MEMORIES

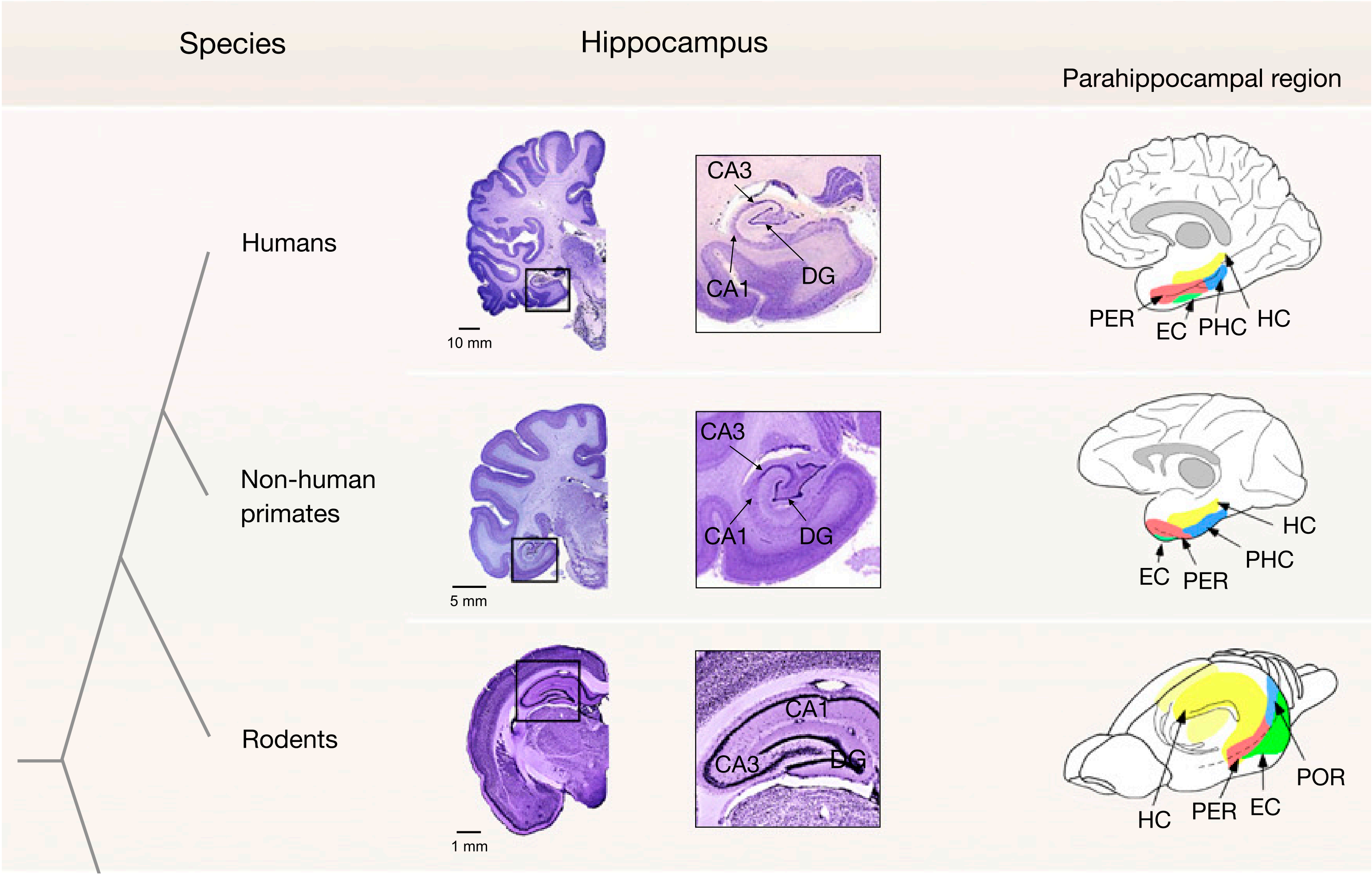
Larry Squire

- MEMORY
  - DECLARATIVE
    - SEMANTIC — FACTS
    - EPISODIC — EVENTS
    - MEDIAL TEMPORAL LOBES — Hippocampus and Parahippocampal region
  - NONDECLARATIVE
    - SKILLS & HABITS — MOTOR, COGNITIVE — STRIATUM
    - PRIMING & PERCEPTUAL LEARNING — SHIFTS IN JUDGMENTS AND PREFERENCE — CORTEX
    - SIMPLE CLASSICAL CONDITIONING
      - EMOTIONAL RESPONSES — AMYGDALA
      - SKELETAL RESPONSES — CEREBELLUM
    - NONASSOCIATIVE LEARNING — HABITUATION, SENSITIZATION — REFLEX PATHWAYS

Adapted from Squire (1992)

DECLARATIVE MEMORY

- Memories that can be “declared” or made “explicit”
- Characterized by flexible expression
- Depends on the medial temporal lobes (hippocampus + parahippocampal region)



Allen & Fortin (2013)

DECLARATIVE MEMORY
PATIENT H.M.

J. Neurol. Neurosurg. Psychiat., 1957, **20**, 11.

LOSS OF RECENT MEMORY AFTER BILATERAL HIPPOCAMPAL LESIONS

BY

WILLIAM BEECHER SCOVILLE and BRENDA MILNER

From the Department of Neurosurgery, Hartford Hospital, and the Department of Neurology and Neurosurgery, McGill University, and the Montreal Neurological Institute, Canada

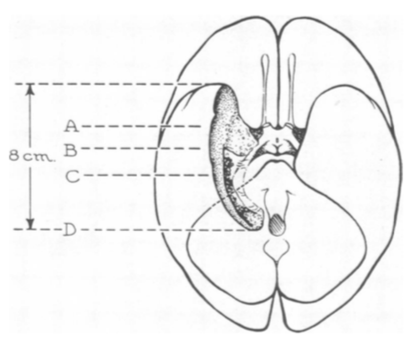
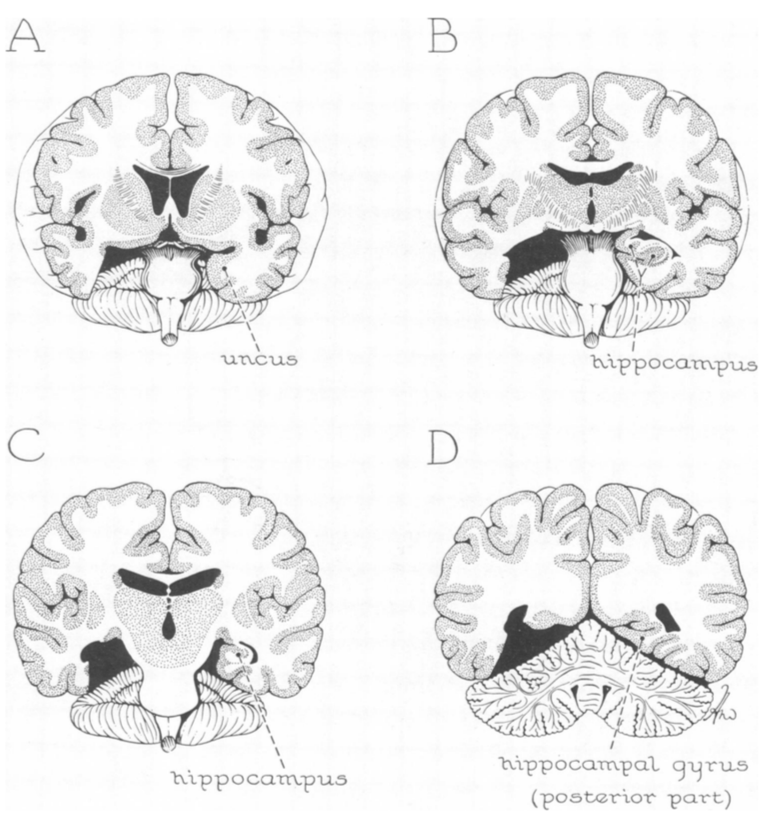
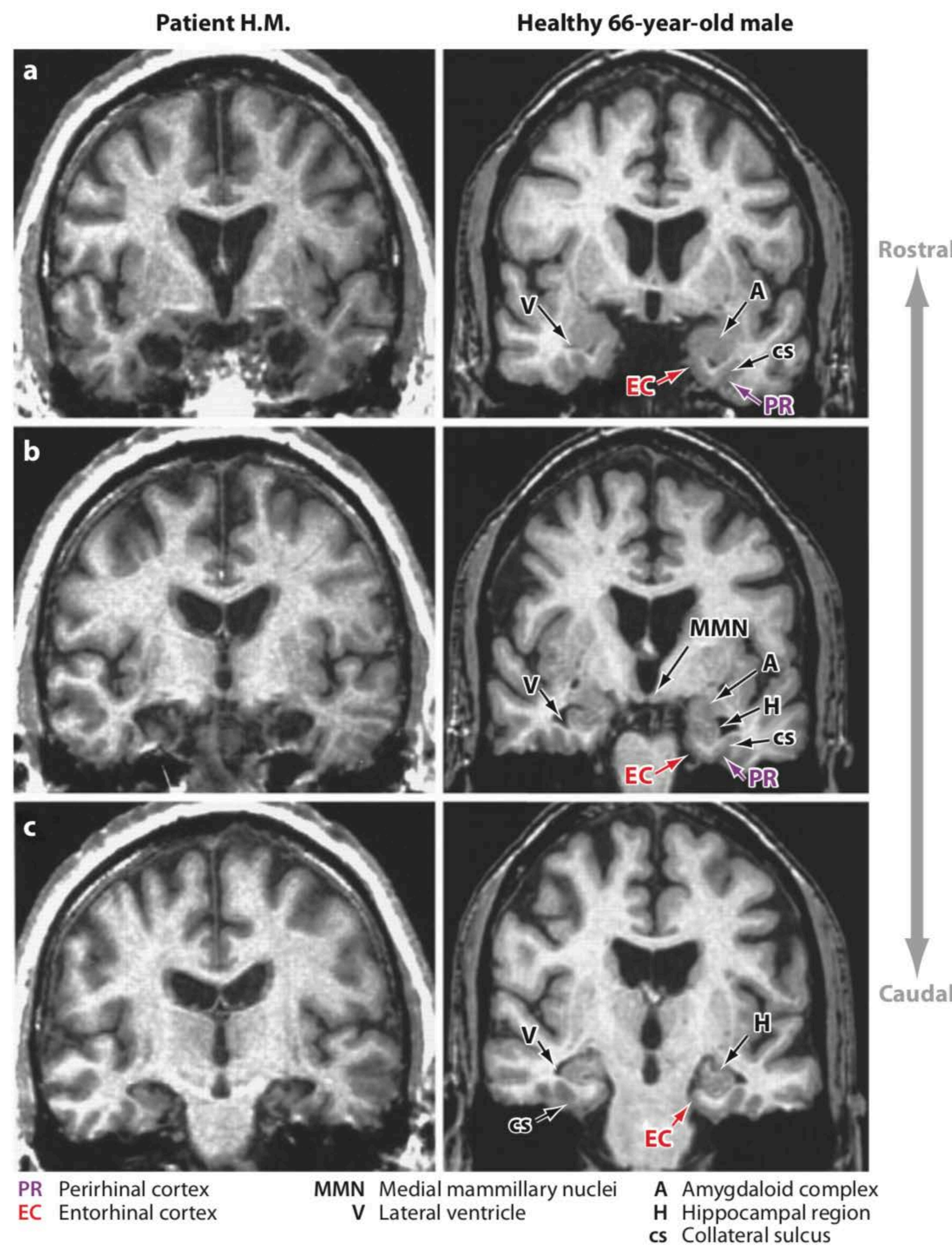


FIG. 2.—Diagrammatic cross-sections of human brain illustrating extent of attempted bilateral medial temporal lobe resection in the radical operation. (For diagrammatic purposes the resection has been shown on one side only.)



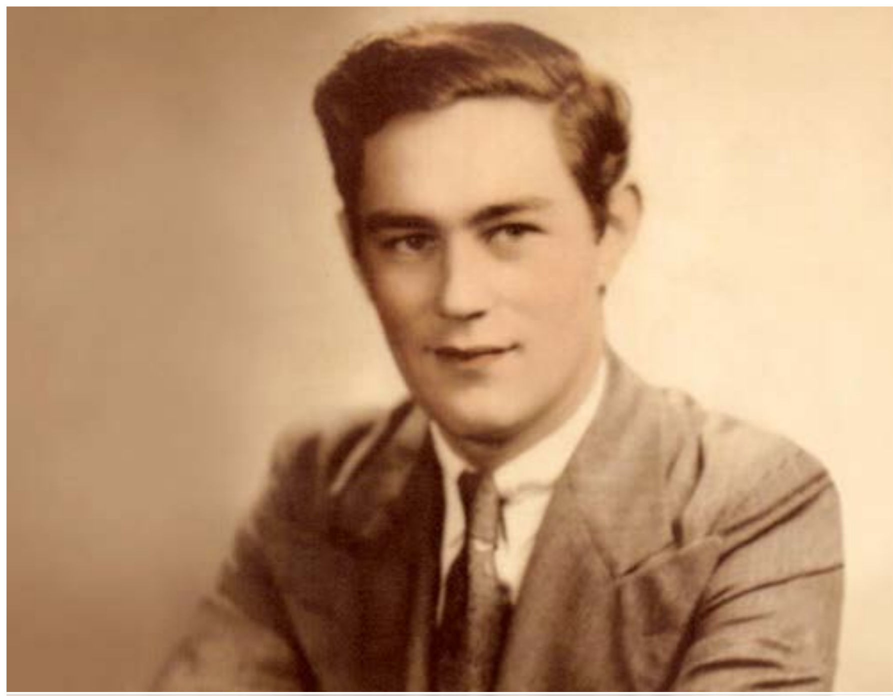


Squire & Wixted (2011)

DECLARATIVE MEMORY

PATIENT H.M.

Henry Gustav Molaison (1926-2008)



In 1953, before his surgery

In the 1970s

Damage to the medial temporal lobe impairs declarative memory, but not non-declarative memories (see properties next)

Limitations: Brain damage includes hippocampus, entorhinal cortex, perirhinal cortex, and parahippocampal cortex. Which region is doing what? That's where the animal models come in…

DECLARATIVE MEMORY
PROPERTIES FOR VALID ANIMAL MODEL OF HUMAN AMNESIA

- Property #1: Sensory, motor, motivational and cognitive processes are intact
- Property #2: Short-term memory (STM) is intact
- Property #3: Beyond STM, memory declines rapidly
    - “Faster forgetting”
- Property #4: Memory deficit is global
    - Not limited to one modality or type of stimulus
- Property #5: Graded retrograde impairment
    - Recent memories are more impaired than remote memories

from Eichenbaum & Cohen (2001)

Hippocampus damage impairs spatial memory tasks in animals (rapid acquisition, flexible expression)

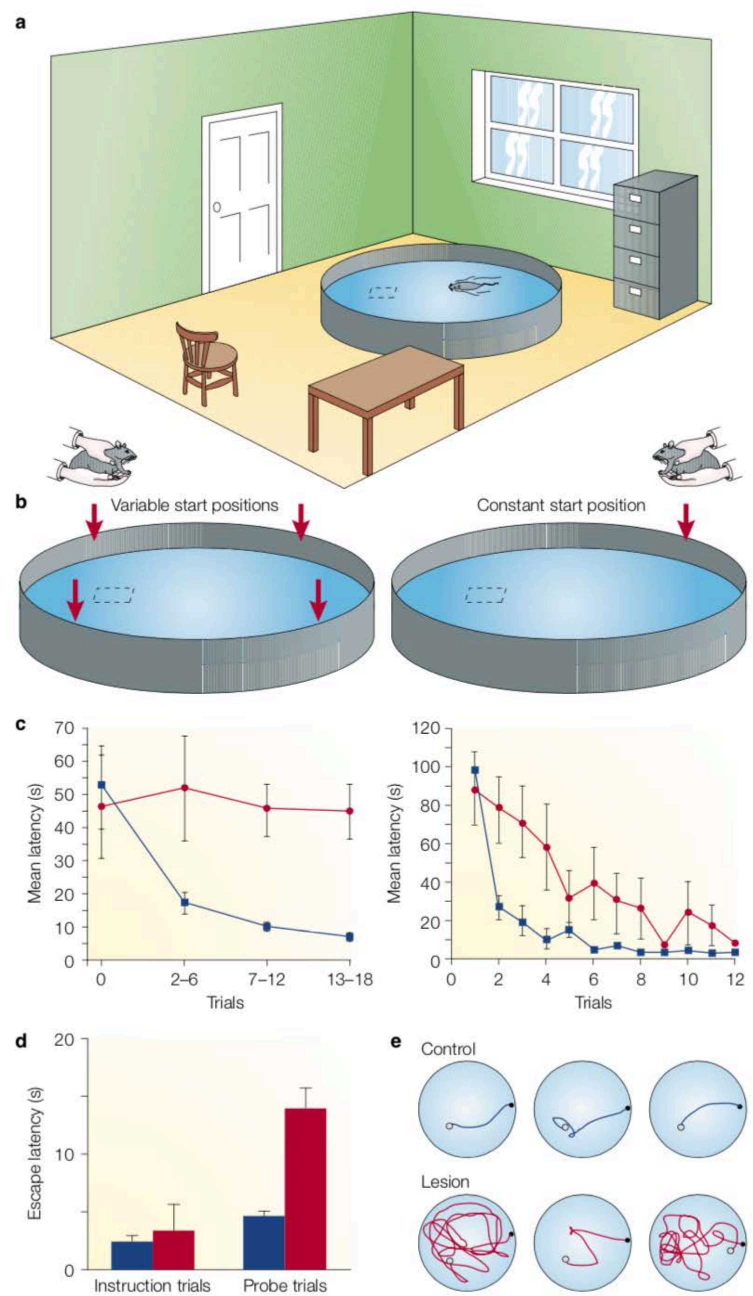


Figure 3 | **Performance of rats with hippocampal damage in the Morris water maze.** **a** | An illustration of the Morris water maze and typical environmental cues[74]. The escape platform, submerged just below the surface of the water, cannot be seen by the rat. **b** | In the conventional version of the task (left), the rat begins each trial from one of four starting locations, and the time required for it to locate the escape platform is measured. In the constant start position version of the task (right), one start location is used consistently. **c** | In the conventional version of the task (left), normal rats (blue) rapidly improve their swim latencies to find the platform across trials, whereas rats with hippocampal damage (red) do not. In the constant start position version of the task (right), rats with hippocampal damage are slightly impaired in acquisition rate, but successfully learn to locate the platform. **d** | During probe testing, normal rats (blue) rapidly locate the escape platform both on repetitions of the original instruction trials and on probe trials that begin at new start positions. Rats with hippocampal damage (red) also do well on repetitions of the instruction trials, but poorly on the probe trials. **e** | Example swim paths in new probe trials by normal rats (blue) and rats with hippocampal damage (red). Normal rats swim directly to the platform, but rats with hippocampal damage are severely impaired.

from Eichenbaum (2000)

DECLARATIVE MEMORY
ANIMAL MODELS

Hippocampus damage impairs expression of (non-spatial) memory for a single experience in social learning of food odors

Social transmission of food preference paradigm

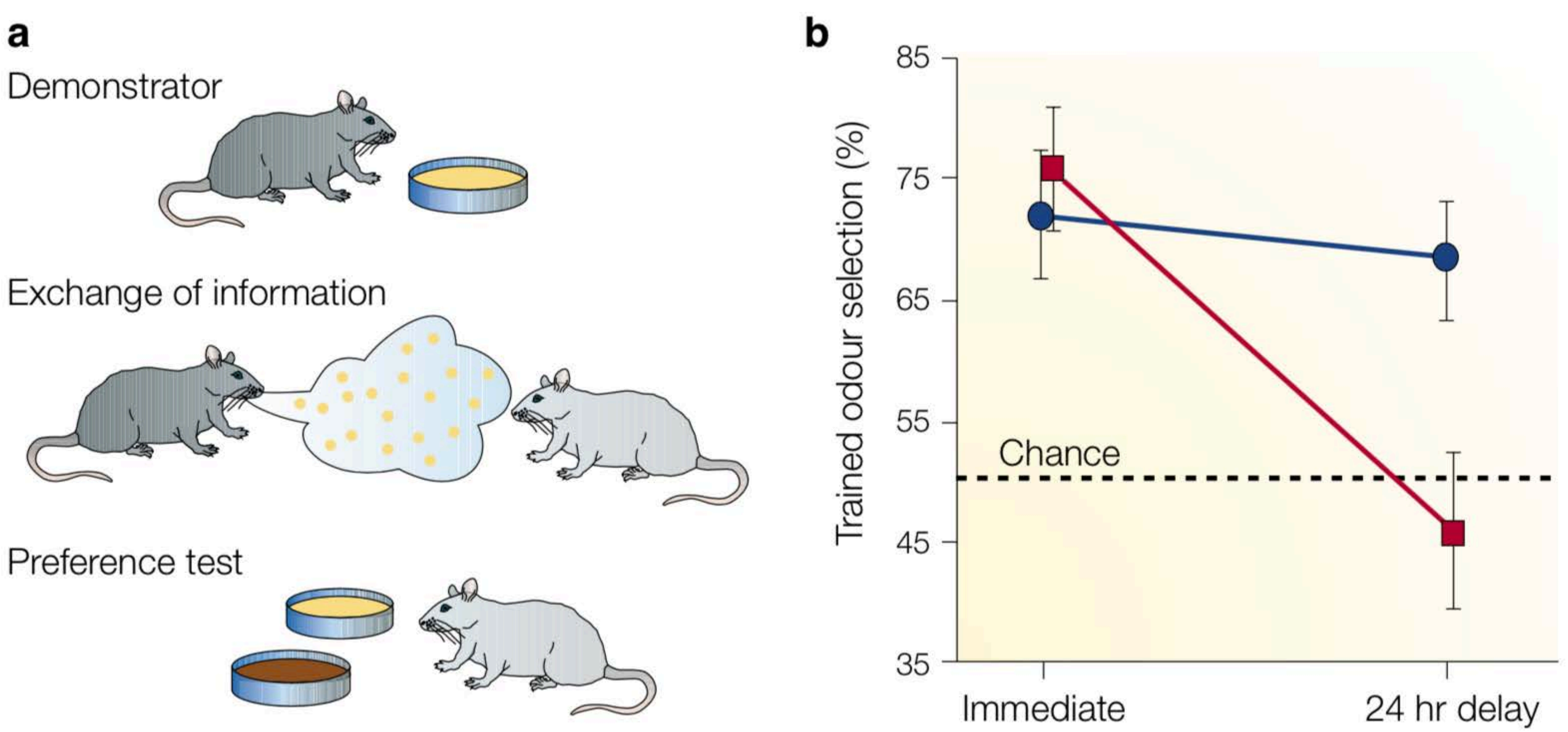


Figure 4 | **The social transmission of food preferences task. a** | Initially a 'demonstrator' rat eats food containing a new odour. Then, during a social encounter, the demonstrator exchanges information about the food odour with the subject rat[76]. Subsequently the subject is given a preference test for the new food odour versus another food odour. **b** | Preference test results. Normal rats (blue) show a strong preference for the demonstrated food odour both immediately and one day following the social encounter. Rats with hippocampal lesions (red) shown intact performance on the immediate test but forget within one day.

from Eichenbaum (2000)

DECLARATIVE MEMORY

ANIMAL MODELS

Hippocampus damage impairs the flexible expression of relationships among (non-spatial) experiences

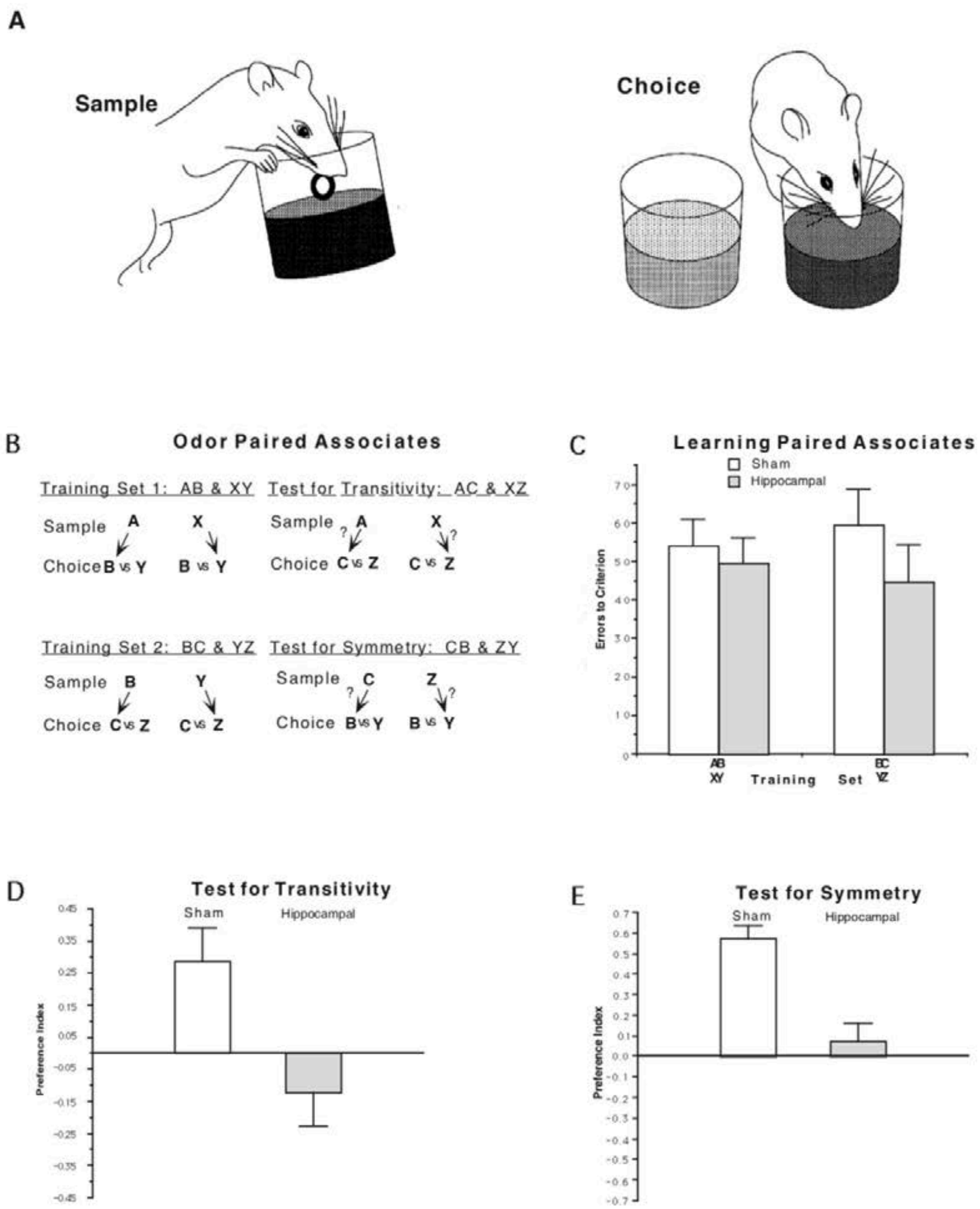
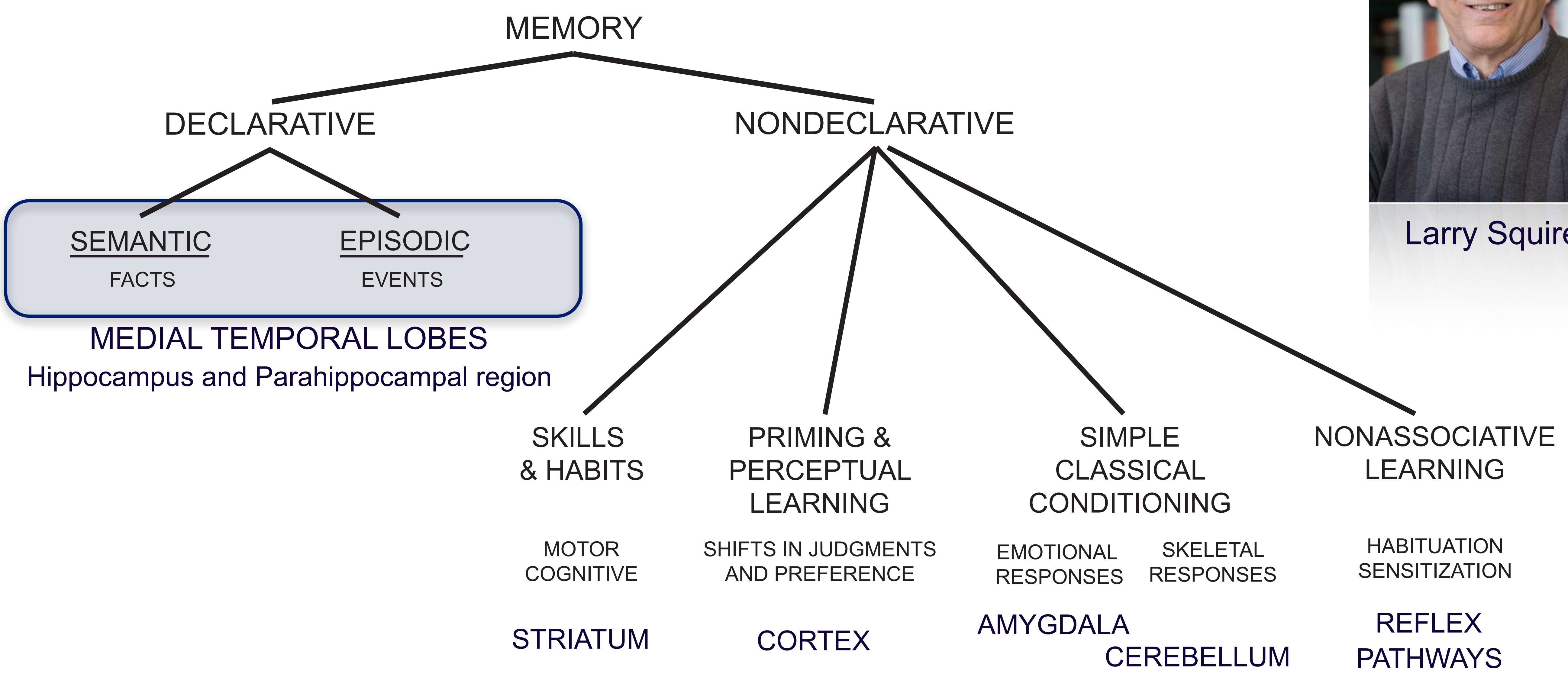


Figure 1 Odor paired associate learning and inferential expression of odor-odor associations. (*A*) Training on odor-odor paired associates. Each training trial consisted of two phases. In the sample phase, the subject was presented with a cup containing a scented mixture of sand and ground rat chow with a buried reward. In the subsequent choice phase, two scented choices were presented. Both choice items involved odors that were different from the sample odor, and which item was baited depended on the identity of the sample. (*B*) Schematic diagram of paired associate training and probe testing. Letters represent odor stimulus items; arrows without question marks indicate trained pairings, whereas arrows with question marks indicate expected transitive and symmetrical choices. Rats are first trained on two overlapping sets of paired associates (*left*). Then (*right*) they are tested for inferential expression in two ways. In the test for transitivity, they are presented with one of two sample cues from the first training set and are required to select between the choice cues from the second set, based on the shared associates of these items. In the test for symmetry or reversibility of the associations, they are presented with one of two choice cues from the second set and required to select the appropriate sample cue from that set. (*C*) Errors to criterion on acquisition of the two sets of paired associates for sham operated and hippocampal subjects. (*D*) Preferences on the test for transitive inference. For these probe trials a preference score was calculated as (X – Y)/(X + Y), where X and Y were the digging times in the transitive and alternate choices, respectively. (*E*) Preferences on the test for symmetrical expression.

Bunsey & Eichenbaum (1996)

MULTIPLE MEMORY SYSTEMS

DECLARATIVE, EPISODIC AND SEMANTIC MEMORY



Adapted from Squire (1992)

DECLARATIVE MEMORY SYSTEM
EPISODIC VS SEMANTIC MEMORY

- Declarative memory:
  - Memories that can be “declared” or made “explicit”
  - Flexible expression
- Two types
  - Episodic (autobiographical) memory
    - Memory for events, personal experiences
    - Memory of the event is tied to the spatial and temporal context in which it occurs
  - Semantic memory
    - Memory for facts, general knowledge of the world
    - Context-independent

DECLARATIVE MEMORY SYSTEM

EPISODIC VS SEMANTIC MEMORY

Patient K.C. (interviewed by Endel Tulving)

Episodic memory

Semantic memory

What we learned: brain damage can selectively impair episodic memory but spare semantic memory

Limitations: Because his brain damage is extensive, we do not know which regions are important. Again, that's where animal models come in…

DECLARATIVE MEMORY SYSTEM

EPISODIC VS SEMANTIC MEMORY

First strong evidence that the hippocampus may be primarily important for episodic memory

Differential Effects of Early Hippocampal Pathology on Episodic and Semantic Memory

F. Vargha-Khadem,* D. G. Gadian, K. E. Watkins, A. Connelly, W. Van Paesschen, M. Mishkin

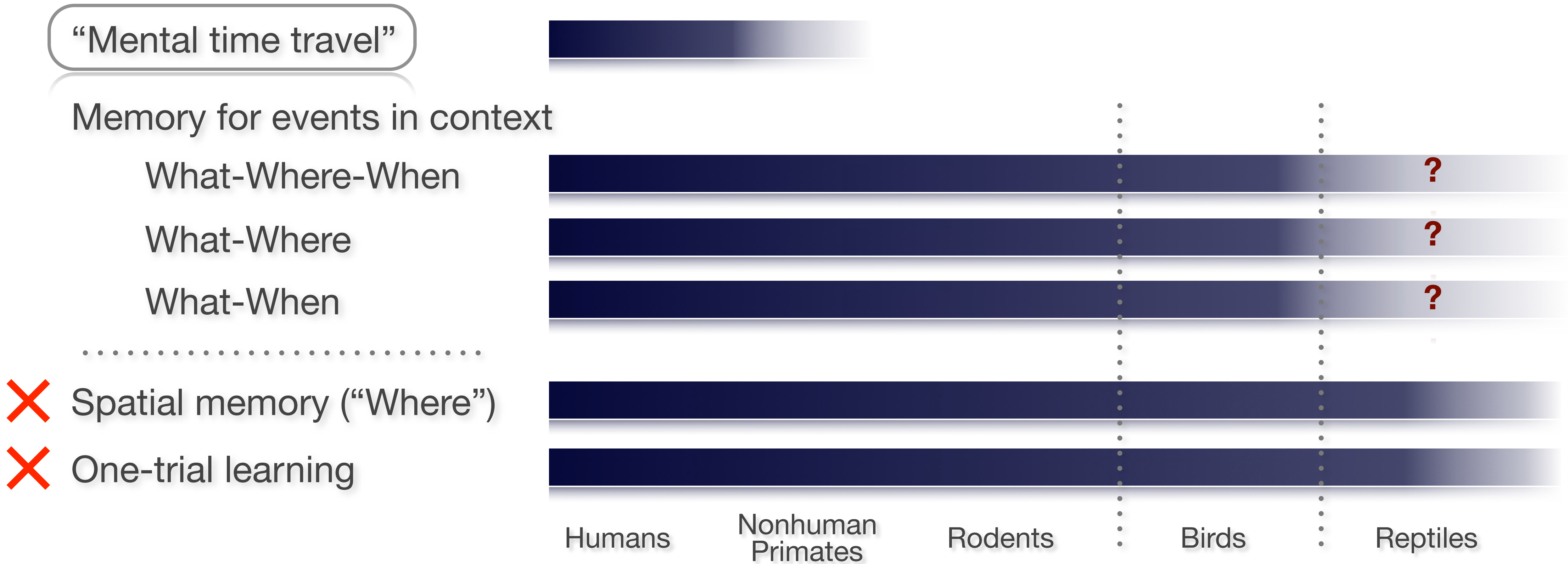
Global anterograde amnesia is described in three patients with brain injuries that occurred in one case at birth, in another by age 4, and in the third at age 9. Magnetic resonance techniques revealed bilateral hippocampal pathology in all three cases. Remarkably, despite their pronounced amnesia for the episodes of everyday life, all three patients attended mainstream schools and attained levels of speech and language competence, literacy, and factual knowledge that are within the low average to average range. The findings provide support for the view that the episodic and semantic components of cognitive memory are partly dissociable, with only the episodic component being fully dependent on the hippocampus.

SCIENCE • VOL. 277 • 18 JULY 1997 • www.sciencemag.org

<u>Limitations</u>: Brain damage occurred early in development, so the brain may have reorganized. Effects may be different in adults.

EPISODIC MEMORY CAPACITY ACROSS SPECIES

DEFINITIONS AND BEHAVIORAL EVIDENCE



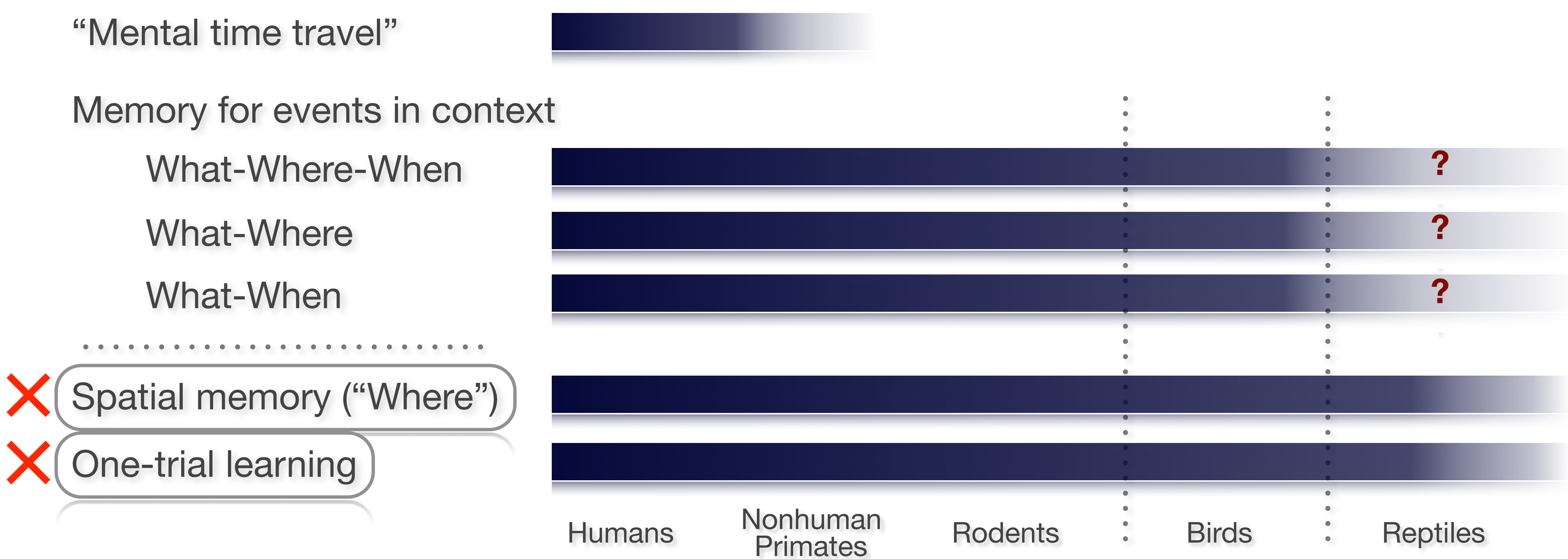
Different definitions of episodic memory

Episodic memory refers to the capacity to "mentally time travel" to re-experience specific events (Tulving, 2002)

Episodic memory involves the capacity to recall information about specific events, along with the spatial and temporal contexts in which they occurred (Tulving, 1972)

EPISODIC MEMORY CAPACITY ACROSS SPECIES

DEFINITIONS AND BEHAVIORAL EVIDENCE



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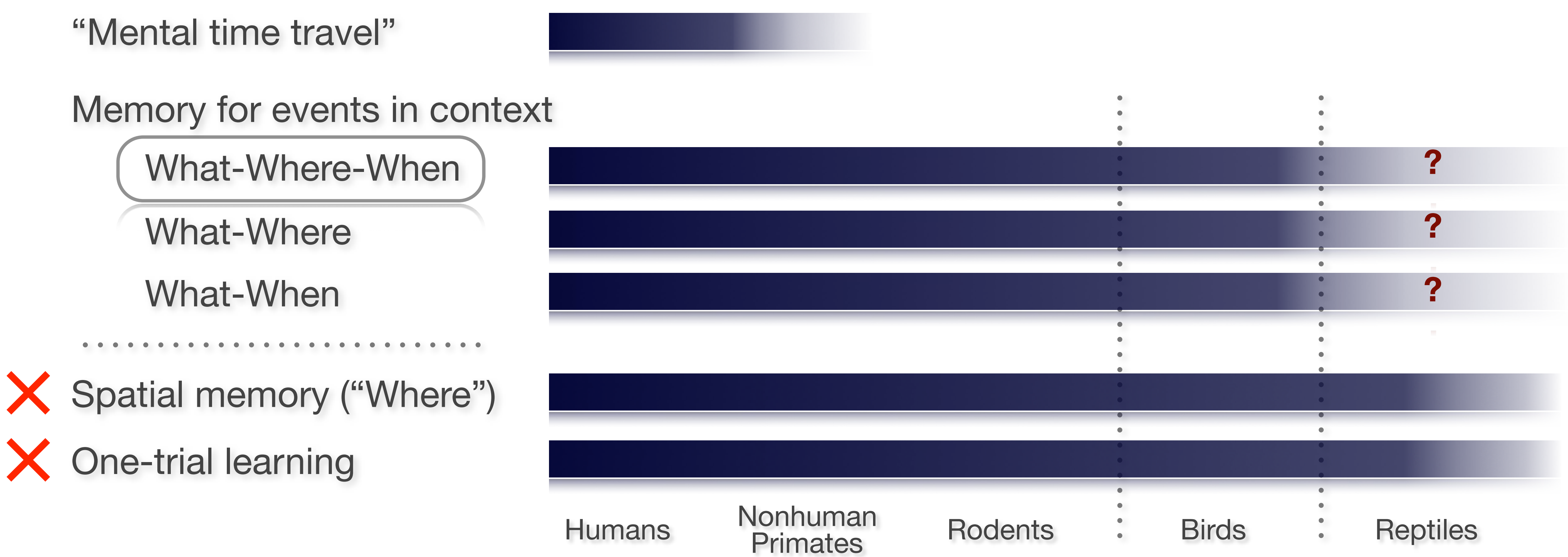
DEFINITIONS AND BEHAVIORAL EVIDENCE



Box 2 | **Behavioural criteria for episodic-like memory in animals**

Content: **recollecting what happened, where and when on the basis of a specific past experience.**
Structure: **forming an integrated ‘what–where–when’ representation.**
Flexibility: **episodic memory is set within a declarative framework and so involves the flexible deployment of information.**

Clayton, Bussey & Dickinson (2003)

EPISODIC MEMORY CAPACITY ACROSS SPECIES

MEMORY FOR “WHAT-WHERE-WHEN”

- First animal model of episodic(-like) memory (Clayton & Dickinson, 1998)

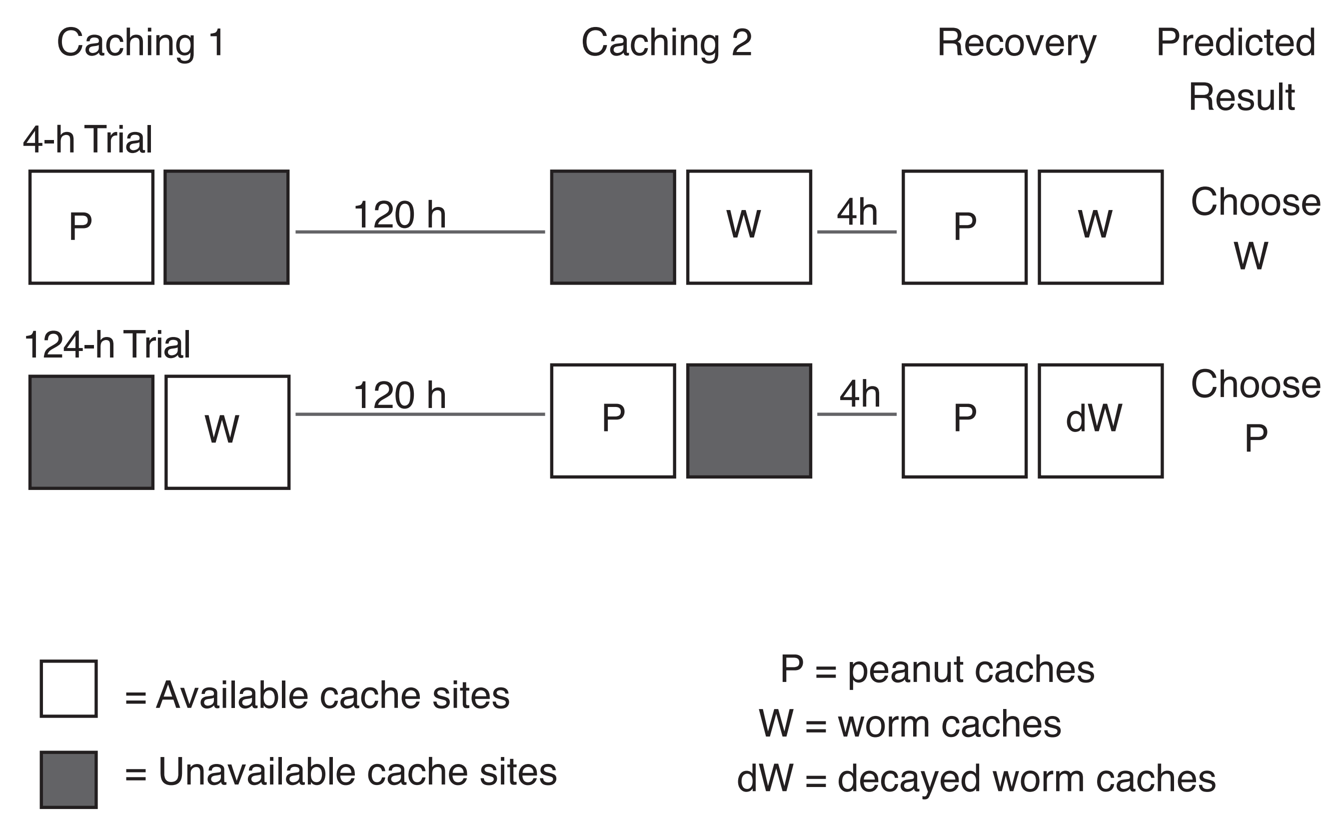
“What-Where-When” memory in scrub jays

“What”: Worm or peanut?

“Where”: Which location?

“When”: 4h or 124h ago?

Experimental design



Clayton & Dickinson (1998)

EPISODIC MEMORY CAPACITY ACROSS SPECIES
MEMORY FOR "WHAT-WHERE-WHEN"

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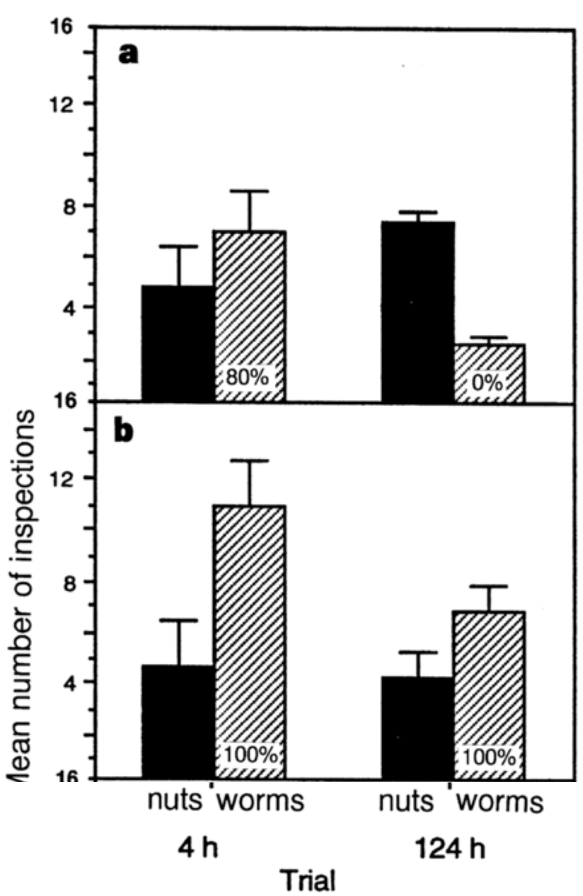
"What-Where-When" memory in scrub jays

"*What*": Worm or peanut?

"*Where*": Which location?

"*When*": 4h or 124h ago?

Number of inspections directed to worms vs peanuts locations



Degrade group
Inspected the peanut side more than worm side at 124h

Replenish group
Inspected the worm side more than the peanut side at 124h

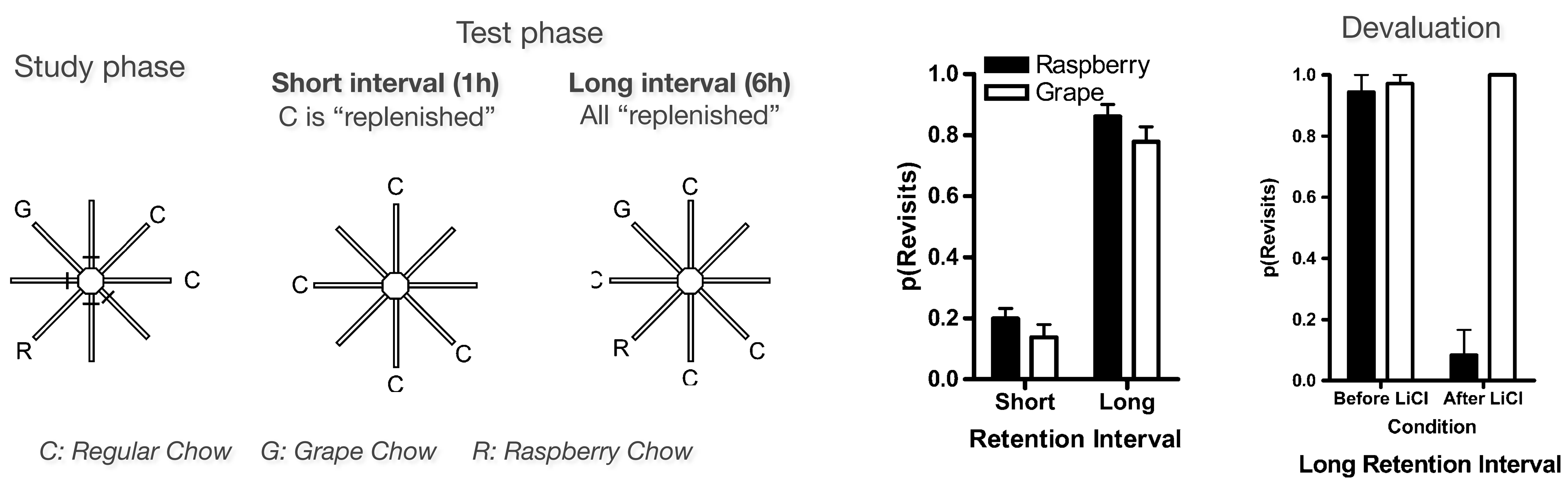
(Pilfer group not shown)

Clayton & Dickinson (1998)

EPISODIC MEMORY CAPACITY ACROSS SPECIES

MEMORY FOR "WHAT-WHERE-WHEN"

- First animal model of episodic(-like) memory (Clayton & Dickinson, 1998)
  - Also evidence in magpies (Zinkivskay et al., 2009), black-capped chickadees (Feeney et al., 2009), and pigeons (Zentall et al., 2008)
- This approach was subsequently adapted for mammals
  - Rats (e.g., Babb & Crystal, 2005, 2006; Eacott et al., 2005; Kart-Teke et al., 2006; Ergorul & Eichenbaum, 2004)



Babb & Crystal (2006)

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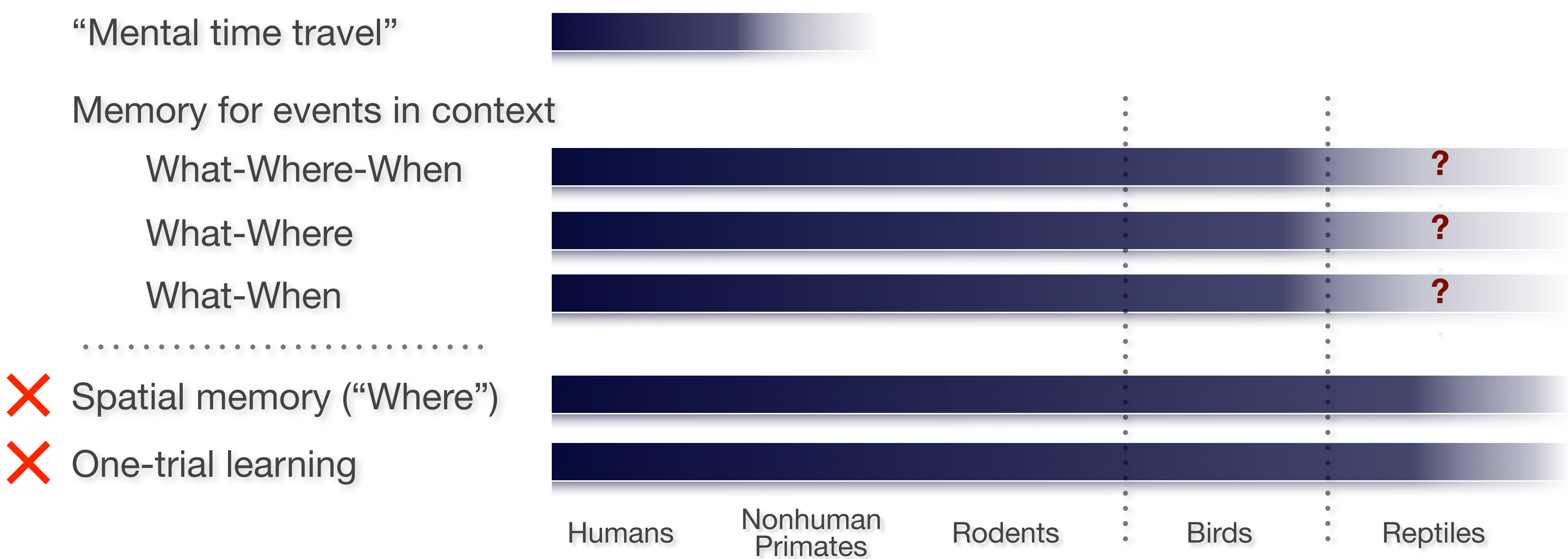
  - Rats (e.g., Babb & Crystal, 2005, 2006; Eacott et al., 2005; Kart-Teke et al., 2006; Ergorul & Eichenbaum, 2004)
  - Mice (e.g., Dere et al., 2005; DeVito & Eichenbaum, 2010; Davis et al., 2012)
  - Meadow voles (Ferkin et al., 2008)
  - Monkeys (e.g., Hoffman et al., 2009)
  - Humans (e.g., Holland & Smulders, 2011; Hayne & Imuta, 2011)

Limitations of What-Where-When model

- Very stringent criterion
- Difficult to investigate its neurobiological basis (e.g., role of hippocampus)

EPISODIC MEMORY CAPACITY ACROSS SPECIES

DEFINITIONS AND BEHAVIORAL EVIDENCE



<u>Updated</u> behavioral criteria for episodic memory in animals

Content: The individual remembers information about the <u>event and its context</u> of occurrence (e.g., memory for “what”, “where” and/or “when”)

Structure: Information about the event and its context is integrated in a single representation

Flexibility: The memory can be expressed to support adaptive behavior in novel situations

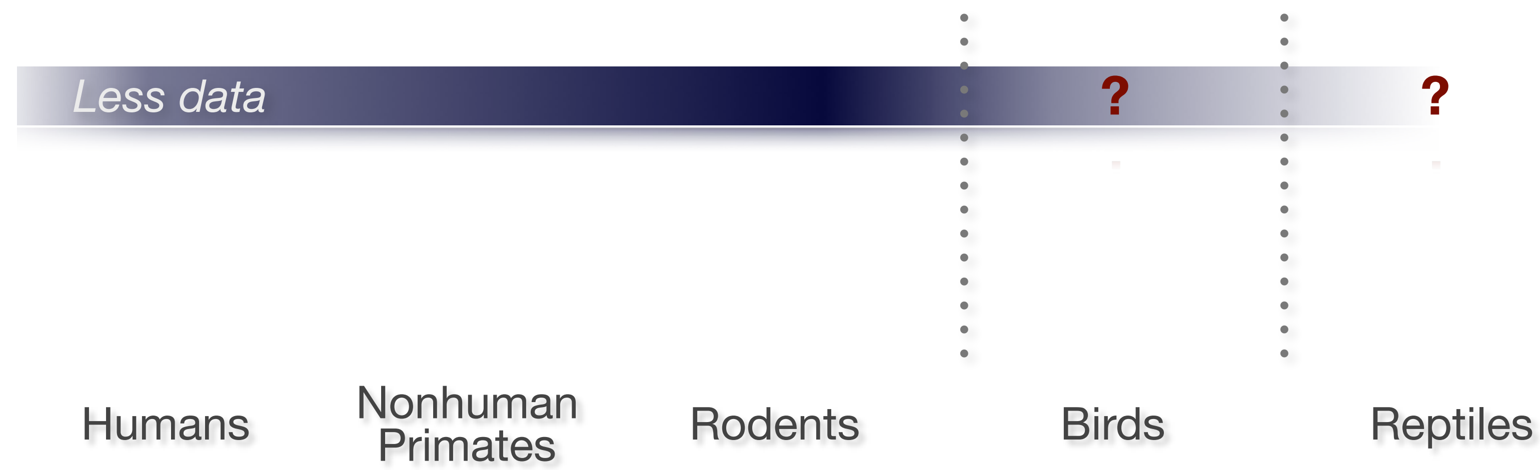
Allen & Fortin (2013)

So… what’s the role of the hippocampus in episodic memory?

ROLE OF THE HIPPOCAMPUS IN EPISODIC MEMORY
INTEGRATION OF EVENT AND CONTEXTUAL INFO

Integration of *What-Where-When*, *What-Where* or *What-When*

Depends on integrity of hippocampus



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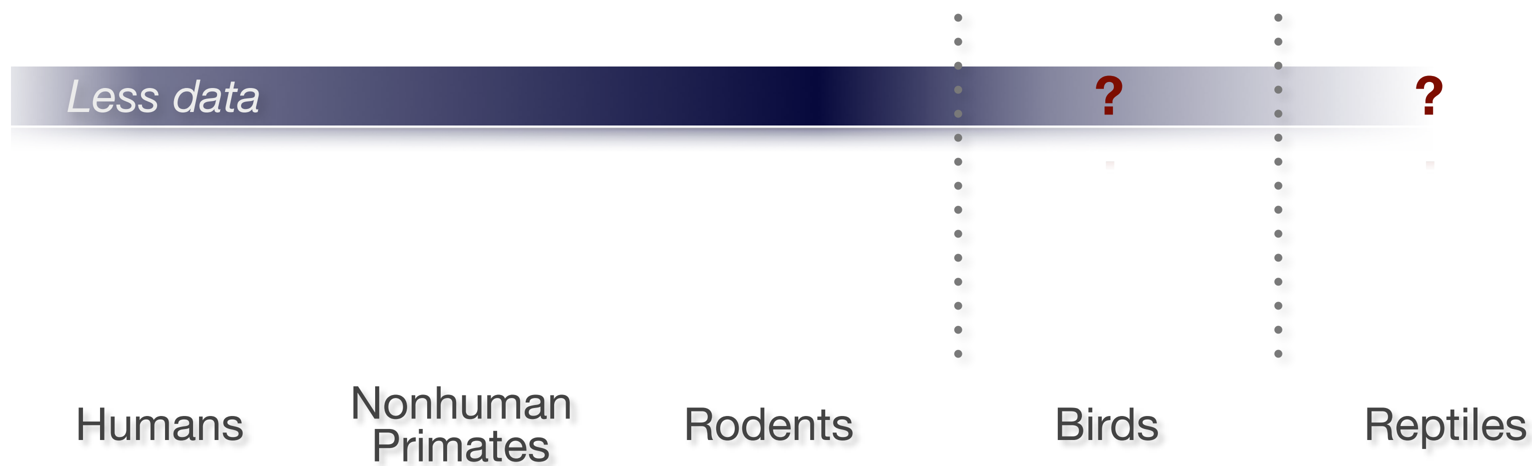
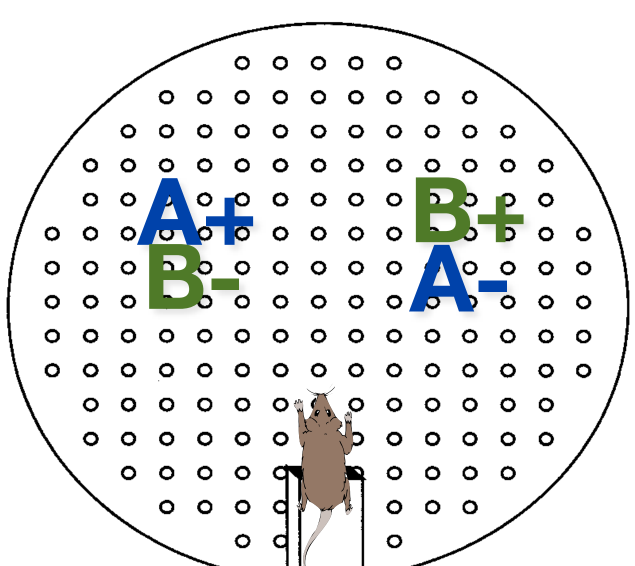
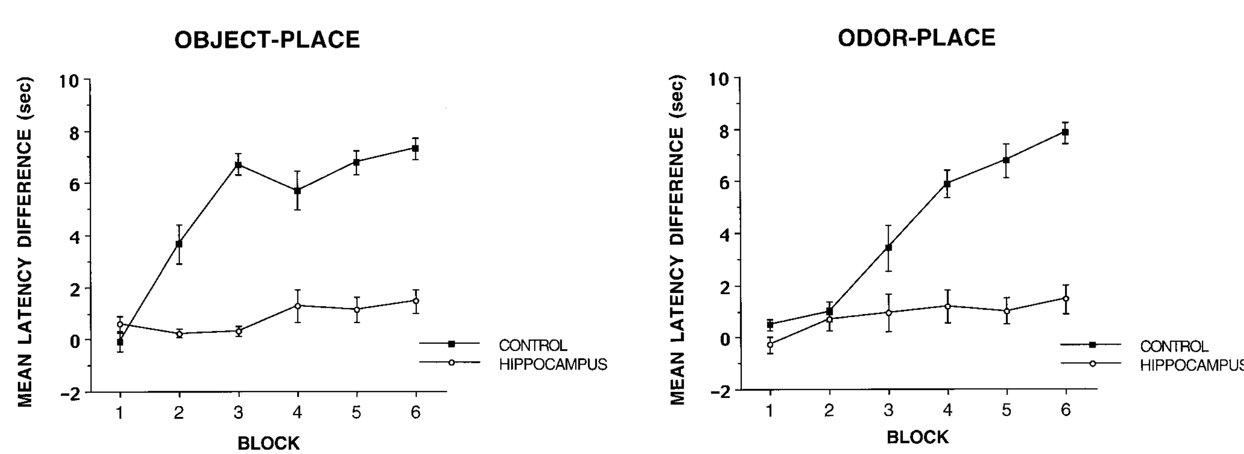


The hippocampus is critical for remembering “what-where” associations

Item (object or odor) is rewarded if in correct location



Rats with damage to the hippocampus are impaired on object-place or odor-place associations



Gilbert & Kesner, 2002

ROLE OF THE HIPPOCAMPUS IN EPISODIC MEMORY

INTEGRATION OF EVENT AND CONTEXTUAL INFO

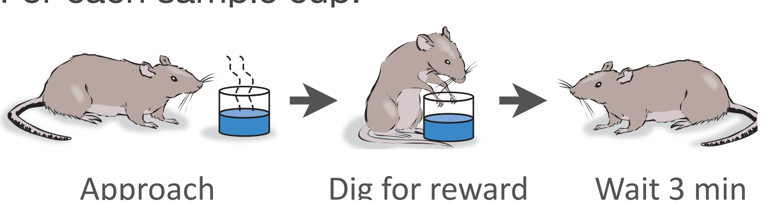
The hippocampus is critical for remembering "what-when" associations

Sequence of events

Odor sequence:

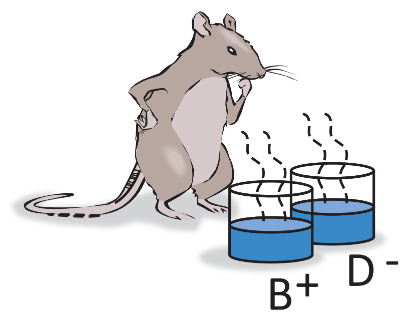
A —2-min→ B —2-min→ C —2-min→ D —2-min→ E

For each sample cup:



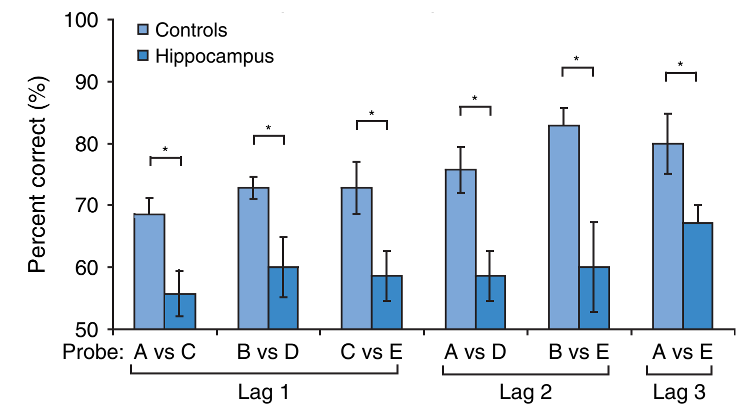
"What-When": Memory for the order in which the items were presented

Present two odors from the sequence



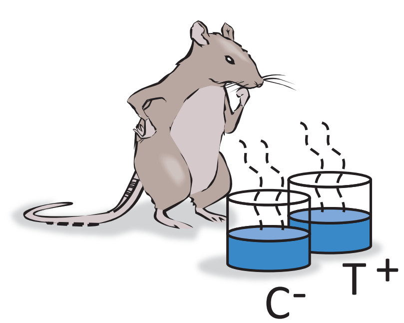
Select odor cup appearing earlier in the sequence

Depends on the hippocampus



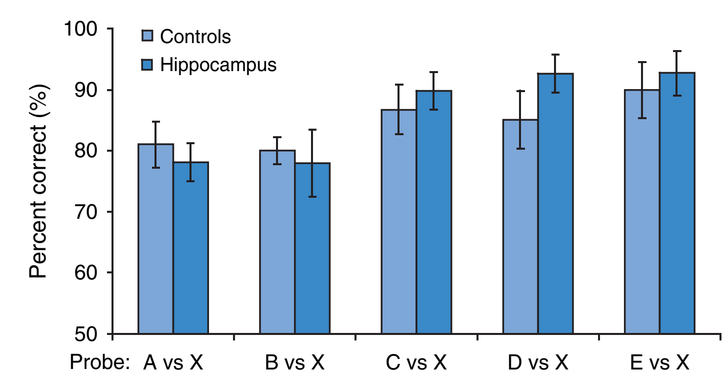
"What": Memory for the items on the list

Show one odor presented in the sequence with another that was not



Select odor cup not presented in the sequence

Does not depend on the hippocampus



Fortin, Agster & Eichenbaum (2002) Nature Neuroscience: 5 , 458-462.

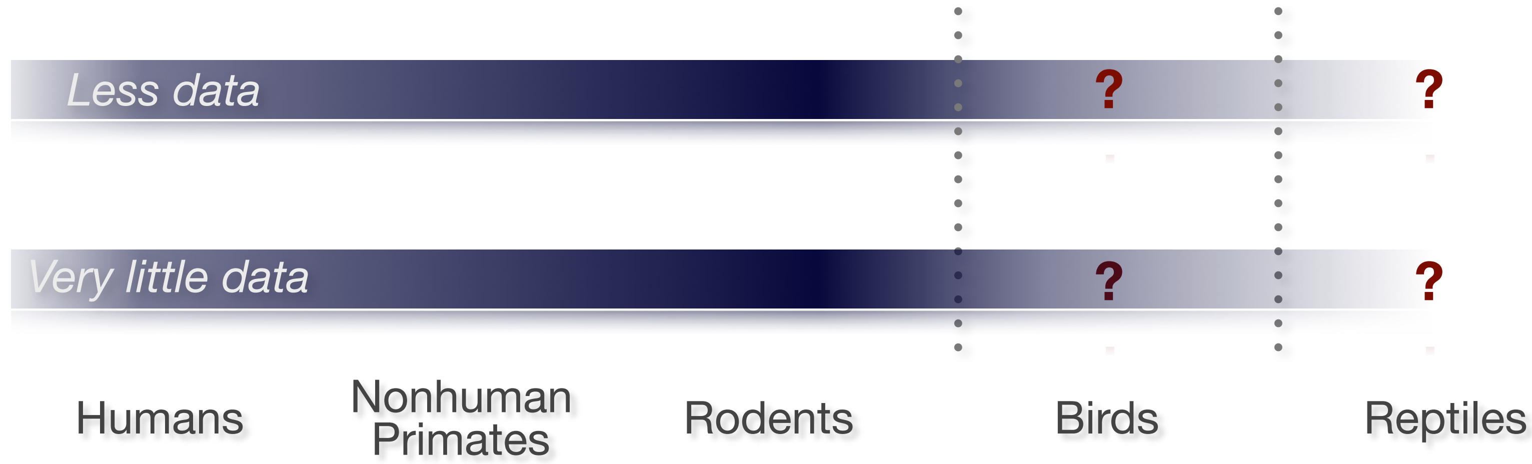
ROLE OF THE HIPPOCAMPUS IN EPISODIC MEMORY

INTEGRATION OF EVENT AND CONTEXTUAL INFO

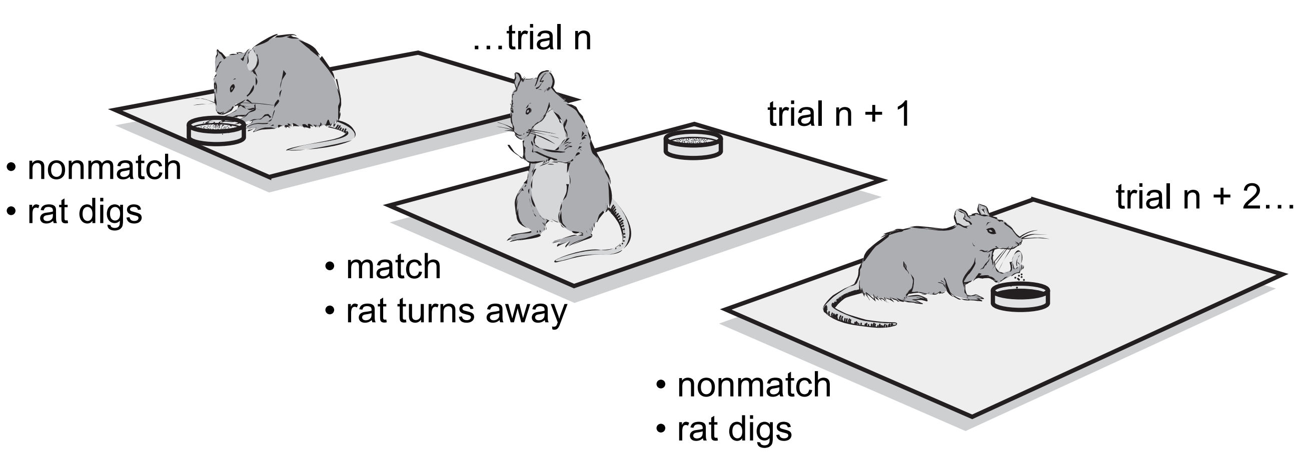
Integration of *What-Where-When*, *What-Where* or *What-When*

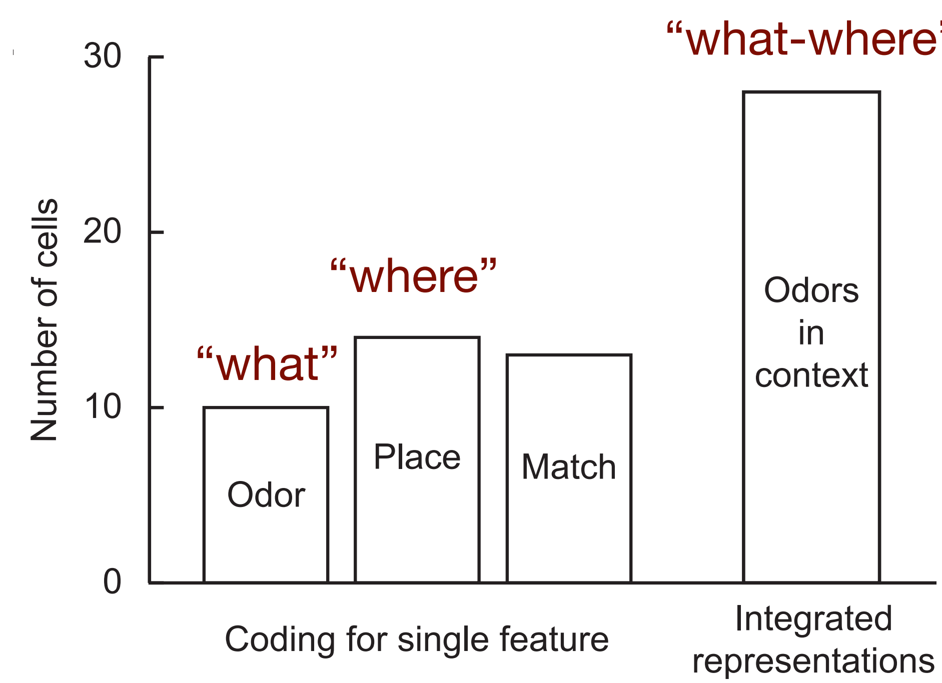
Depends on integrity of hippocampus

Reflected in coding of hippocampal neurons



Integration of "What-Where" in hippocampal neurons





Eichenbaum & Fortin (2009) [Adapted from Wood et al. (1999)]

ROLE OF THE HIPPOCAMPUS IN EPISODIC MEMORY
SPATIAL MEMORY ("WHERE") ≠ EPISODIC MEMORY

- The hippocampus is critical for forming a "spatial map" (O'Keefe & Nadel, 1978)

Rodents: O'Keefe & Nadel, 1978; Morris et al., 1996; Kesner et al., 2004

Monkeys: Smith & Milner, 1981; Buckley & Gaffan, 2000; Lavenex & Lavenex, 2009

Humans: Burgess et al., 2002

Birds: Colombo et al.; 1997 (pigeons); Gagliardo et al., 1999 (pigeons); Hampton & Shettleworth, 1996a,b (Juncos & Chickadees)

Reptiles: Rodriguez et al., 2002 (turtles)

Teleost fishes: Rodriguez et al., 2002 (goldfish)

- Spatial coding
  - Evidence for hippocampal "place cells"

Rodents: O'Keefe & Nadel, 1978

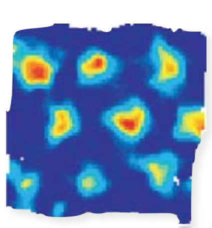
Monkeys: Nishijo et al.,1997; Matsumura et al., 1999; Rolls et al., 2005;

Humans: ???

Bats: Yartsev, Witter & Ulanovsky, 2012

Birds: Bingman & Sharp, 2006, Kahn et al., 2008 (pigeons)

  - Evidence for entorhinal "grid cells"



Rodents: Fyhn et al., 2004; Hafting et al., 2005; Fyhn et al., 2007; Moser et al., 2008;

Monkeys: Killian, Jutras & Buffalo, 2012

Humans: Doeller, Barry & Burgess, 2010

Bats: Yartsev, Witter & Ulanovsky, 2012

Birds: Bingman & Sharp, 2006, Kahn et al., 2008 (pigeons)

Episodic memory requires memory for <u>specific event and its context</u>