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Introduction to animal reinforcement learning

Cognition and Neuroscience
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Reinforcement Learning

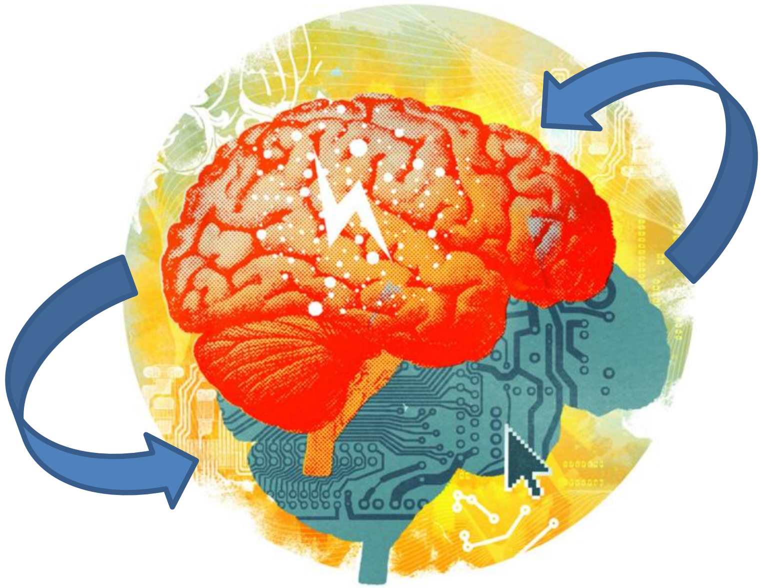
Alongside its important role in the development of deep learning, neuroscience was also instrumental in erecting a second pillar of contemporary AI, stimulating the emergence of the field of reinforcement learning (RL). RL methods address the problem of how to maximize future reward by mapping states in the environment to actions and are among the most widely used tools in AI research (Sutton and Barto, 1998). Although it is not widely appreciated among AI researchers, RL methods were originally inspired by research into animal learning. In particular, the development of temporal-difference (TD) methods, a critical component of many RL models, was inextricably intertwined with research into animal behavior in conditioning experiments. TD methods are real-time models that learn from differences between temporally successive predictions, rather than having to wait until the actual reward is delivered. Of particular relevance was an effect called second-order conditioning, where affective significance is conferred on a conditioned stimulus (CS) through association with another CS rather than directly via association with the unconditioned stimulus (Sutton and Barto, 1981). TD learning provides a natural explanation for second-order conditioning and indeed has gone on to explain a much wider range of findings from neuroscience, as we discuss below.

Here, as in the case of deep learning, investigations initially inspired by observations from neuroscience led to further developments that have strongly shaped the direction of AI research. From their neuroscience-informed origins, TD methods and related techniques have gone on to supply the core technology for recent advances in AI, ranging from robotic control (Hafner and Riedmiller, 2011) to expert play in backgammon (Tesauro, 1995) and Go (Silver et al., 2016).

Neuron
Review 2017

Neuroscience-Inspired Artificial Intelligence

Demis Hassabis,[1,2,*] Dharshan Kumaran,[1,3] Christopher Summerfield,[1,4] and Matthew Botvinick[1,2]



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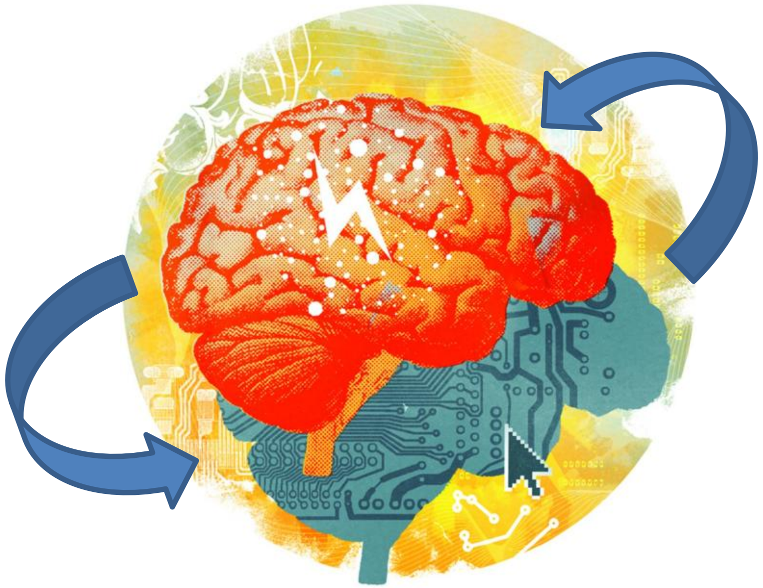

Learning objectives

- Define optimal decision making and the credit assignment problem.
- Define learning and distinguish between non-associative and associative learning.
- Define reinforcement learning and differentiate between primary and secondary reinforcers.
- Explain the three learning systems that enable organisms to make predictions and select appropriate behaviors.
- Define Pavlovian learning and describe how a neutral stimulus becomes a conditioned stimulus through association with an unconditioned stimulus, leading to a conditioned response.
- Describe the processes of acquisition, extinction and generalization of Pavlovian learning.
- Define neural plasticity and Hebbian plasticity and explain how it represents the basis of learning.
- Describe the role of the amygdala and hippocampus in Pavlovian learning.
- Explain Instrumental learning.
- Explain Thorndike's Law of Effect, which states that behaviors are influenced by their consequences.
- Explain how different types of reinforcement shape behavior.
- Describe how different schedules of reinforcement shape behavior.

Decisions, decisions, decisions!

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Optimal decision making:

Decisions, decisions, decisions!

Optimal decision making:

- Maximize rewards
- Minimize punishments

Why is it hard?

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Decisions, decisions, decisions!

Optimal decision making:

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Why is it hard?

- Outcome (i.e. reward/punishment) may be delayed
- Outcomes may depend on a series of actions

Decisions, decisions, decisions!

Optimal decision making:

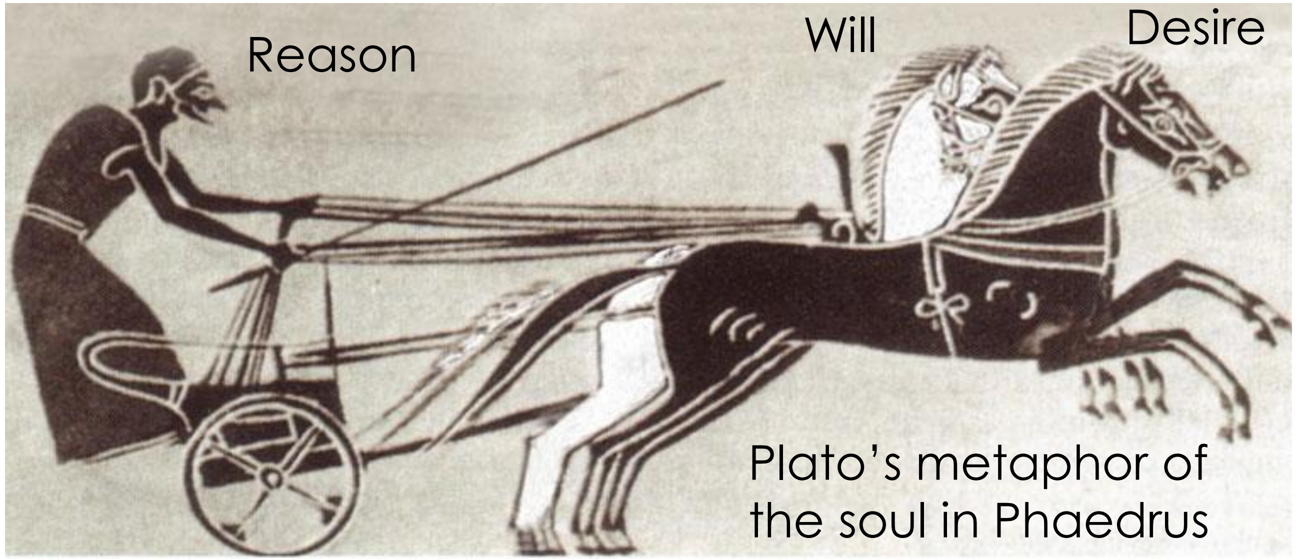
- Maximize rewards
- Minimize punishments

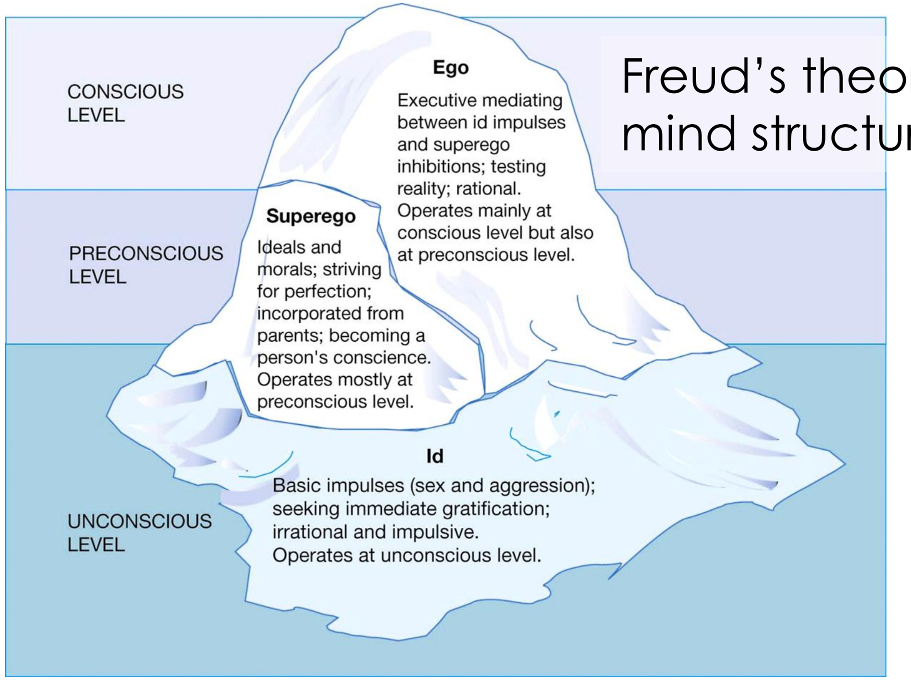
Credit assignment problem

How do you distribute credit for success (or blame for failure) of a decision among the many component structures that could have been involved in producing it?

Multiple systems contribute to learning and controlling decision-making in animals

- Human and animal decisions are governed not by a single unitary controller, but rather by multiple, competing sub-systems
- A given behavior can arise in multiple different ways, which are dissociable psychologically, neurally, and computationally
- Multiple roots that lead to a certain decision/behavior/action selection





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Multiple systems contribute to learning and controlling decision-making in animals

Some definitions

- **Learning**: Enduring change in response or behavior that occurs as a result of experience

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- **Non-associative learning**: Change in response or behavior is caused by learning about the properties of a single stimulus: subject is exposed once or repeatedly to a single type of stimulus

Habituation: a **decrease** in an innate response to a stimulus that is presented repeatedly

Sensitization: an **increase** in an innate response to a stimulus that is presented repeatedly

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- Non-associative learning: Change in response or behavior is caused by learning about the properties of a single stimulus: subject is exposed once or repeatedly to a single type of stimulus
- **Associative learning**: Change in response or behavior is caused by learning about the association of at least **two stimuli or events**
    - **Reinforcement learning**: learning about the association of at least **a neutral stimulus or event** and a **reinforcer**

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Reinforcers are stimuli or events that cause a change in response

Primary reinforcer

- A stimulus that is biologically prepared to elicit a response
- It is biologically relevant
- Can be positive or negative

Secondary reinforcer

- A stimulus that comes to elicit a response following associative learning
- A stimulus that has become relevant following associative learning
- Can be positive or negative

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Three learning systems enable organisms to draw on previous experience to **make predictions** about the world and to **select behaviors** appropriate to those predictions:

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1. a **Pavlovian system** that learns to predict biologically significant events so as to trigger appropriate responses;

Pavlovian system

- Prediction learning
- Learns stimulus-outcome associations

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Instrumental system that comprises

2. a **habitual system** that learns to repeat previously successful actions;
3. a **goal-directed system** that evaluates actions on the basis of their specific anticipated consequences.

Pavlovian system

- Prediction learning
- Learns stimulus-outcome associations

Instrumental system

- Control learning
- Learns action-outcome associations

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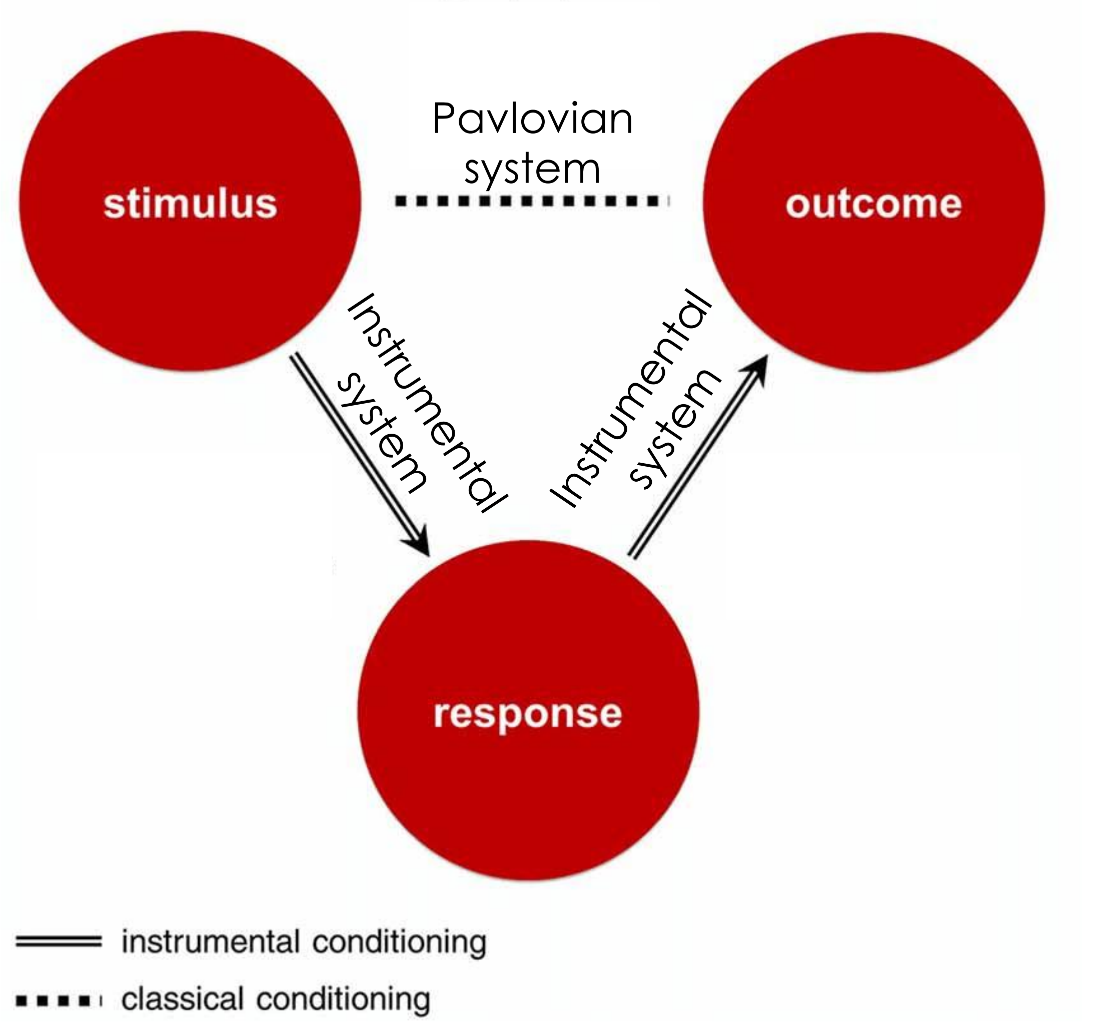
Predictions are for control



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Predictions are for control

If we can predict what situations are associated with rewards we can try to bring those about through our actions

Pavlovian learning

Aka

Pavlovian conditioning

Classical conditioning

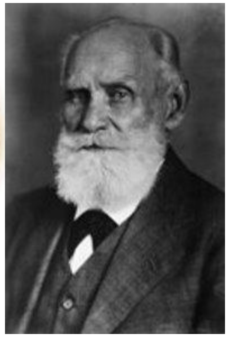
https://youtu.be/xnf8i_IRCcw

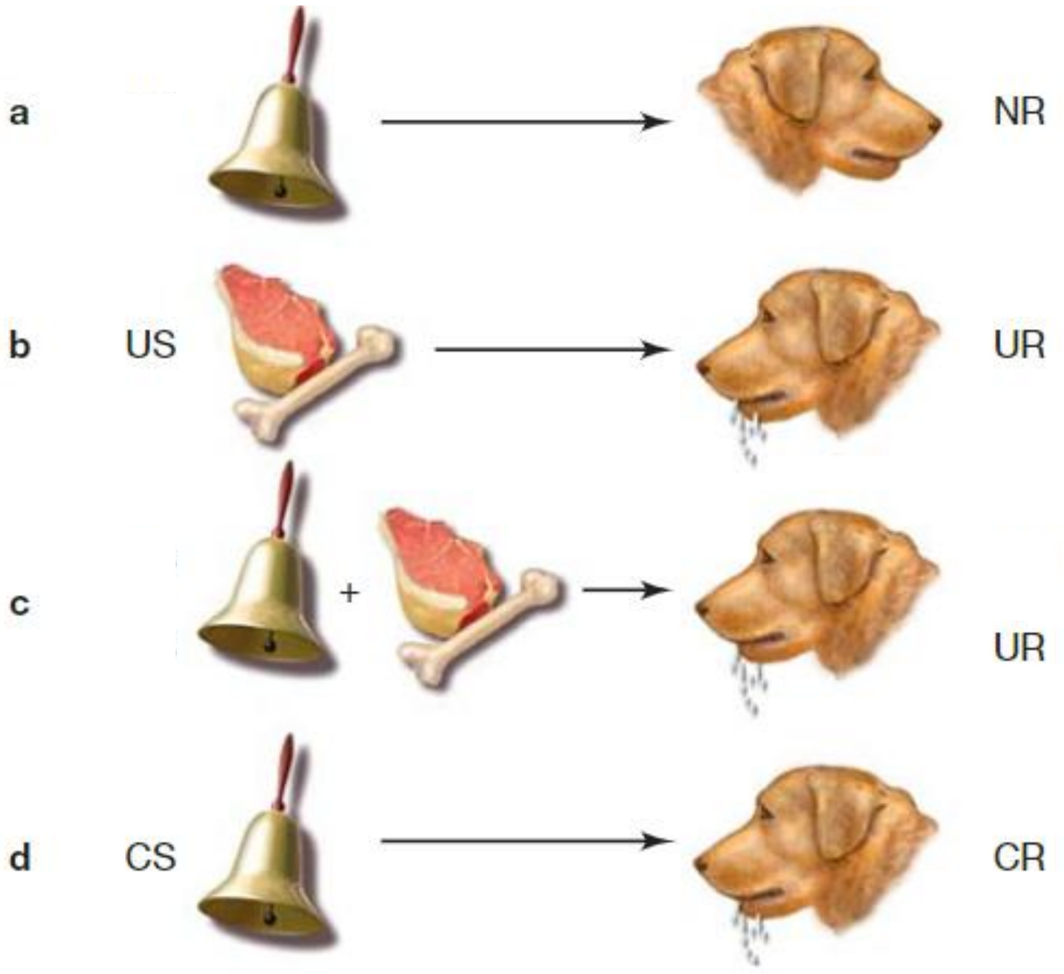
Pavlovian learning system

- Prediction learning
- Learns stimulus-outcome associations
- Learn to predict
    - when reinforces are likely to occur
    - which stimuli tend to precede those reinforcers
- These predictions enable the animal to **emit reflexive responses in anticipation of reinforcers**, instead of responding exclusively in a reactive manner once reinforcers have occurred

Pavlovian learning involves associating a stimulus with an outcome

a) A stimulus is presented that has no meaning to an animal, such as the sound of a bell, there is no response (NR)
b) Presentation of a reinforcer like food (i.e. unconditioned stimulus, US) generates an unconditioned response (UR)
c) When the sound is paired with the food, the animal learns the association
d) the newly conditioned stimulus (CS) alone can elicit the response, which is now called a conditioned response (CR)

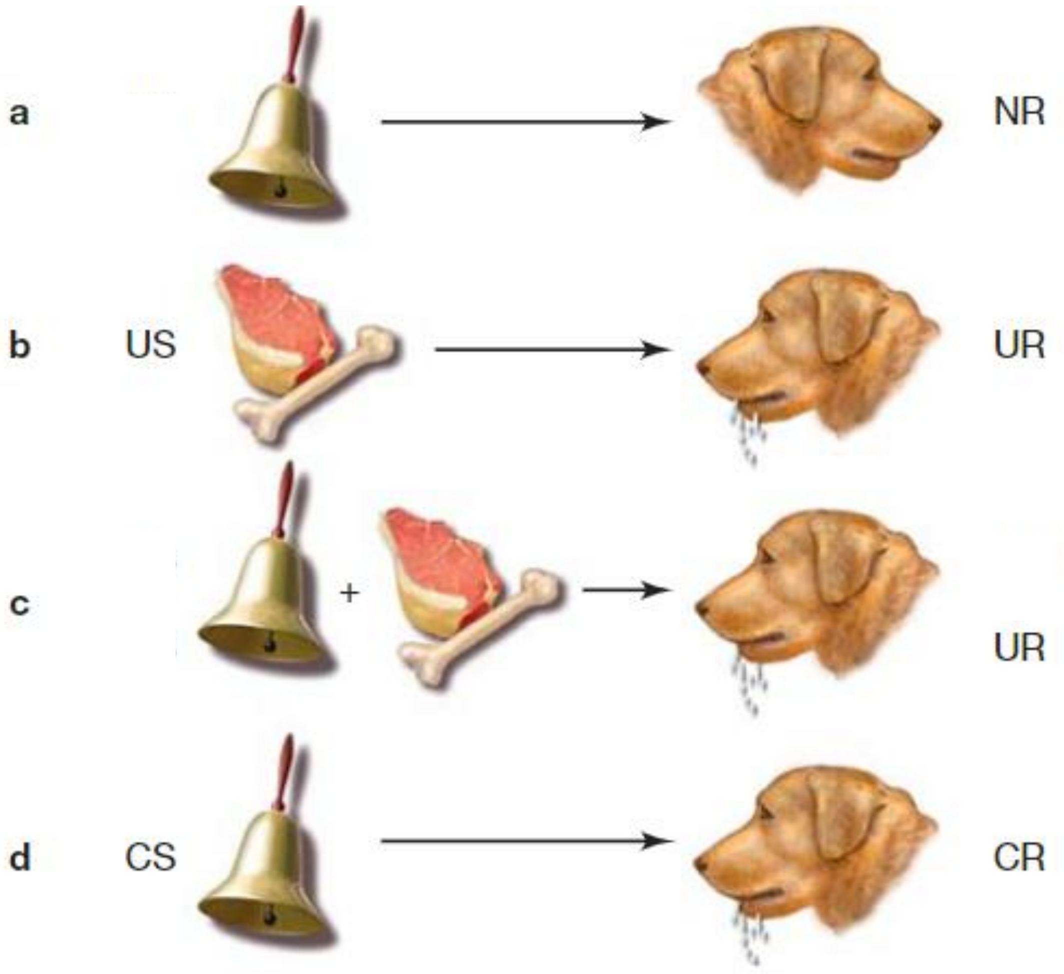




Ivan Pavlov (1849–1936) received a Nobel Prize after first demonstrating this type of learning with his dogs

Pavlovian learning involves associating a stimulus with an outcome

- The unconditioned response (UR) takes place with no learning.
- The conditioned response (CR) must be learned
- Although some conditioned response are identical to the response elicited by the associated outcome (e.g., salivation to food), others are distinct from those that occur in response to the predicted outcome (such as orienting to a visual cue predicting food as opposed to chewing in response to the food itself), perhaps reflecting the fact that the behavior that would be adaptive in preparation for the arrival of an event is sometimes different from that required following its onset



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Pavlovian learning involves associating a stimulus with an outcome

- Watson proposed that psychology should study only **observable behavior**. All talk of mental processes, which cannot be observed (e.g. emotions), should be avoided. → founder of Behaviorism

- Learning was the key, everybody had the same neural equipment on which learning could build.

- The brain as a **blank slate** upon which to build through learning and experience.

John B. Watson (1878–1958)

Pavlovian learning involves associating a stimulus with an outcome

https://youtu.be/FMnhyGozLyE

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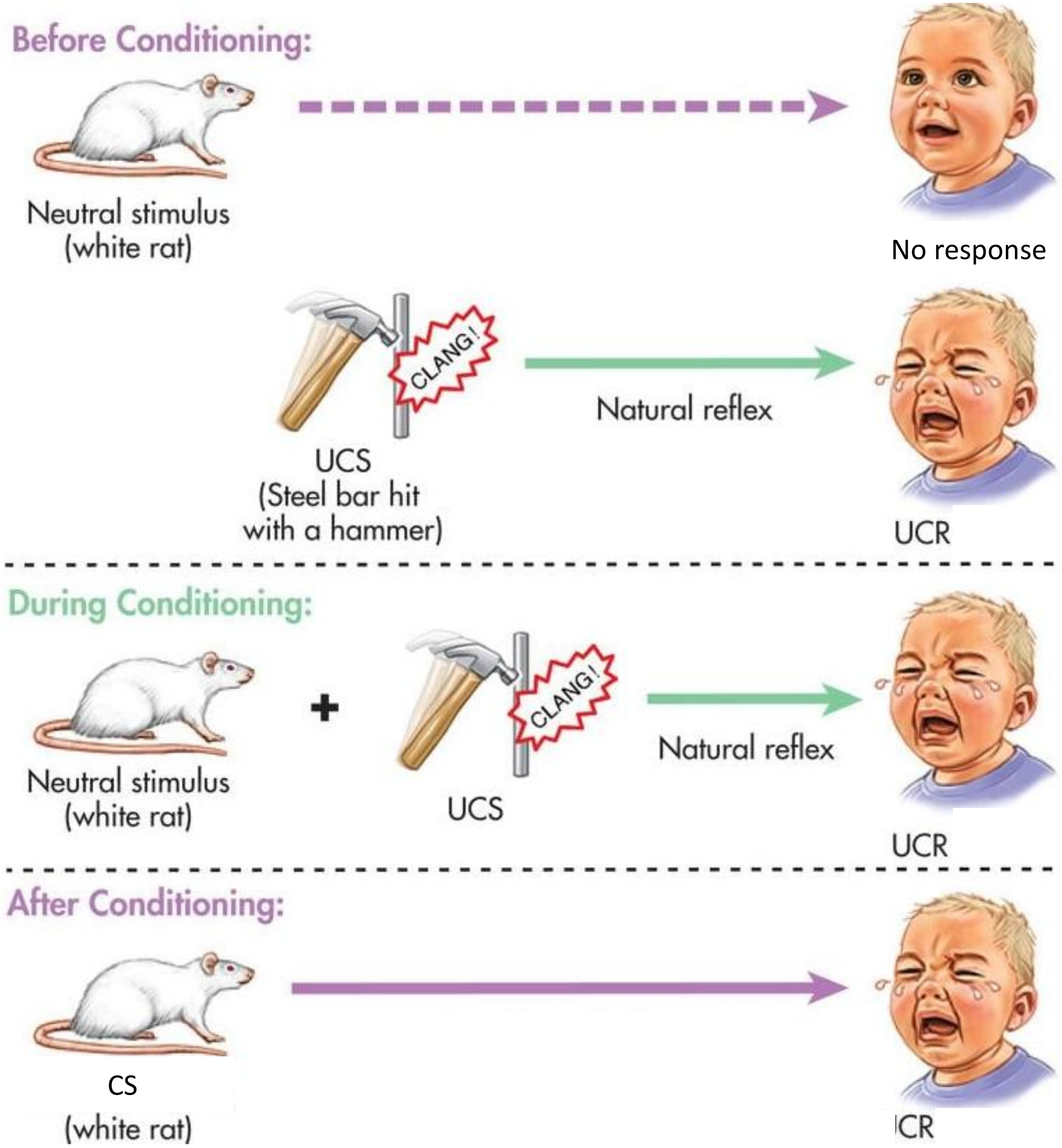
Pavlovian learning involves associating a stimulus with an outcome

Little Albert experiment (1920)



Unconditioned stimulus (UCS)
Unconditioned response (UCR)
Conditioned stimulus (CS)
Conditioned response (CR)

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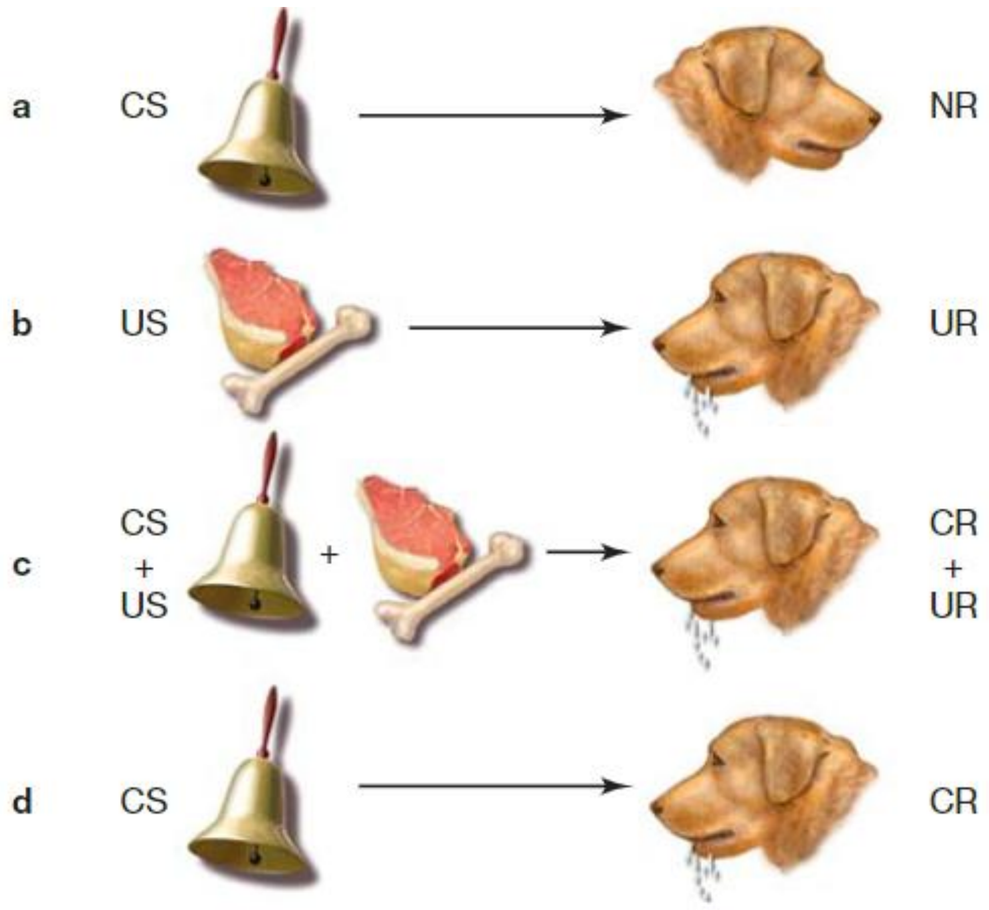
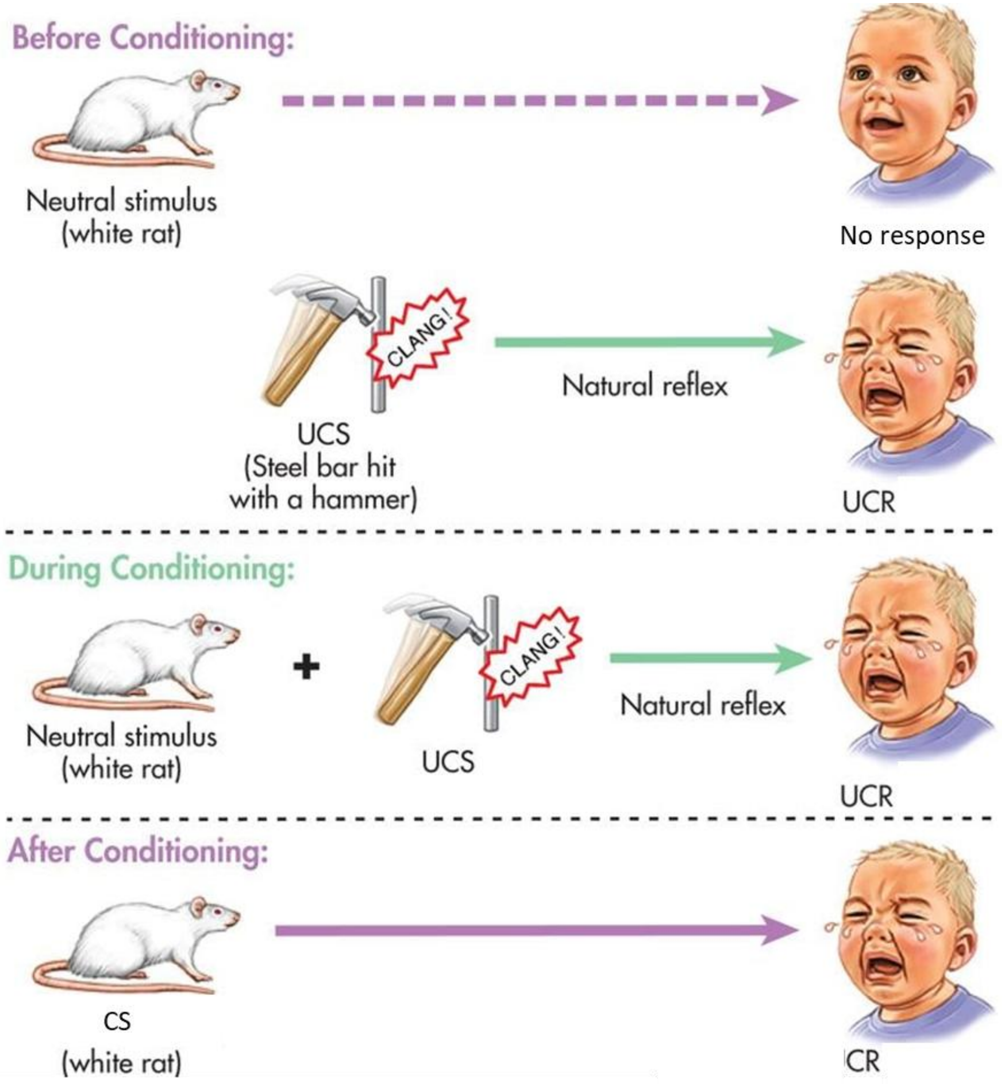
The nature of the outcome triggers different conditioned responses

Appetitive Unconditioned Stimulus



Aversive Unconditioned Stimulus

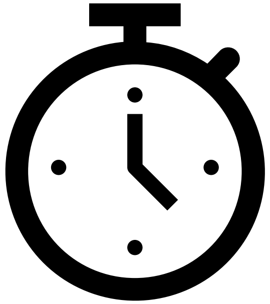


Pavlovian learning in everyday life

Can you come up with some examples?

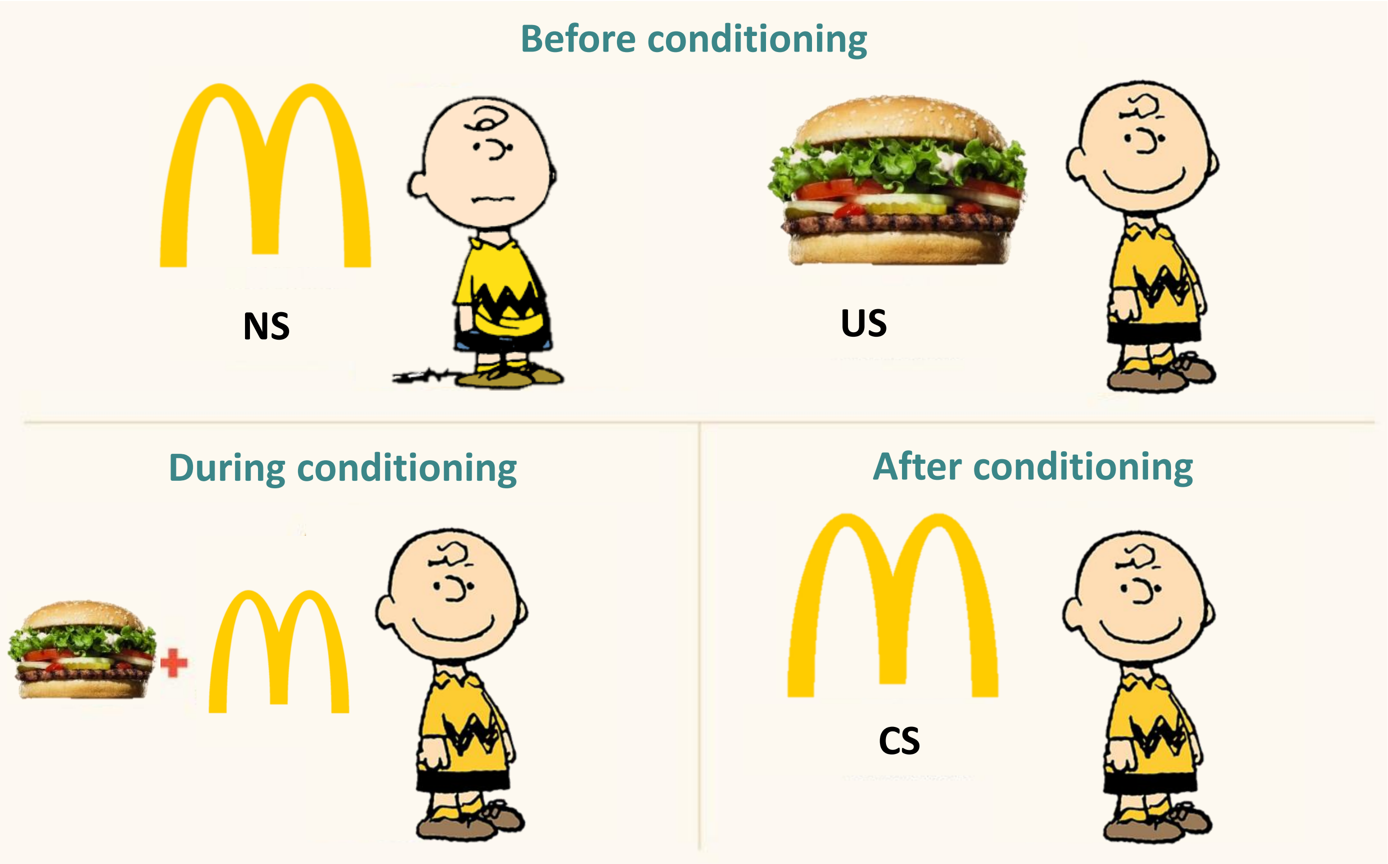
Discuss in pairs:

- Examples of Pavlovian learning
- Identify the
  - conditioned stimulus
  - unconditioned stimulus
  - conditioned response
  - unconditioned response



5 minutes

Pavlovian learning in everyday life



Different classes of conditioned responses

Response involve the whole organism, and can be

- Physiological
- Behavioral
- Change in subjective experience
    - Explicit awareness of CS-US contingency
    - Changes in liking of the CS

Unconditioned Stimulus (US)

Unconditioned response (UR)

Conditioned Stimulus (CS)

Conditioned response (CR)

Physiological conditioned responses are regulated by the autonomic nervous system

Most commonly measured are:

- **Skin conductance response** → increases during CS presentation
- **Pupil response** → dilates during CS presentation
- **Cardiac response** → slows down during CS presentation

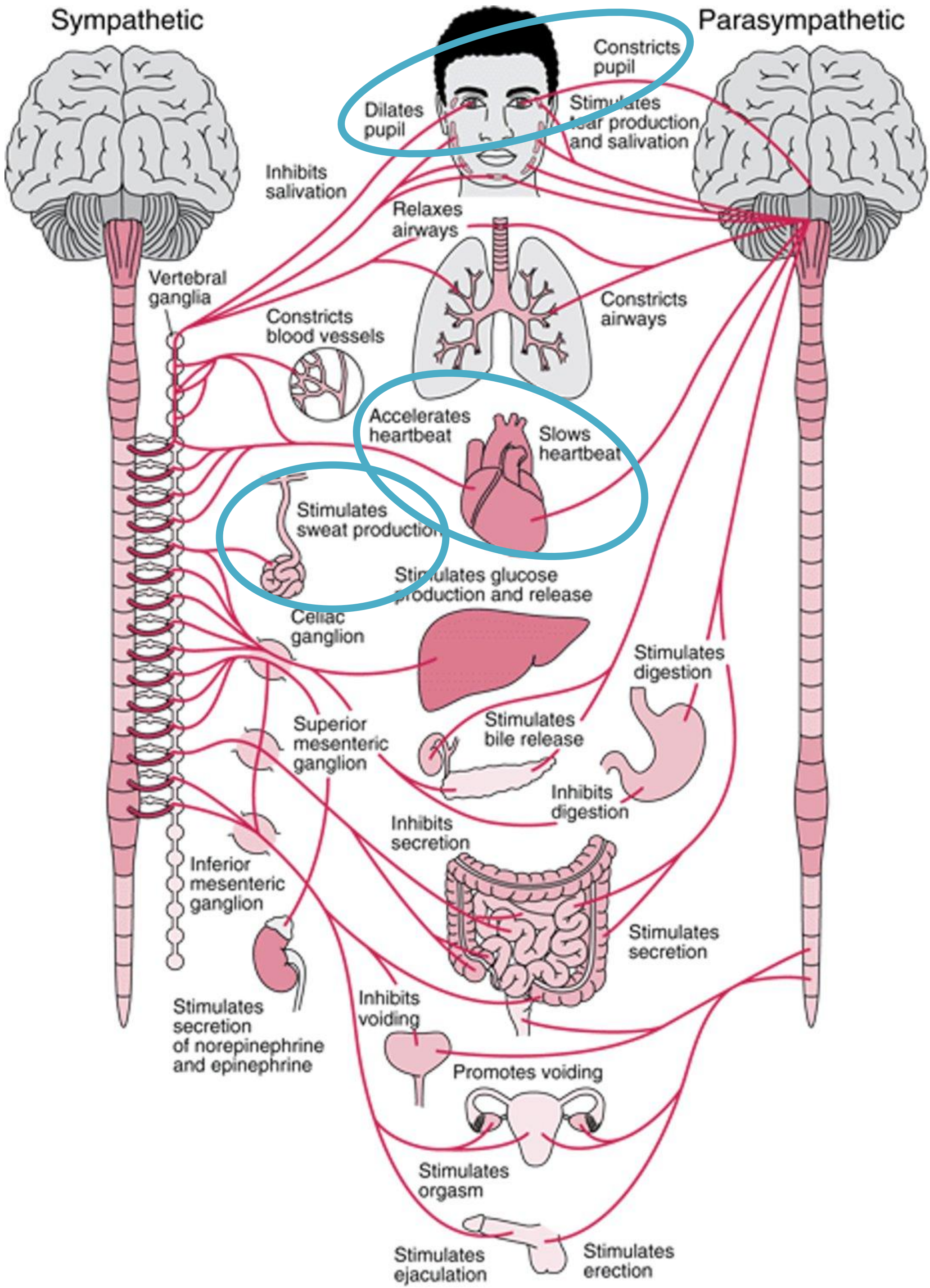
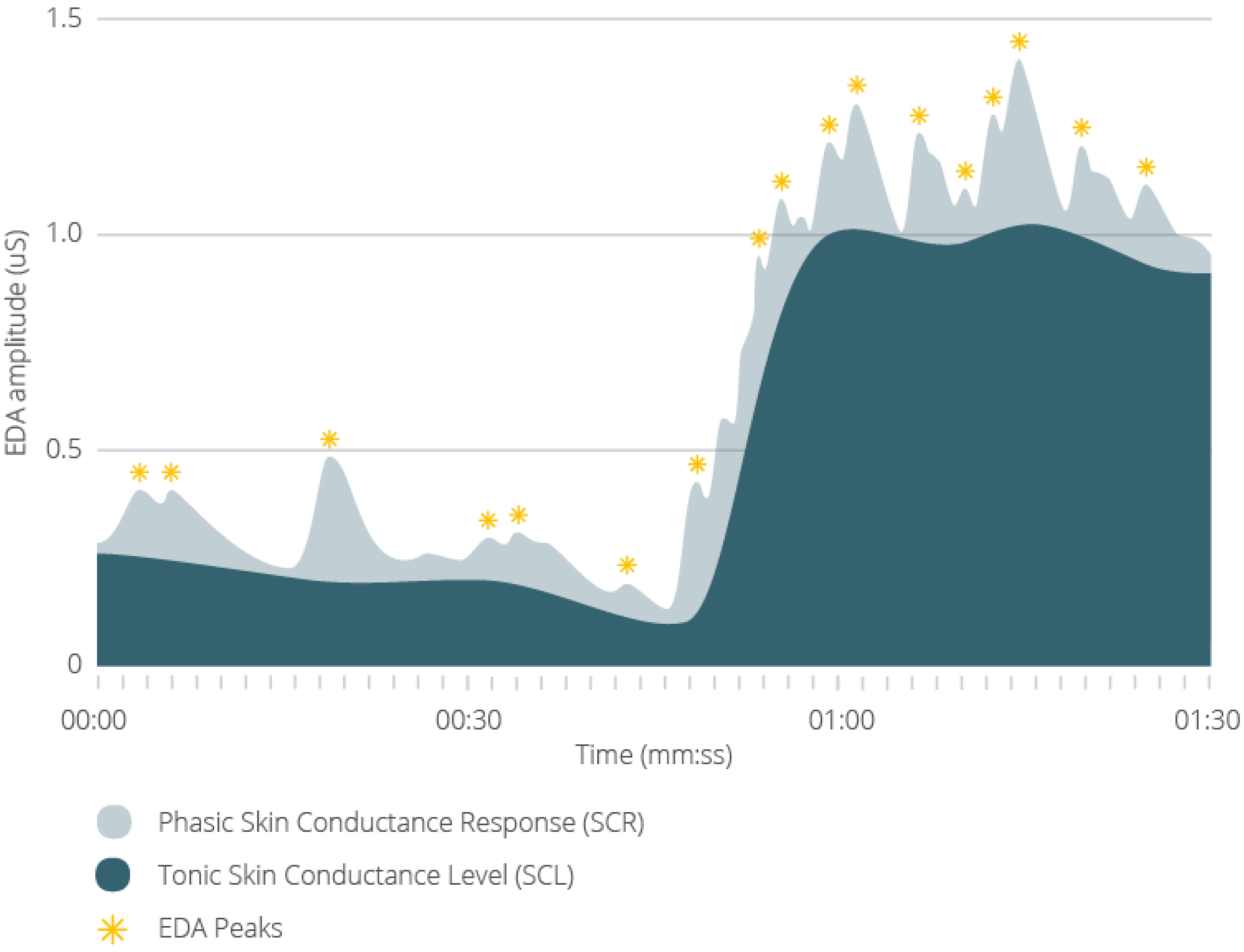
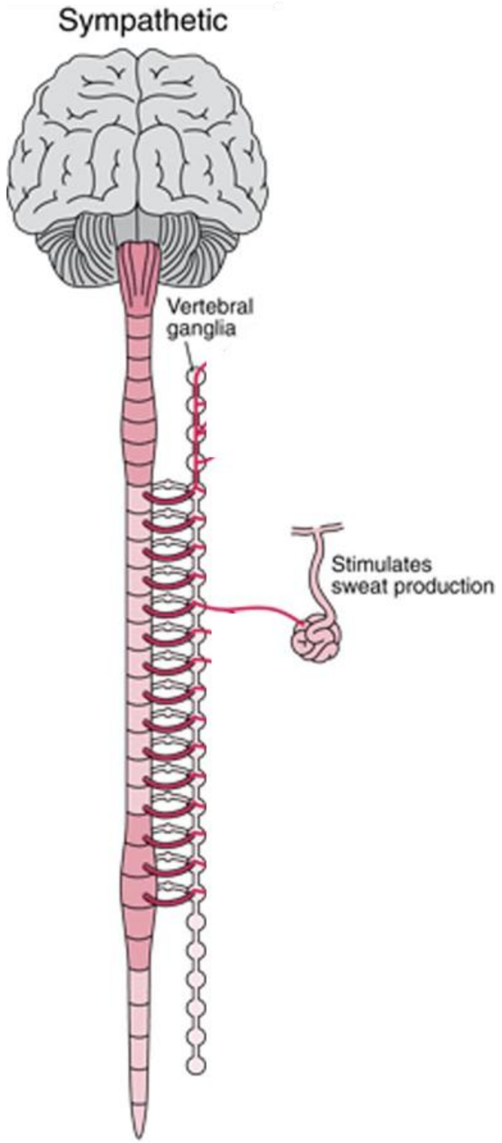


Illustration of changes in electrodermal response over minutes



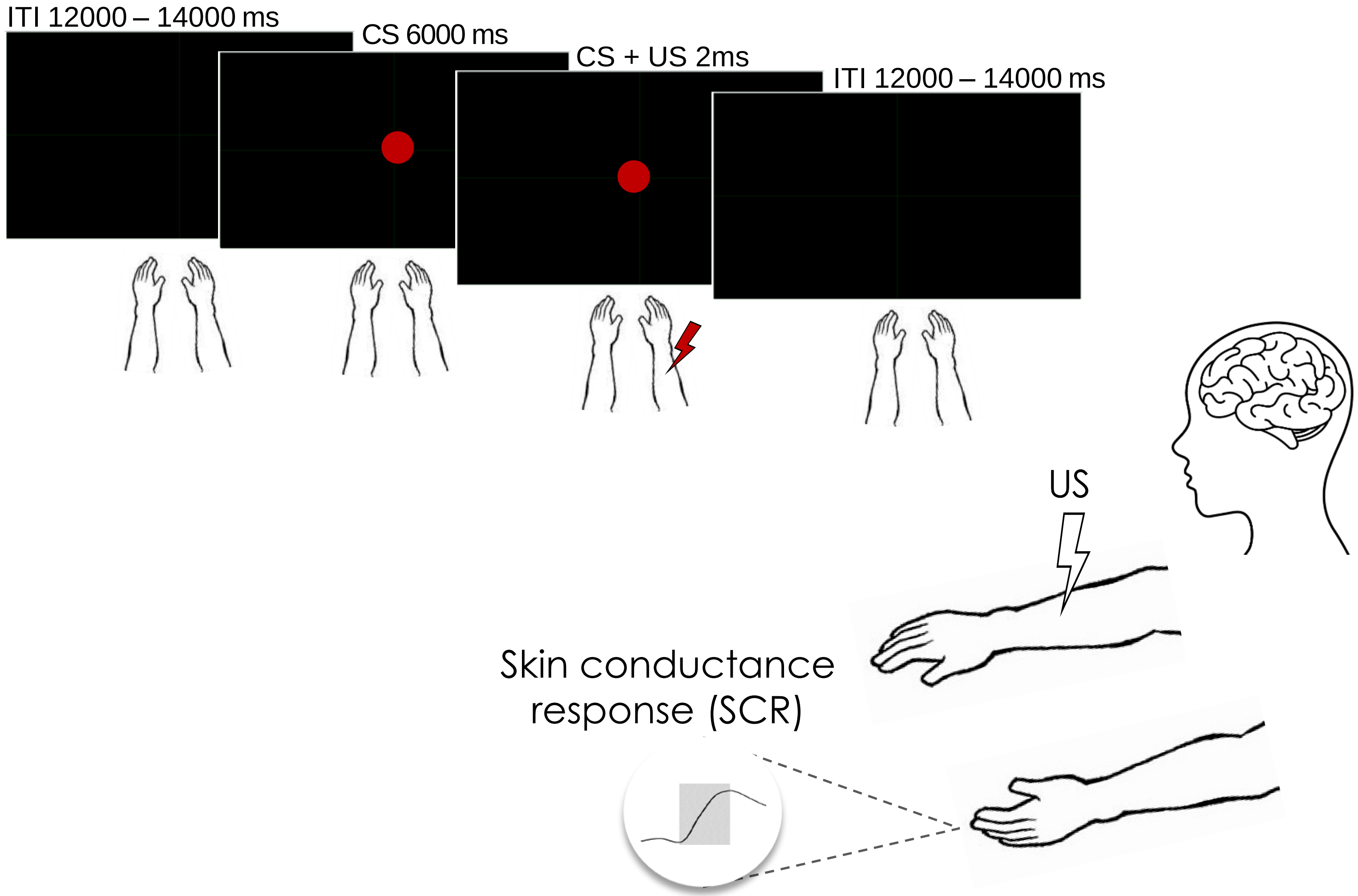


Example of a Pavlovian threat/fear conditioning experiment on humans

Example from a Pavlovian threat/fear conditioning experiment on humans

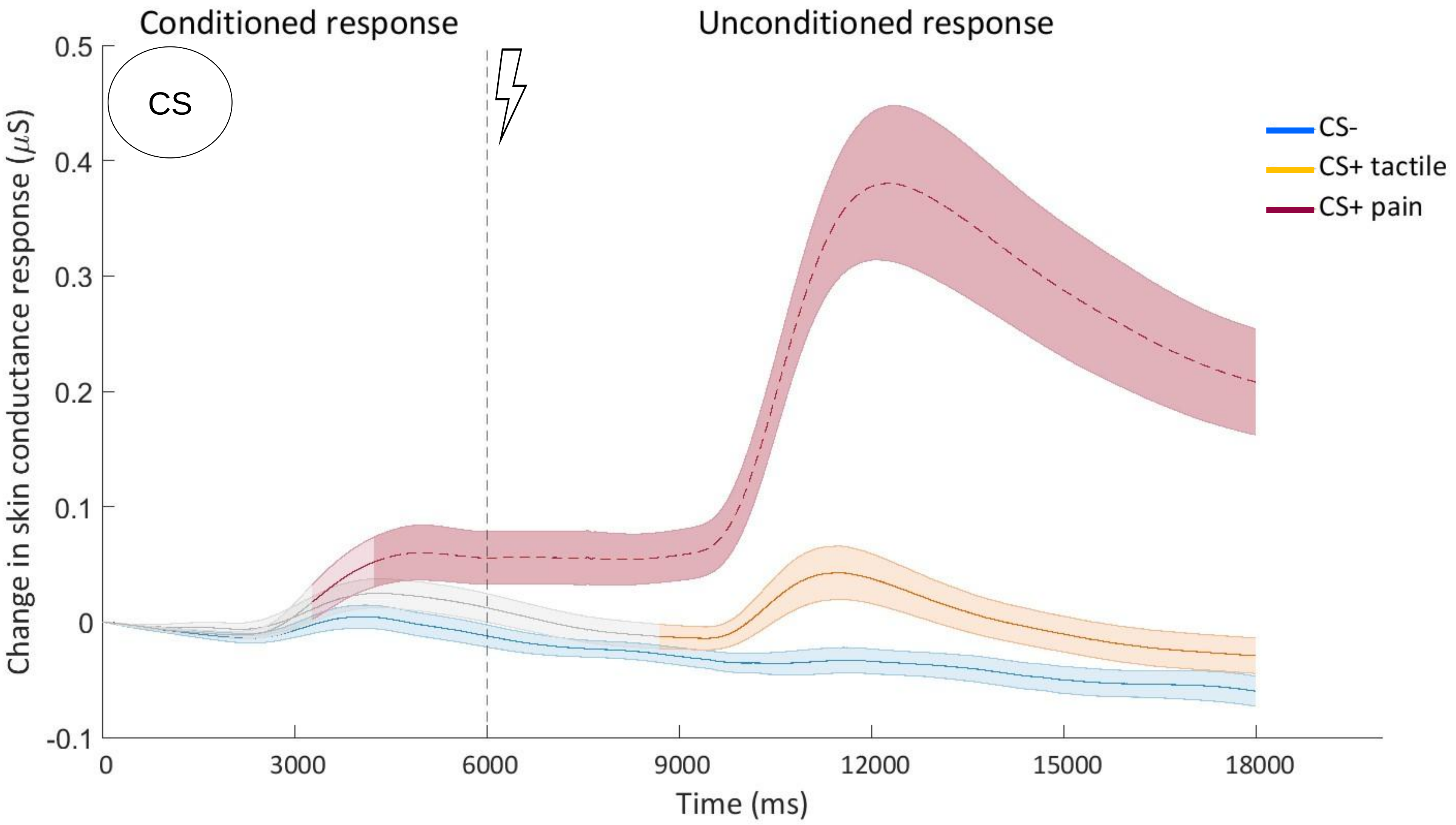
Conditioned stimuli (CS)	Unconditioned stimuli (US)
CS+ Pain	Painful
CS+ Tactile	Tactile
CS-	Nothing

Experimental trial structure



 Dalbagno et al., in preparation

Average skin conductance response to CS+painful, CS+tactile and CS-



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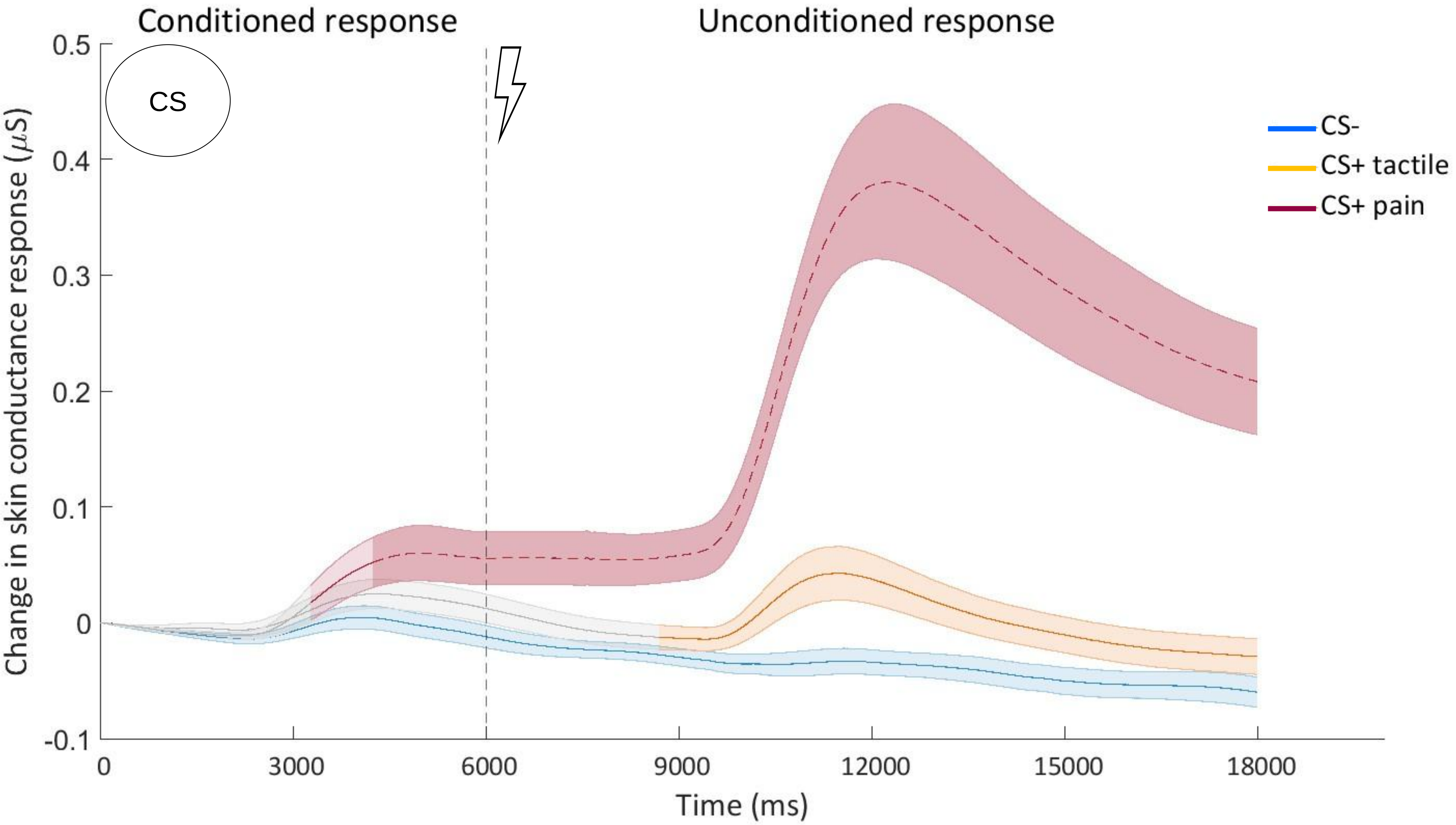
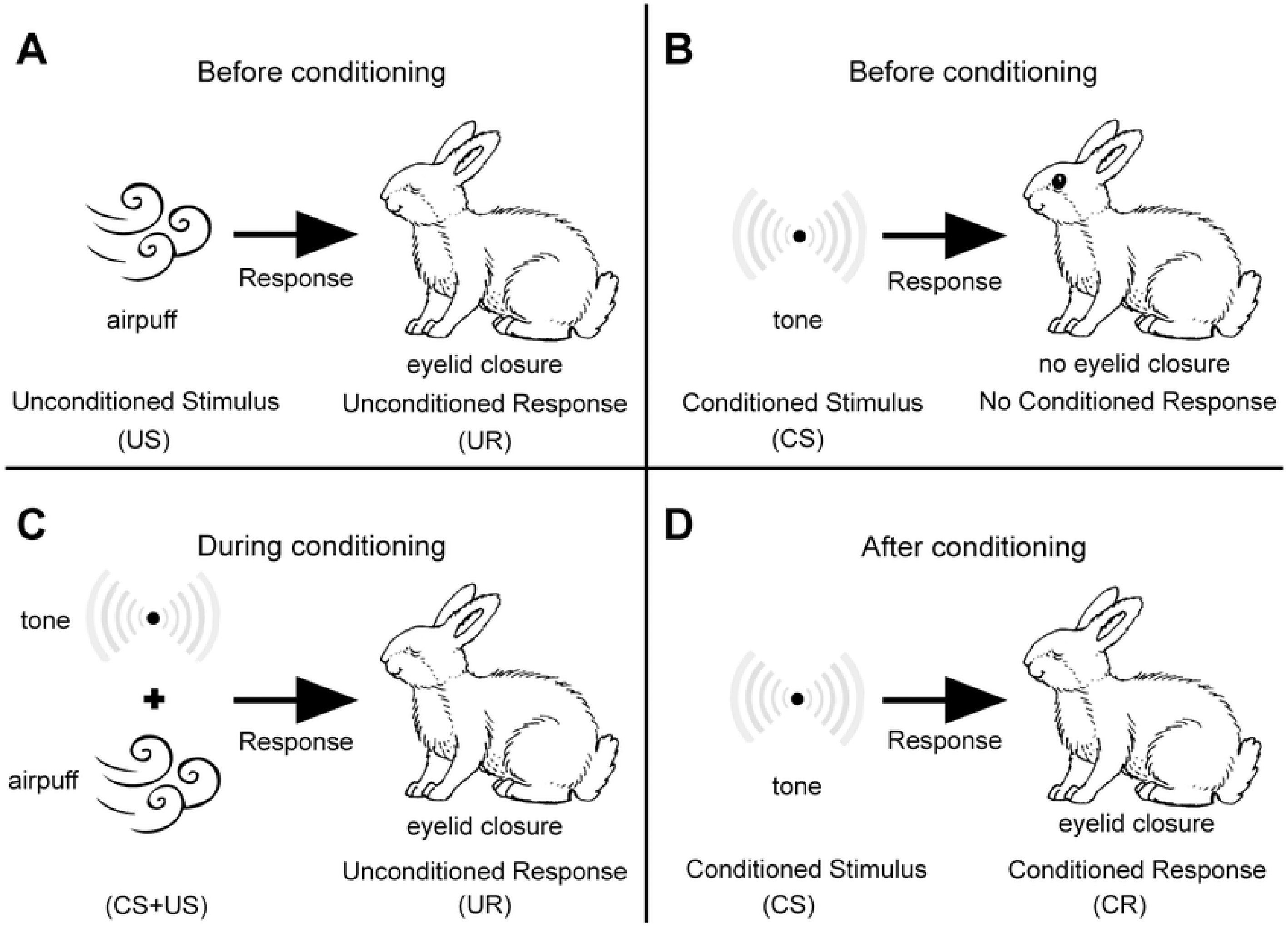


Dalbagno et al., in preparation

Behavioral conditioned responses involve motor reflexes or reflexive/stereotyped behaviors



Sutton, R. S., & Barto, A. G. (2018). Reinforcement learning: An introduction. MIT press.

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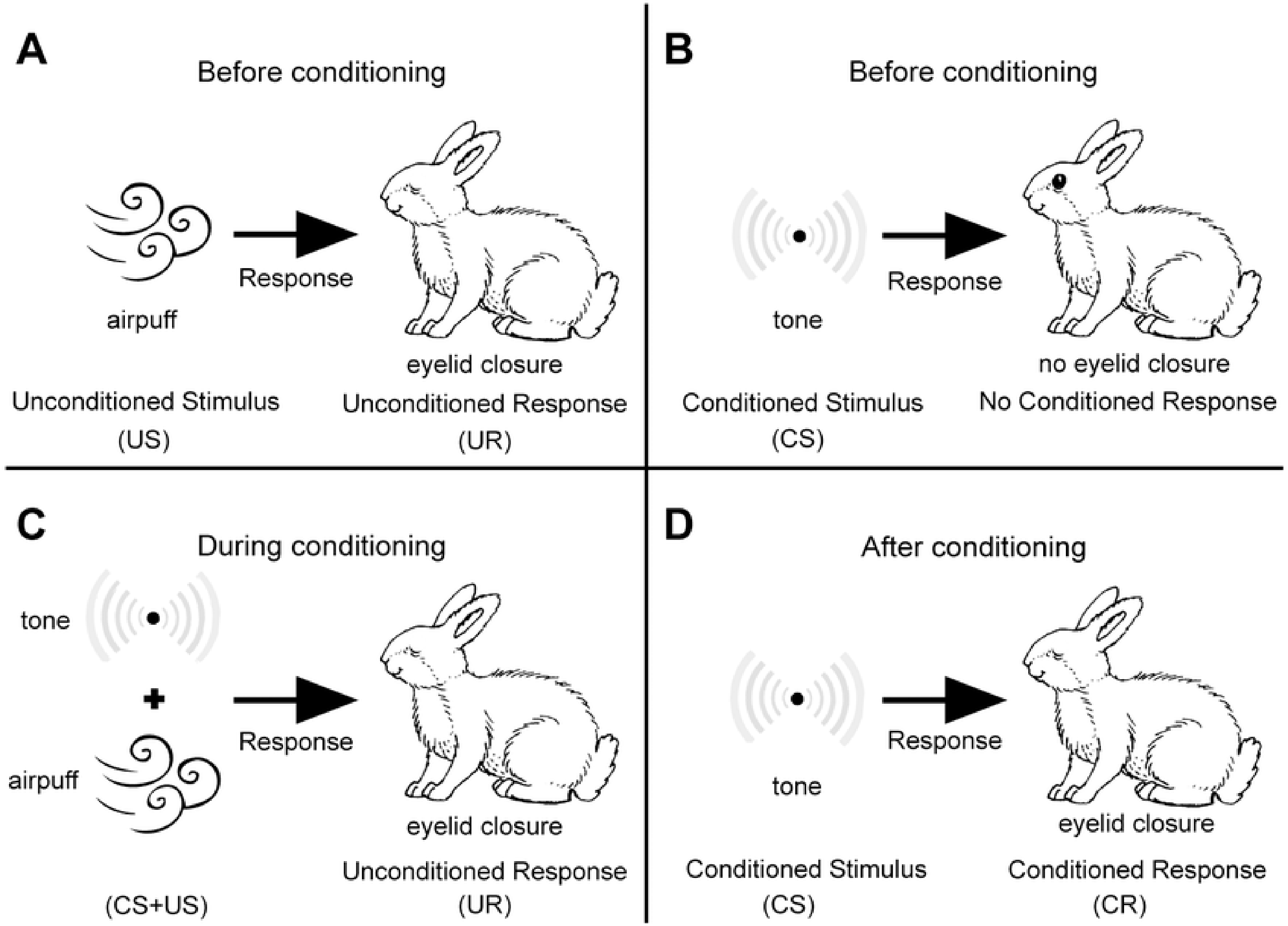
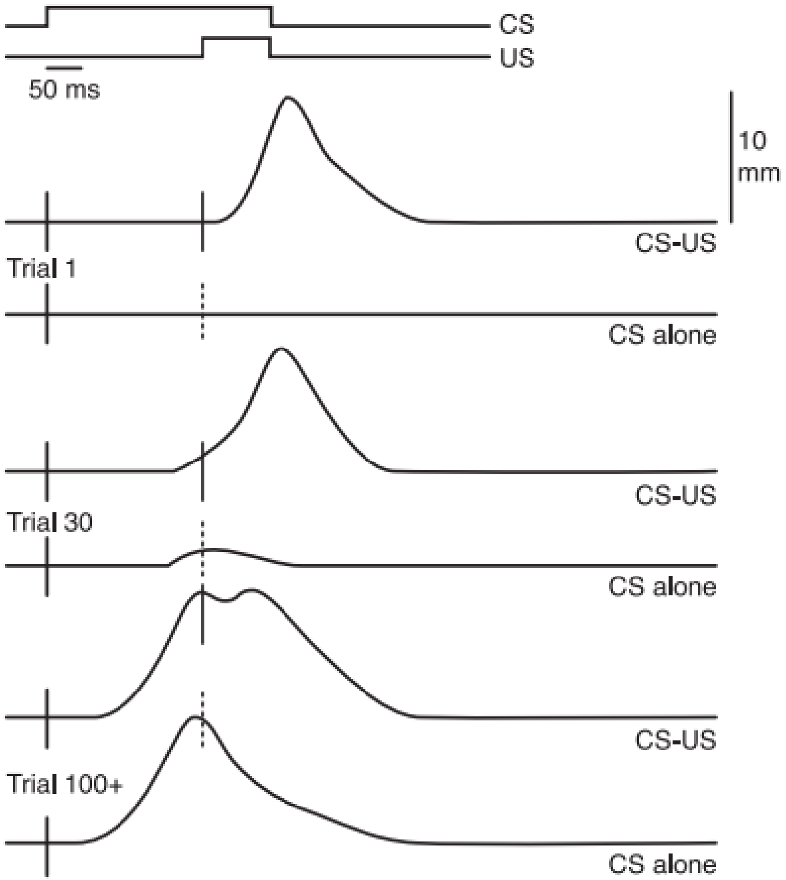


development of the conditioned eyelid response



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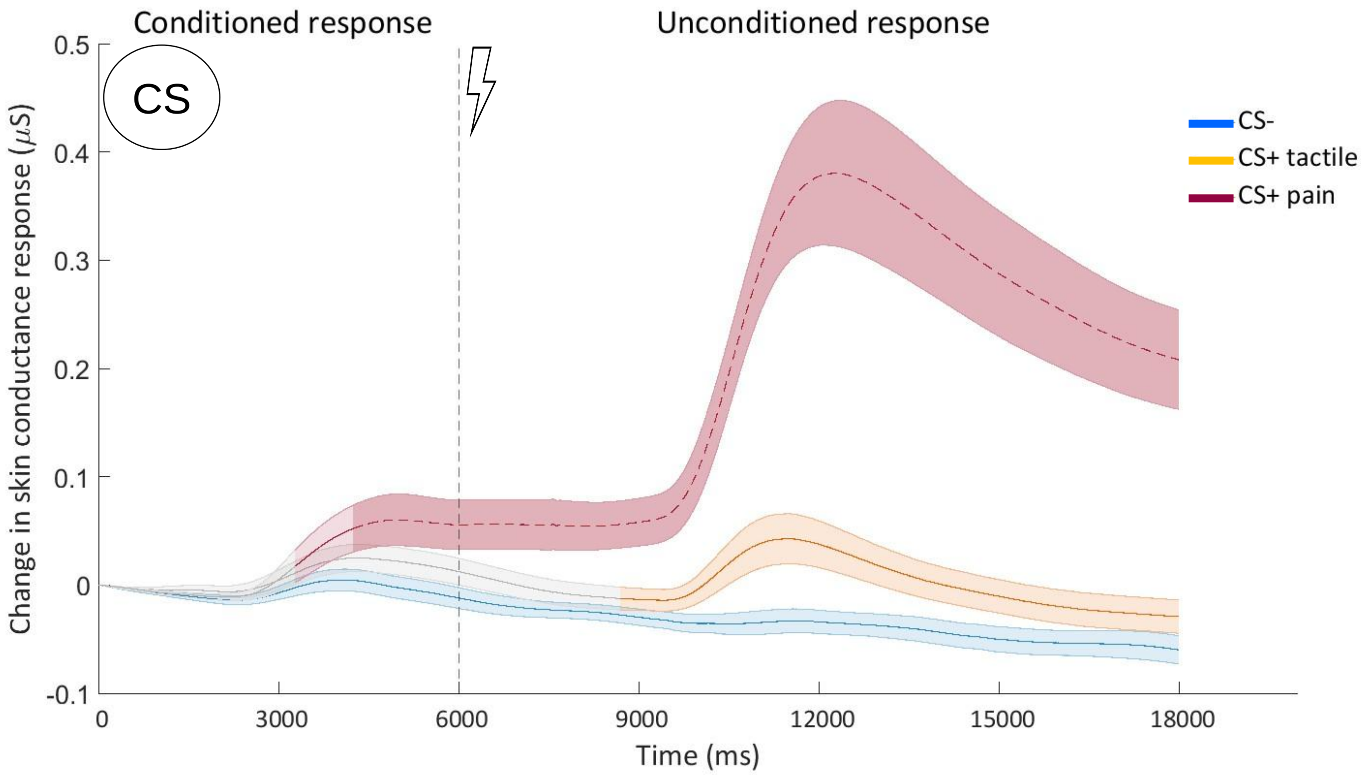
Learning is a predictive process!!

Conditioned responses (CRs), being initiated in anticipation of the unconditioned stimulus (US), offer better response for survival than simply initiating CRs as a reaction to the US.

Can you explain why with some concrete examples?



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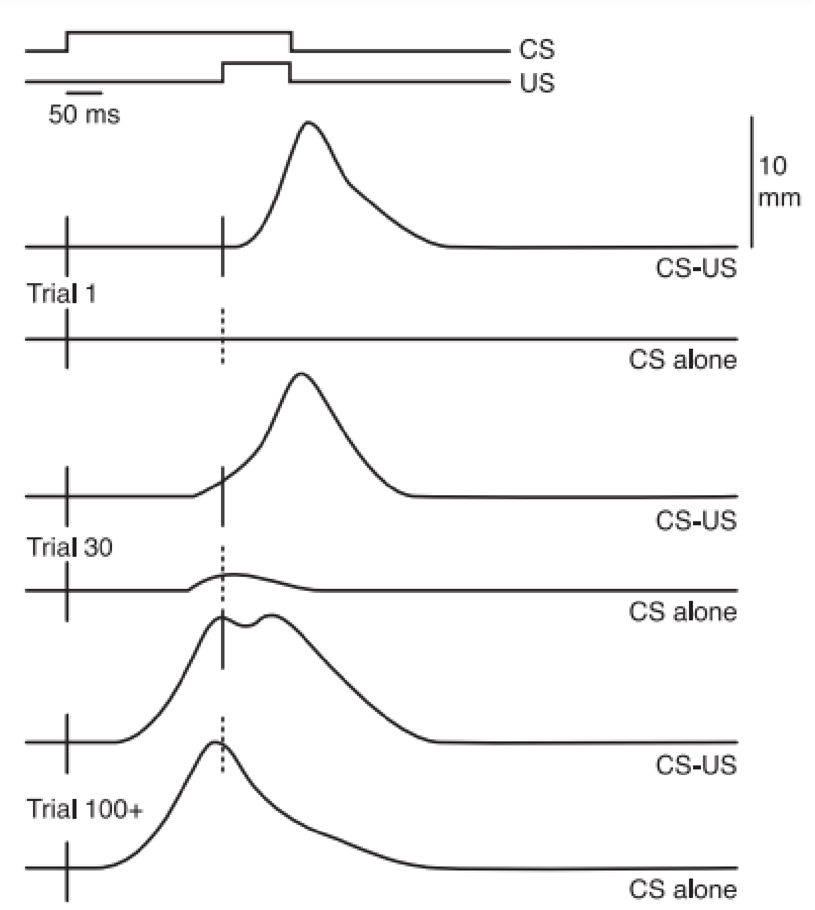

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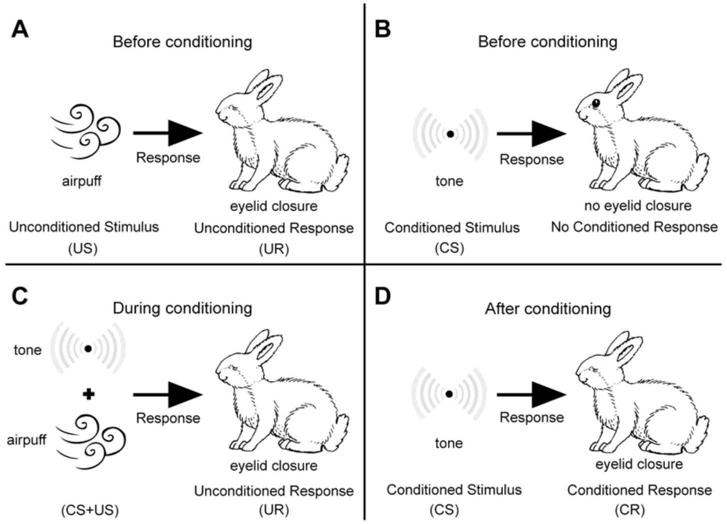
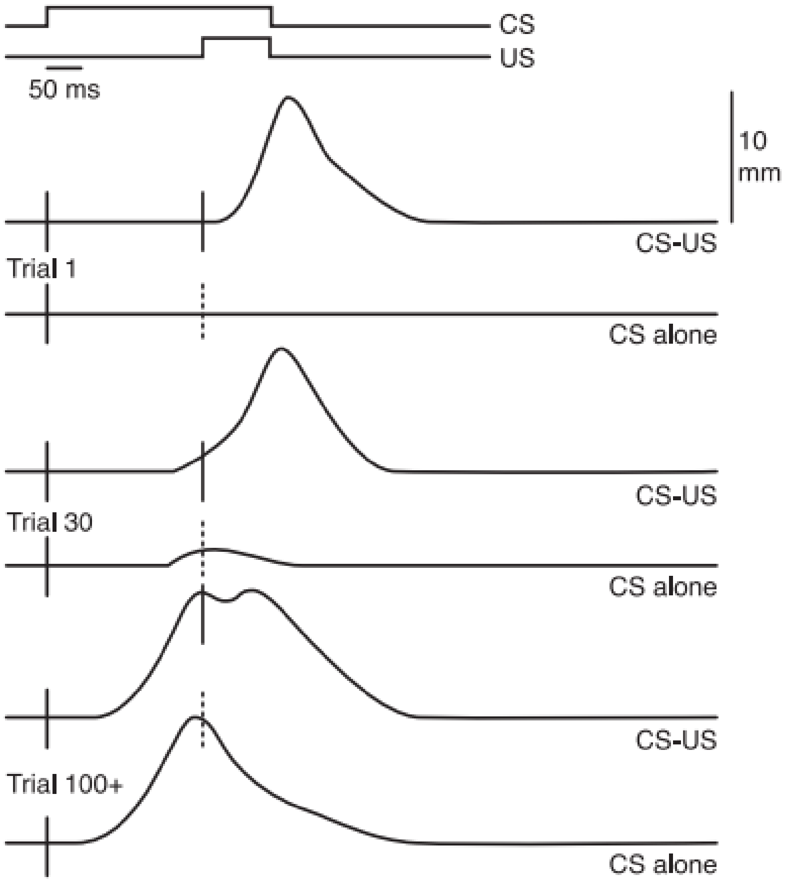
Behavioral conditioned responses involve motor reflexes or reflexive/stereotyped behaviors

The animal respond to the CS with a CR that **prepares the animal for, or protects it from,** the predicted US



The tone comes to trigger a CR consisting of the nictitating membrane closure that begins before the air puff and eventually **becomes timed** so that peak closure occurs just when the air puff is likely to occur. **This CR, being initiated in anticipation of the air puff and appropriately timed, offers better protection than simply initiating closure as a reaction to the irritating US.**

development of the conditioned eyelid response



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Learning is a flexible process!!

Acquisition

- The probability of occurrence of a conditioned response increases if the CS is repeatedly presented with the US.
- Adaptive because...

Extinction

- The probability of occurrence of a conditioned response decreases if the CS is repeatedly presented without the US.
- Adaptive because...

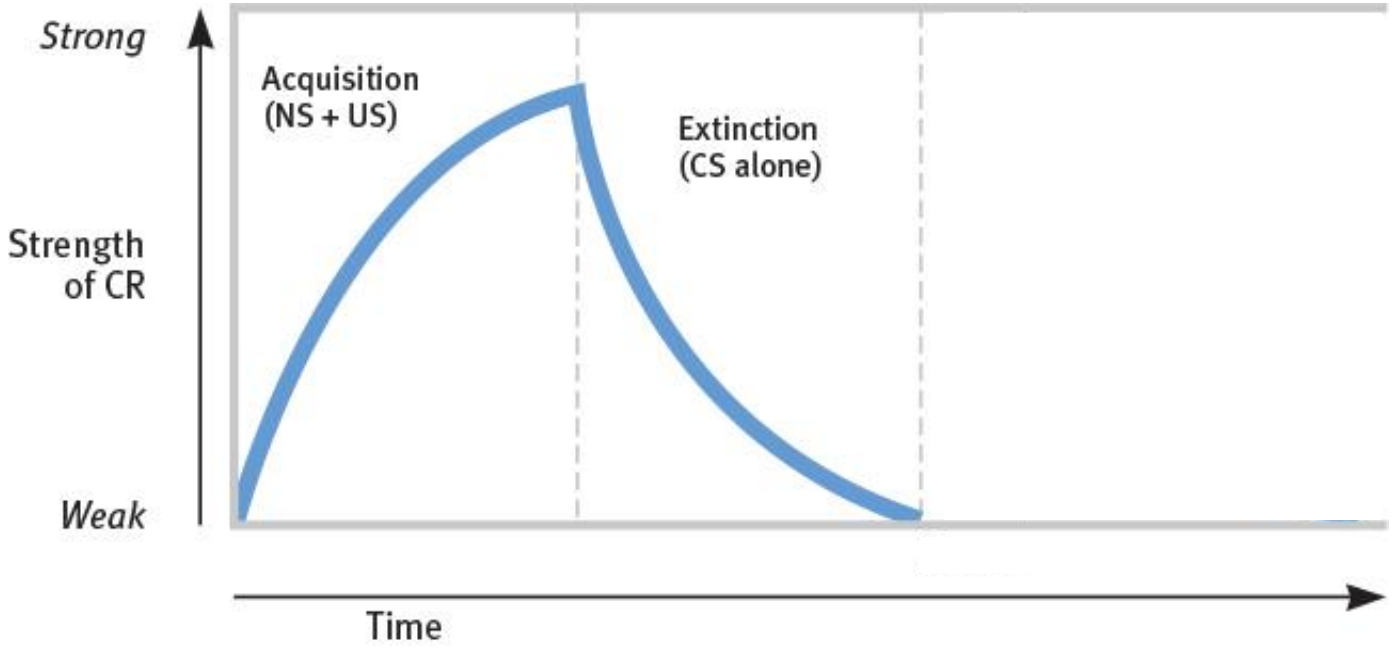


Figure 6.5
Myers/DeWall, *Psychology in Everyday Life*, 4e, © 2017 Worth Publishers

Learning is a flexible process!!

Acquisition

- The probability of occurrence of a conditioned response increases if the CS is repeatedly presented with the US.
- Adaptive mechanism ensures that an animal responds to cues that are meaningful to survival

Extinction

- The probability of occurrence of a conditioned response decreases if the CS is repeatedly presented without the US.
- Adaptive mechanism ensures that an animal stops responding to cues that are no longer meaningful to it

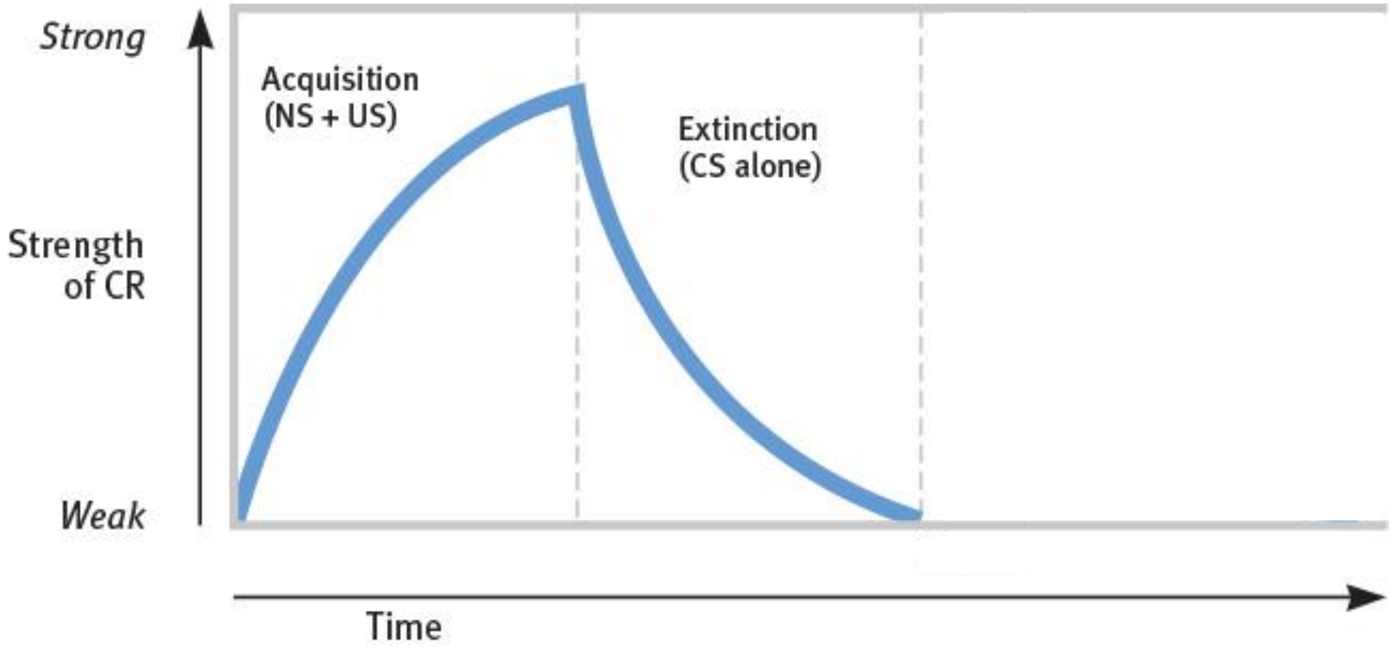


Figure 6.5
Myers/DeWall, *Psychology in Everyday Life*, 4e, © 2017 Worth Publishers

Extinction is not the same as forgetting, BUT it is a form of new learning

BUT HOW WOULD YOU SHOW THIS?

Myers KM, Davis M. Behavioral and neural analysis of extinction. Neuron. 2002 Nov 14;36(4):567-84. doi: 10.1016/s0896-6273(02)01064-4. PMID: 12441048.

Extinction is not the same as forgetting, BUT it is a form of new learning

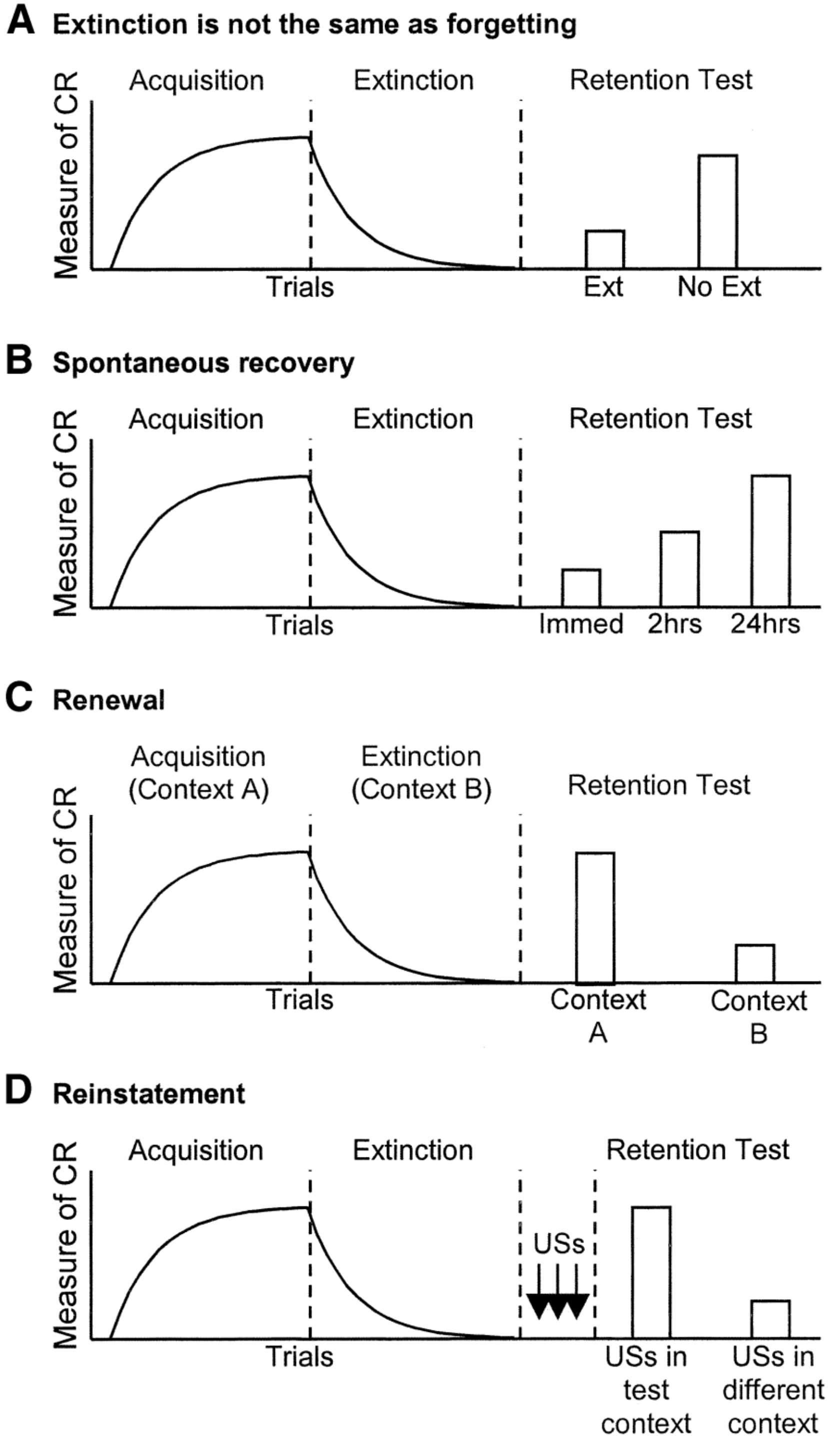
Several evidence supports this:

(A) The acquired conditioned response (CR) does not disappear unless the conditioned stimulus (CS) is nonreinforced in the interval between acquisition and test.

(B) At relatively extended intervals following extinction, the extinguished CR reappears. The magnitude of this "spontaneous recovery" increases with the length of the extinction-to-test interval.

(C) Extinction is context specific. Following acquisition in context A and extinction in context B, a retention test in context B reveals extinction-appropriate behavior (i.e., little or no CR) whereas a similar test in context A reveals acquisition-appropriate behavior (i.e., the extinguished CR is "renewed").

(D) An extinguished CR reappears (is "reinstated") when unsignaled presentations of the US are interposed between the completion of extinction training and a subsequent retention test, but only if the USs are presented within the context of the retention test.



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Learning is a flexible process

Generalization: Other stimuli that are not involved in the initial learning process and that resemble the original CS come to elicit a CR

- Generalization vs discrimination
- Adaptive or maladaptive?

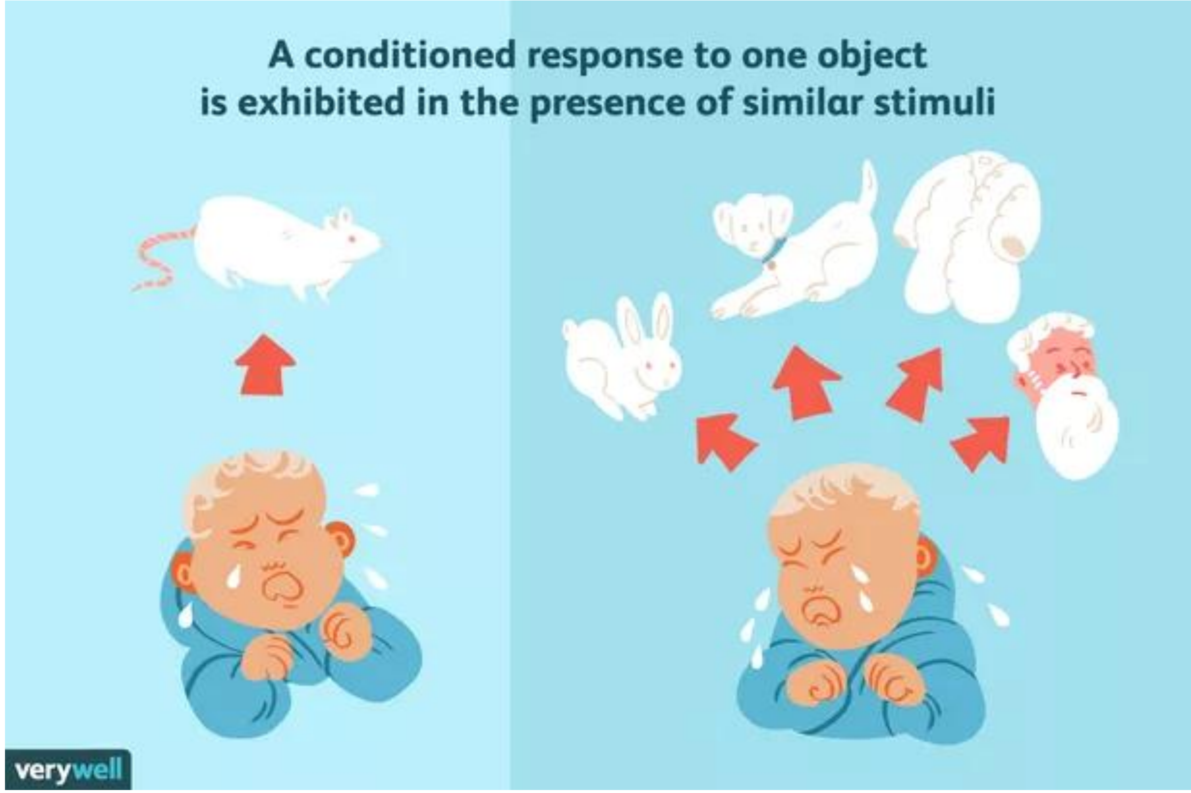

Illustration by Emily Roberts, Verywell

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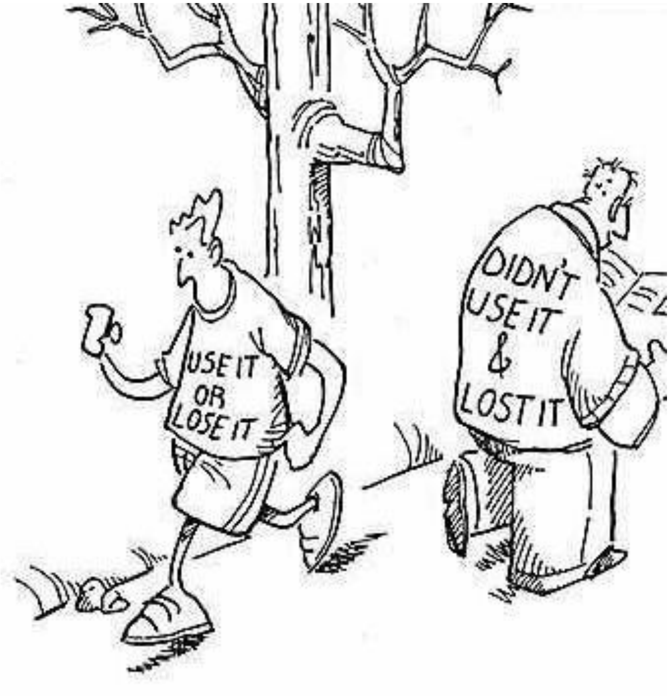
https://youtu.be/G5QAKnMf4Xc

wooclap

Neural plasticity as the basis of learning

Learning is the result of changes in the strength of synaptic interactions among neurons in neural networks

Plasticity: Neural connections can be modified by experience & learning



Changes in the strength of synaptic interactions can be:

- **Short-term changes:** functional physiological changes (lasting seconds to hours) that increase or decrease the effectiveness of existing synaptic connections. --> **Hebbian plasticity**

- **Long-term changes:** structural changes (lasting days) that can give rise to further physiological changes that lead to anatomical alterations, including pruning of preexisting synapses or growth of new ones.

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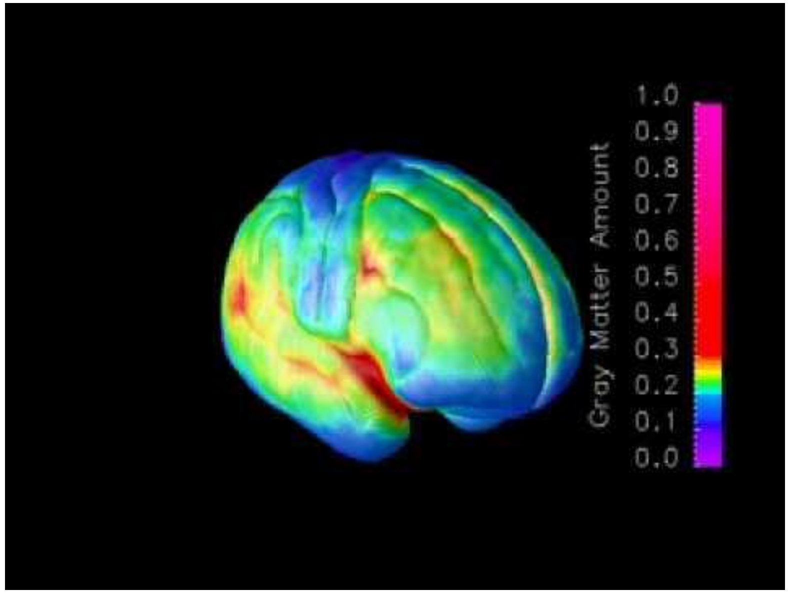

Right oblique view of gray matter maturation over the cortical surface between ages 4 and 21. The side bar shows a color representation in units of GM volume. Gogtay et al., 2004, PNAS
https://doi.org/10.1073/pnas.0402680101

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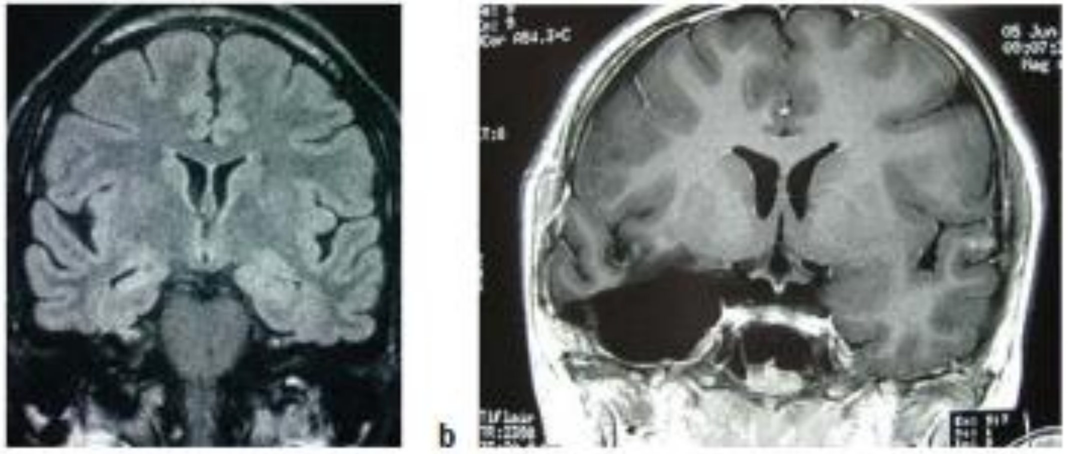
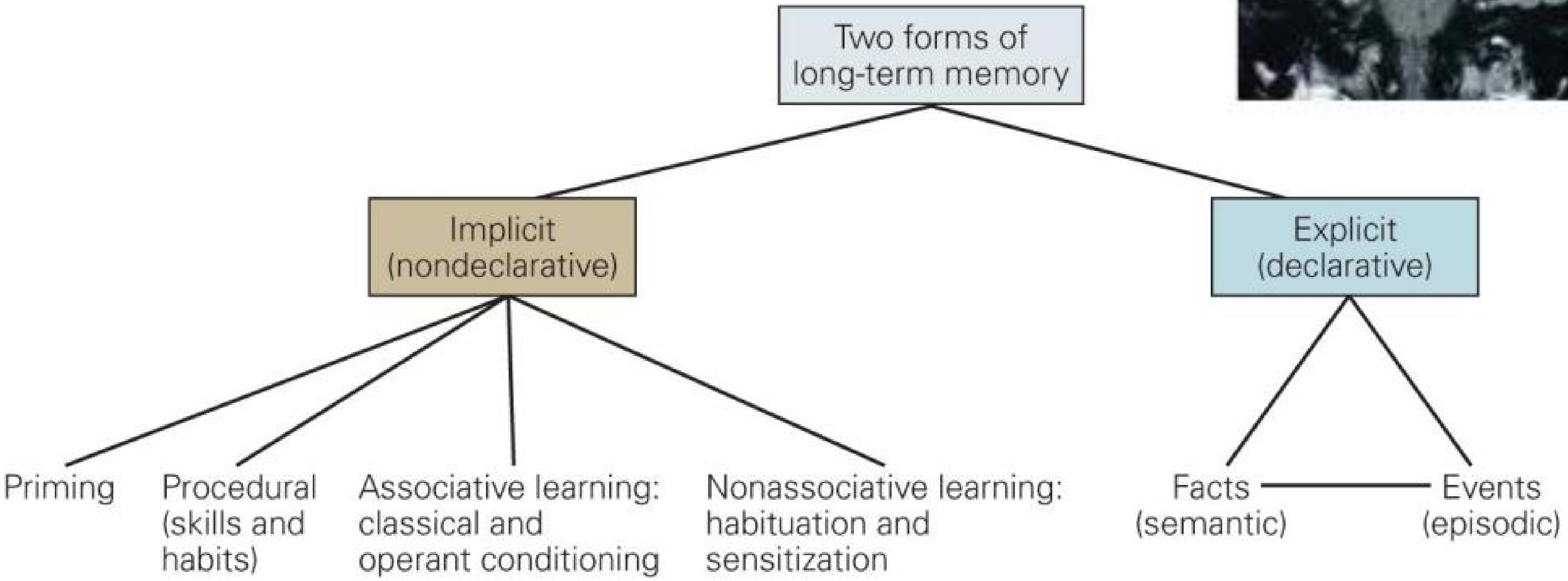
Learning and memory are two interconnected processes

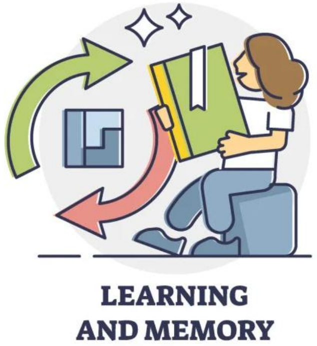
Brenda Milner
(1918–)

Brenda Milner

- provided anatomical and physiological proof that there are **multiple memory systems**
- Showed that the extent of a memory deficit depended on how much of the medial temporal lobe had been removed







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Learning is the result of changes in the strength of synaptic interactions among neurons in neural networks

https://www.pbslearningmedia.org/resource/nvfb-sci-memhackers/wgbh-nova-memory-hackers-full-length-broadcast/

Minute 10.45-16.35: patient HM, neural plasticity as the basis of learning & memory

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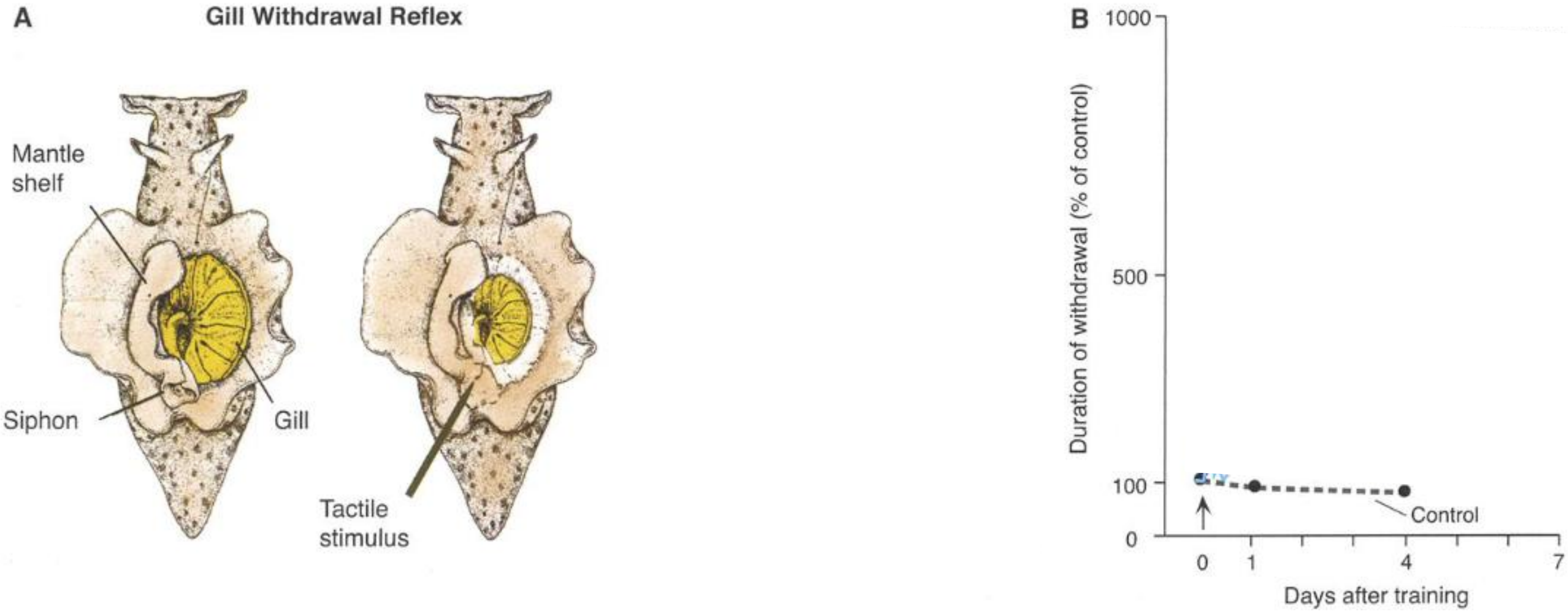
Minute 10.45-16.35: patient HM, neural plasticity as the basis of learning & memory

Minute 16.35-21.20: conditioning of gill withdrawal reflex in aplysia, and growth of new synapses

Learning is the result of changes in the strength of synaptic interactions among neurons in neural networks

The gill withdrawal reflex in Aplysia Californica

- A weak touch to the siphon causes a weak withdrawal reflex of the gill.



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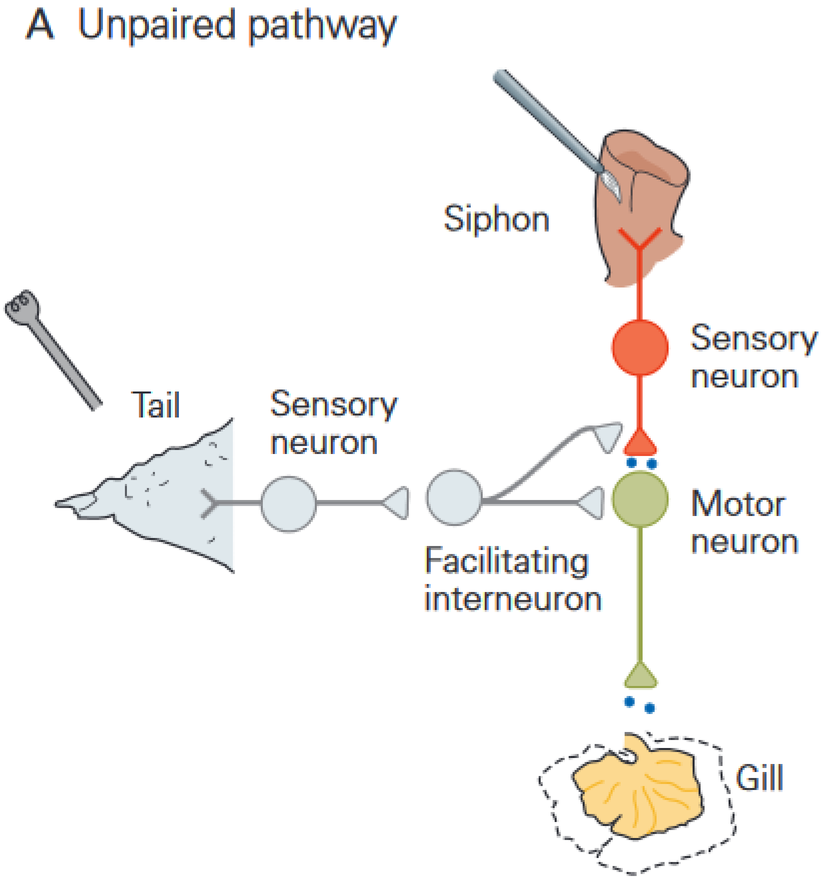

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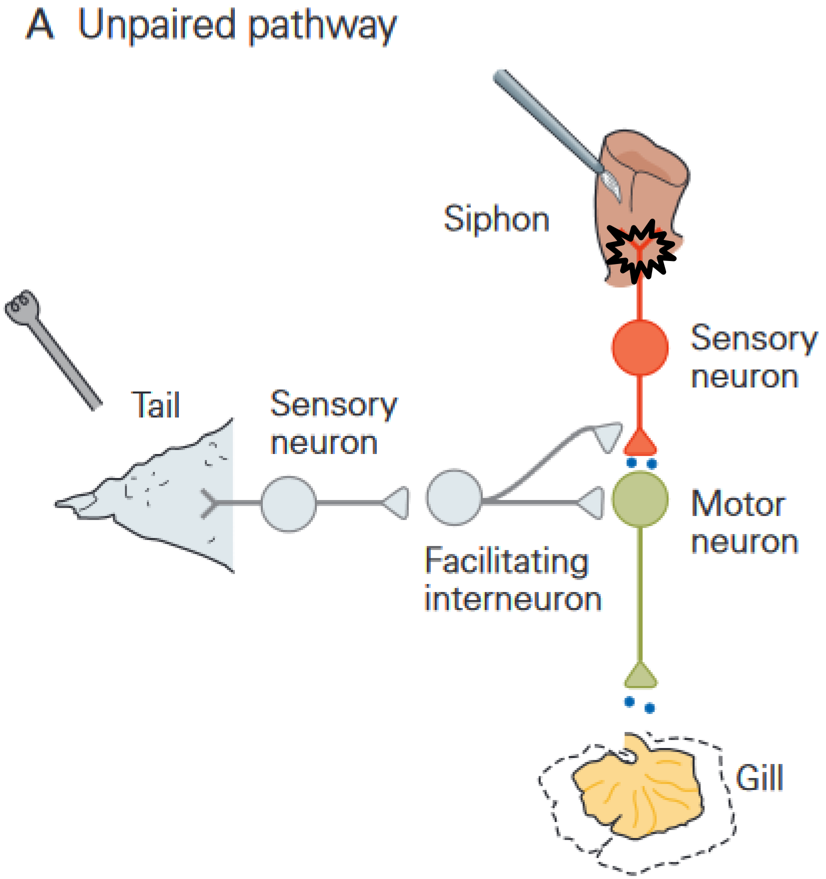

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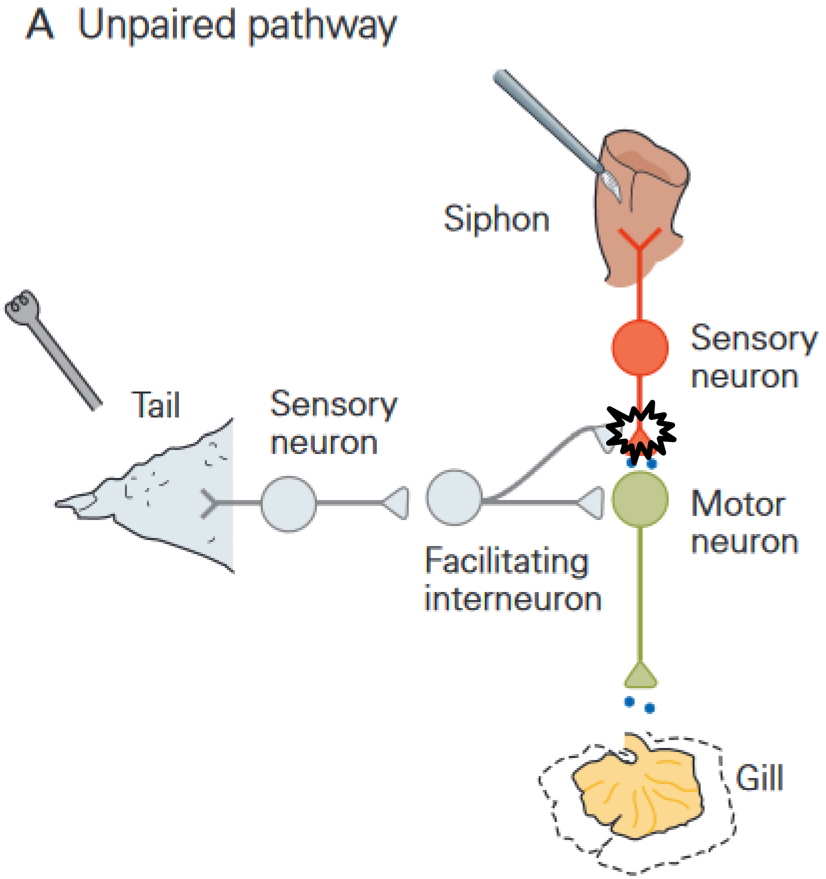

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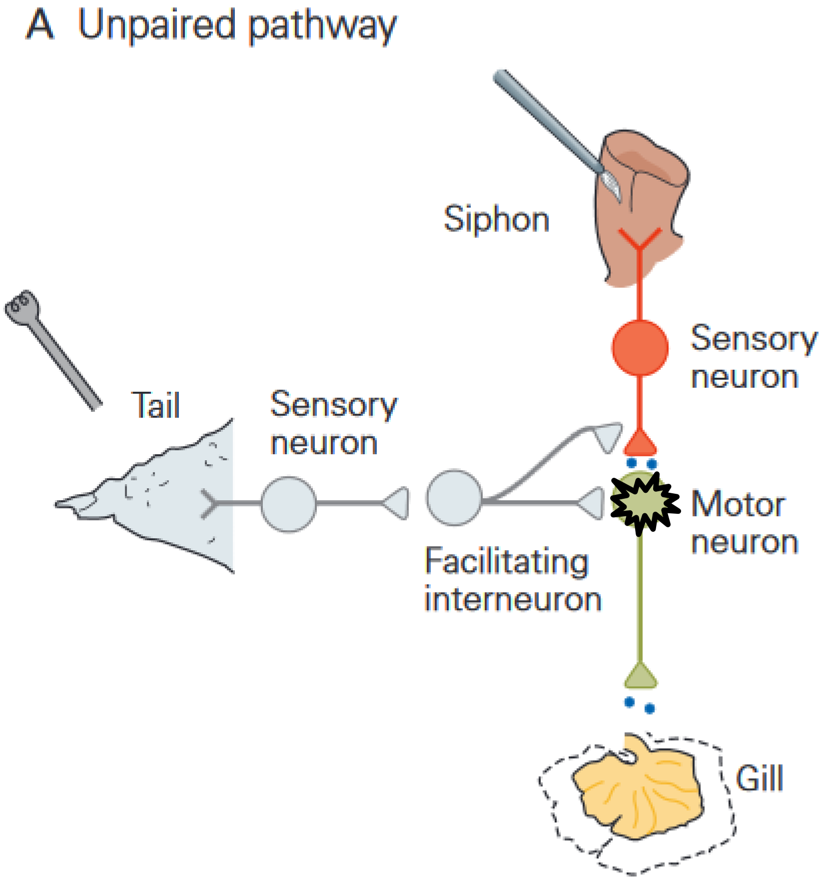

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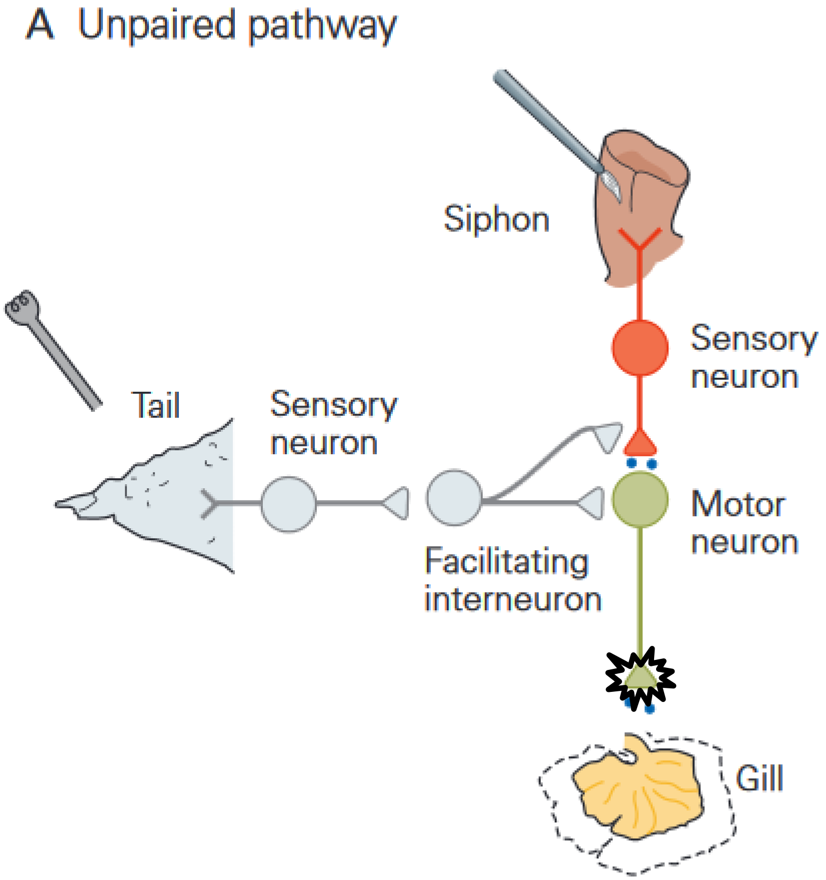

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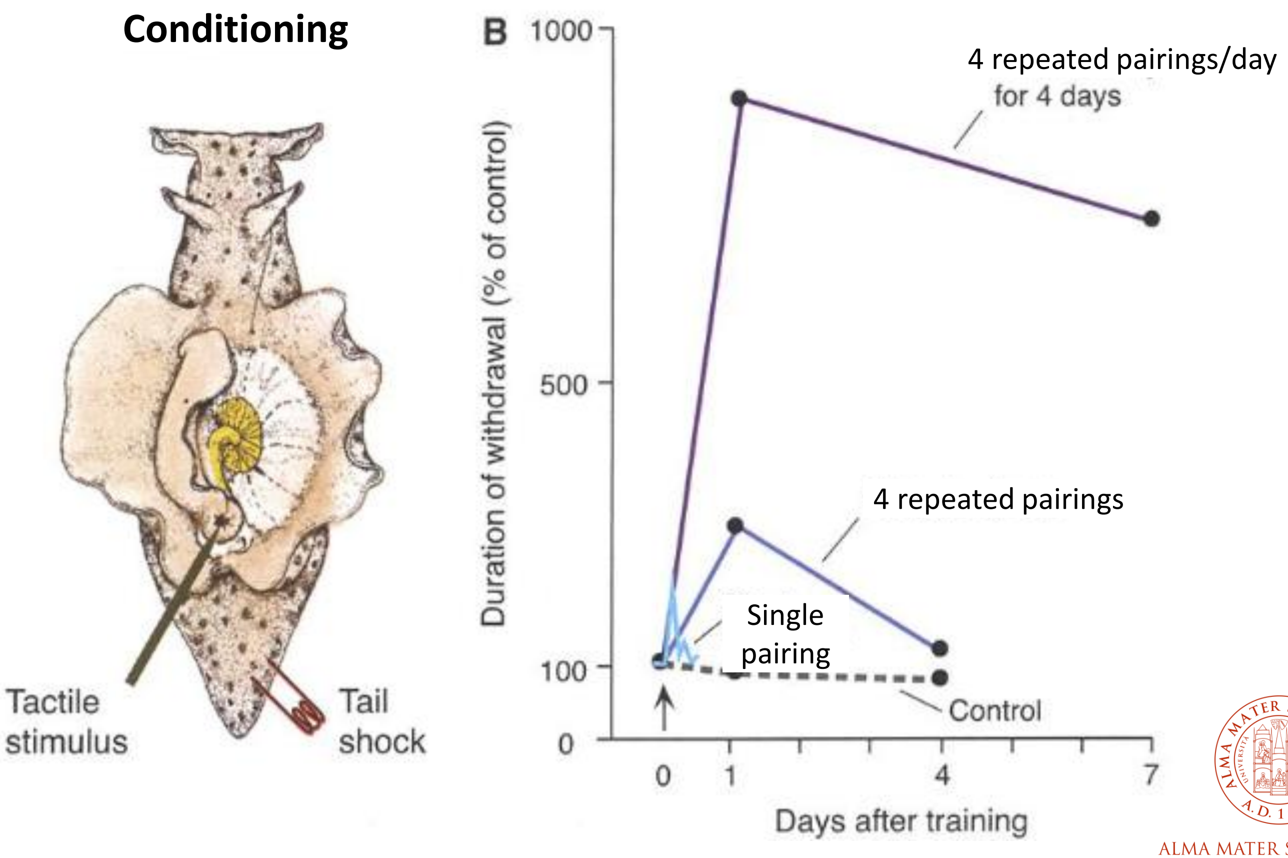

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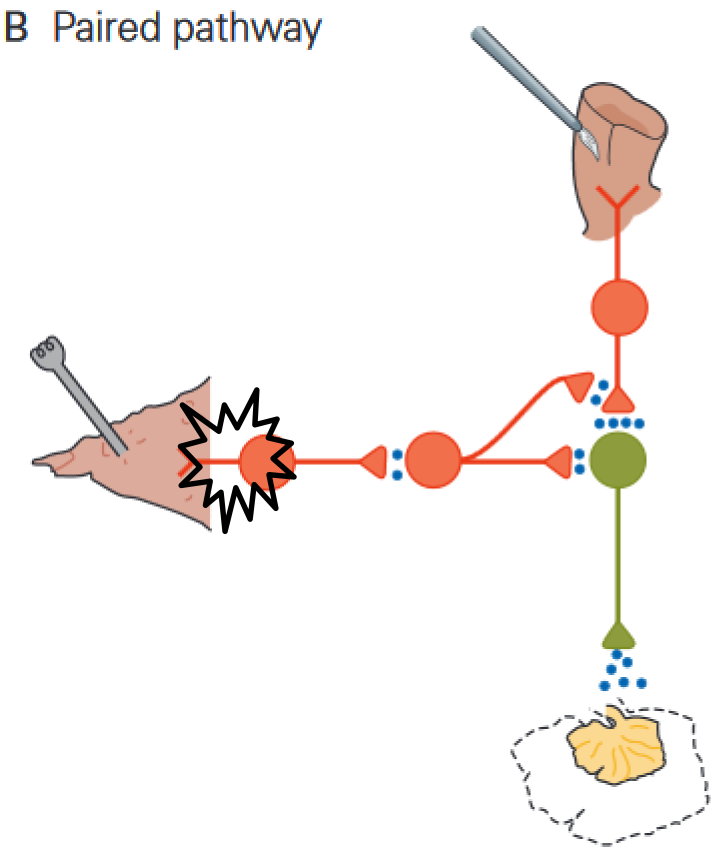

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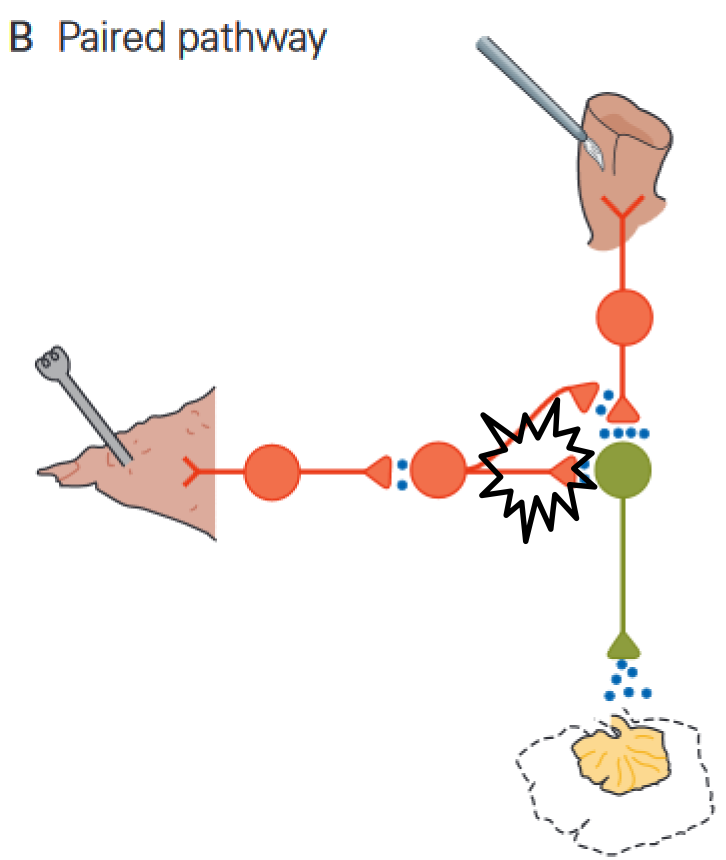

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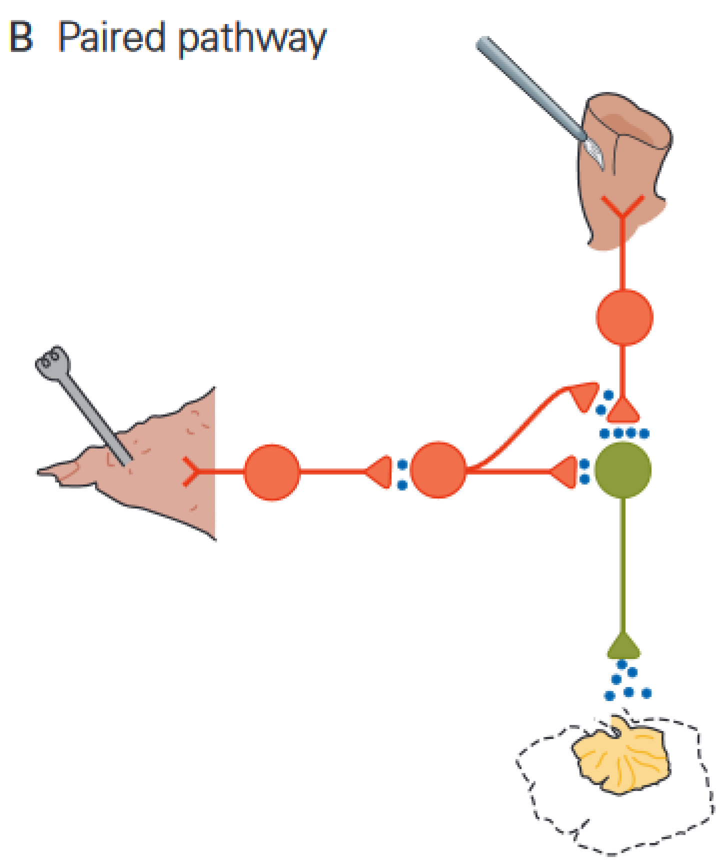

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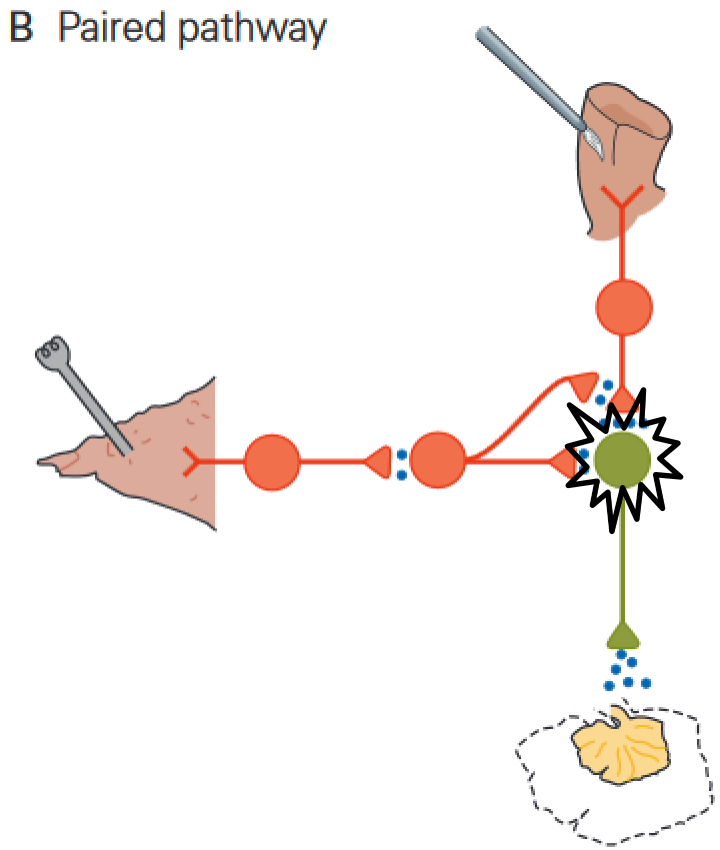

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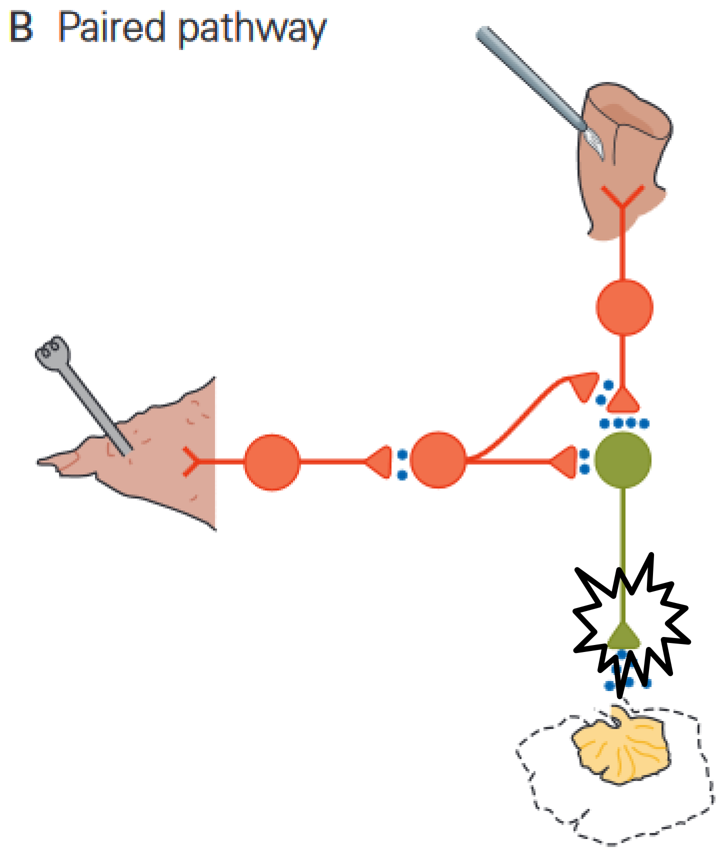

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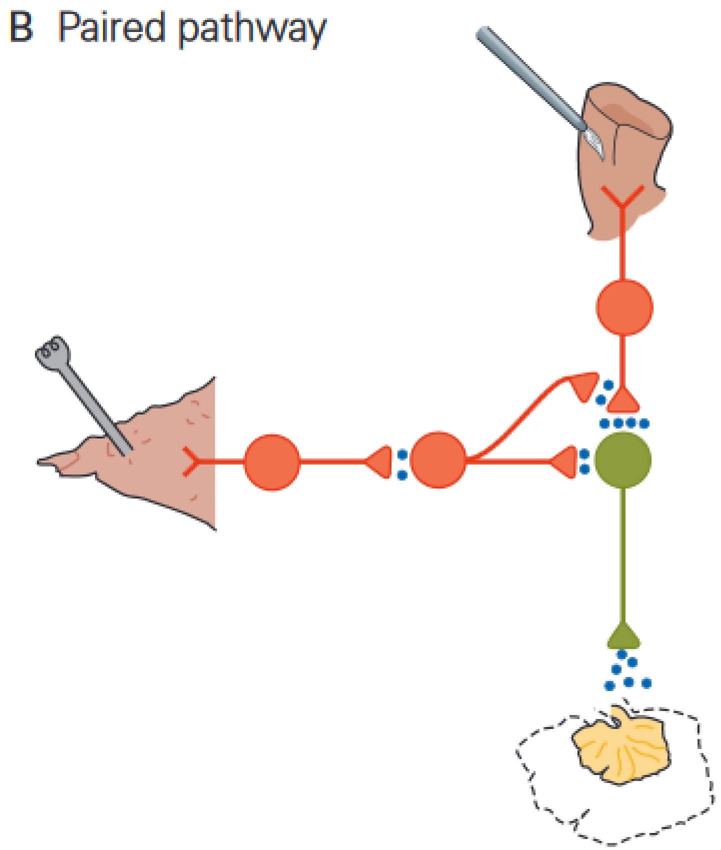

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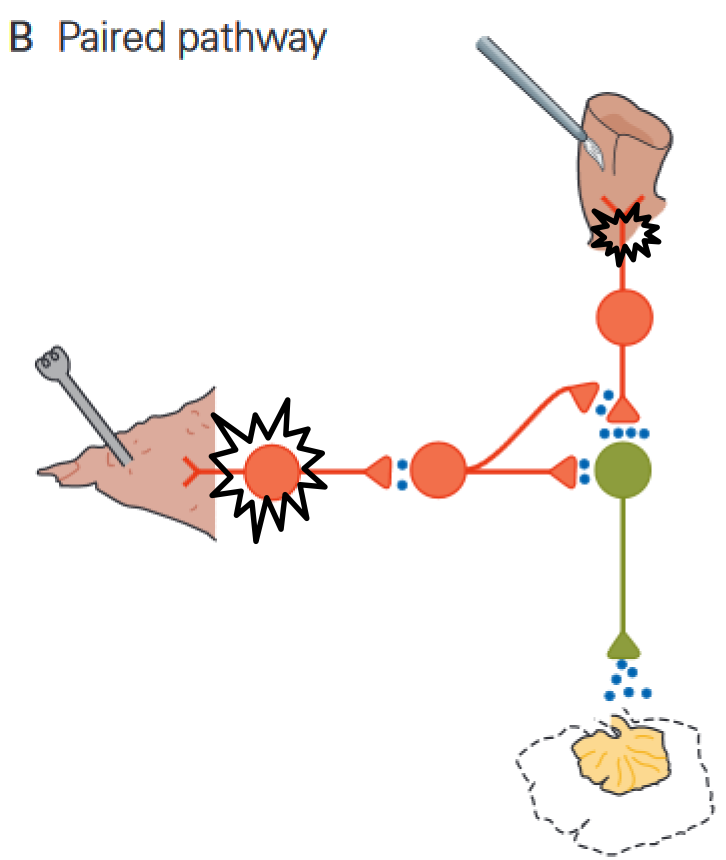

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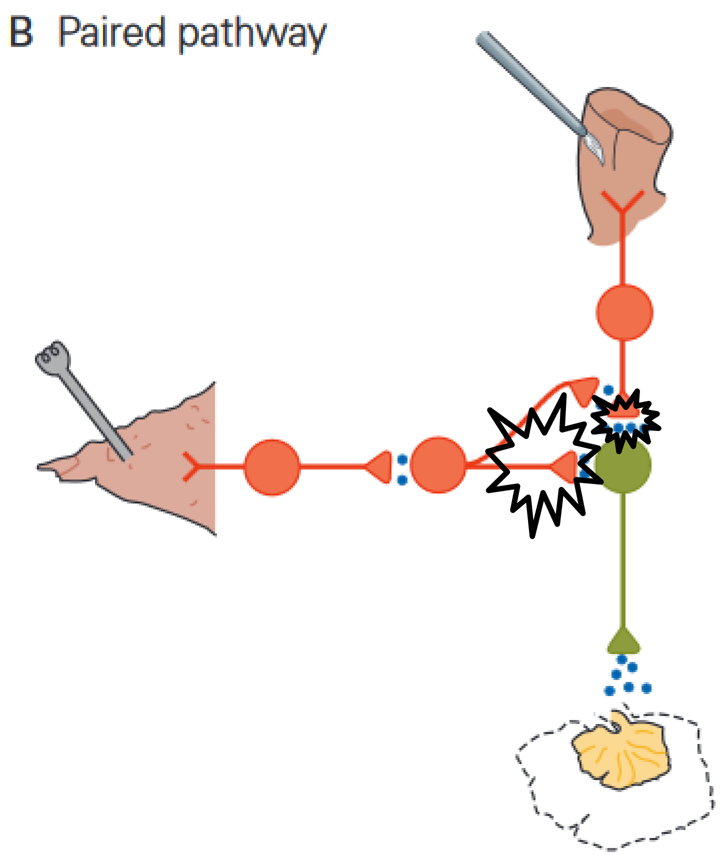

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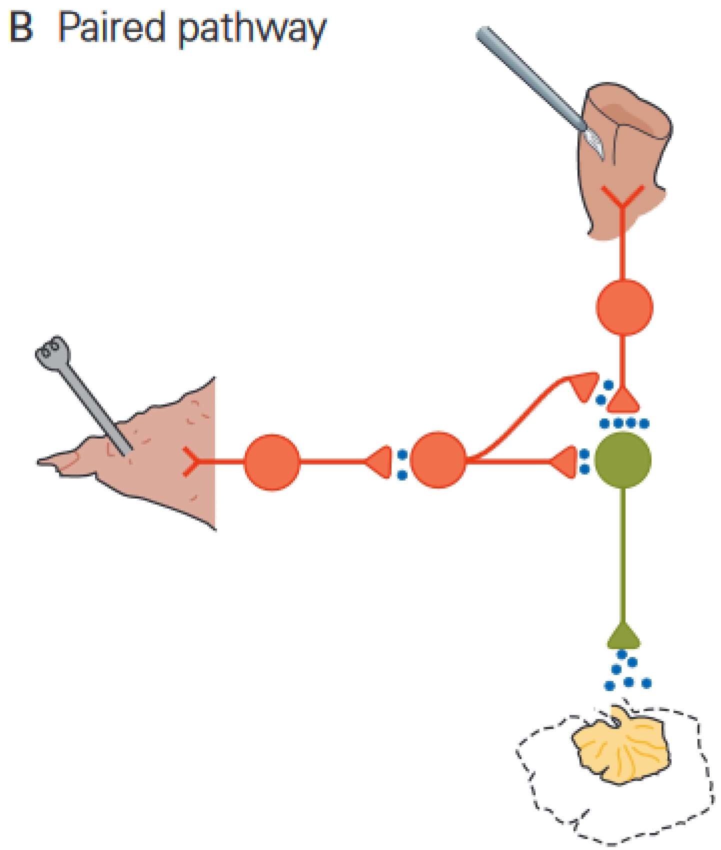

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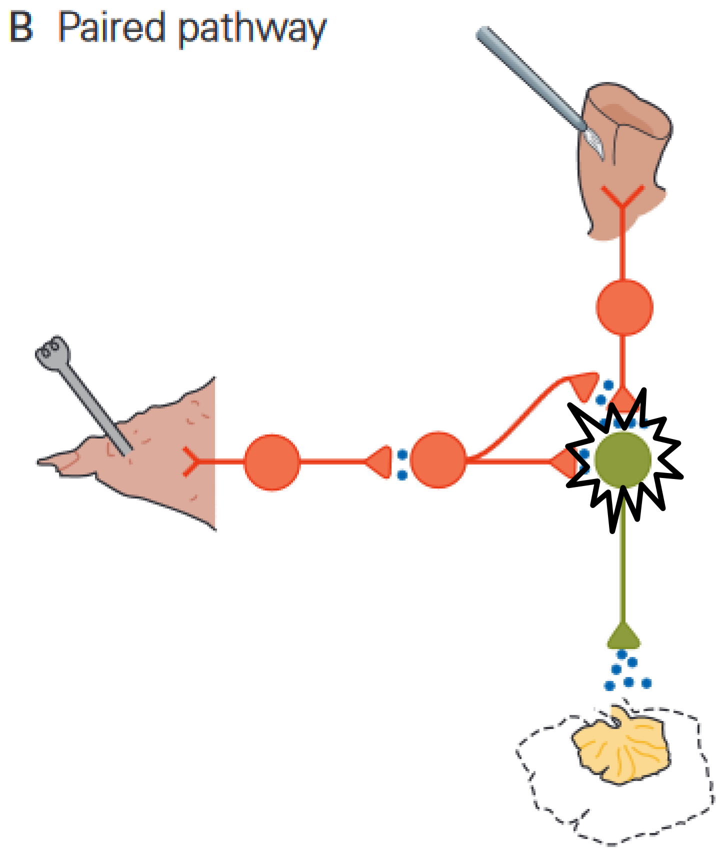

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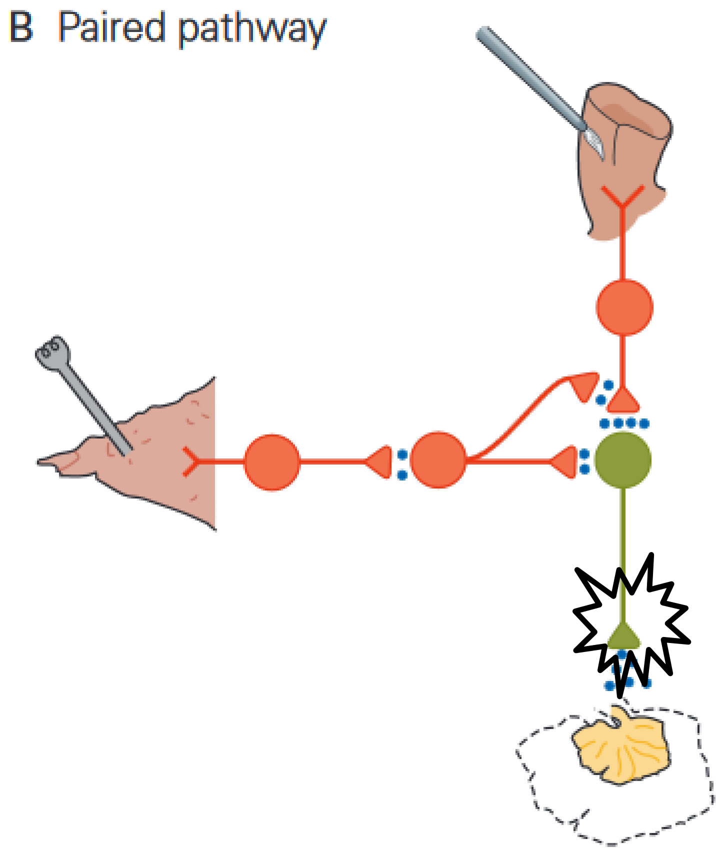

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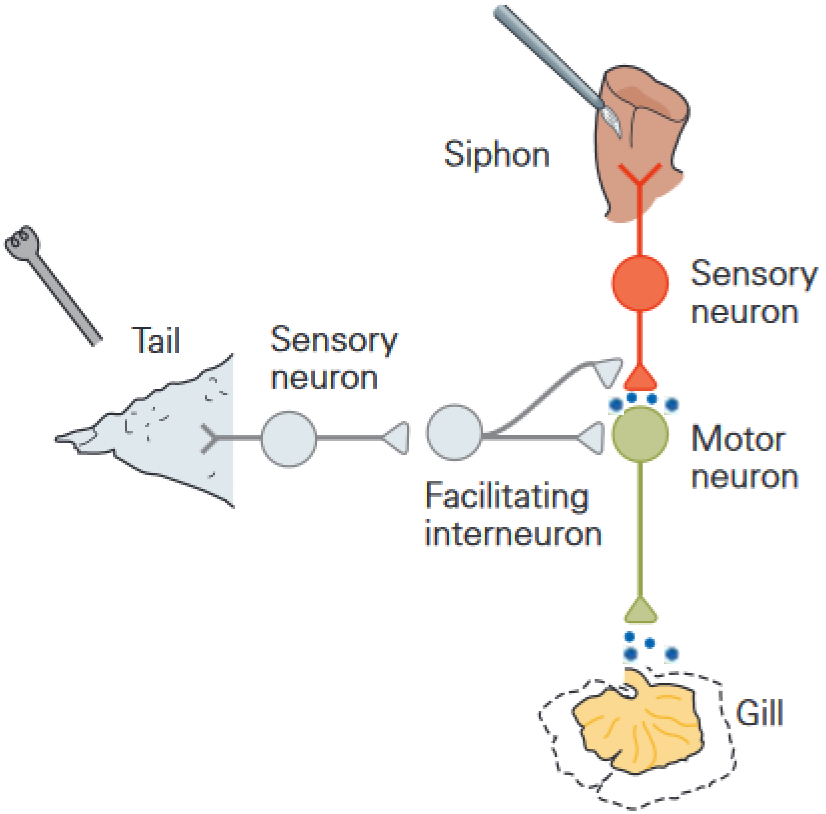

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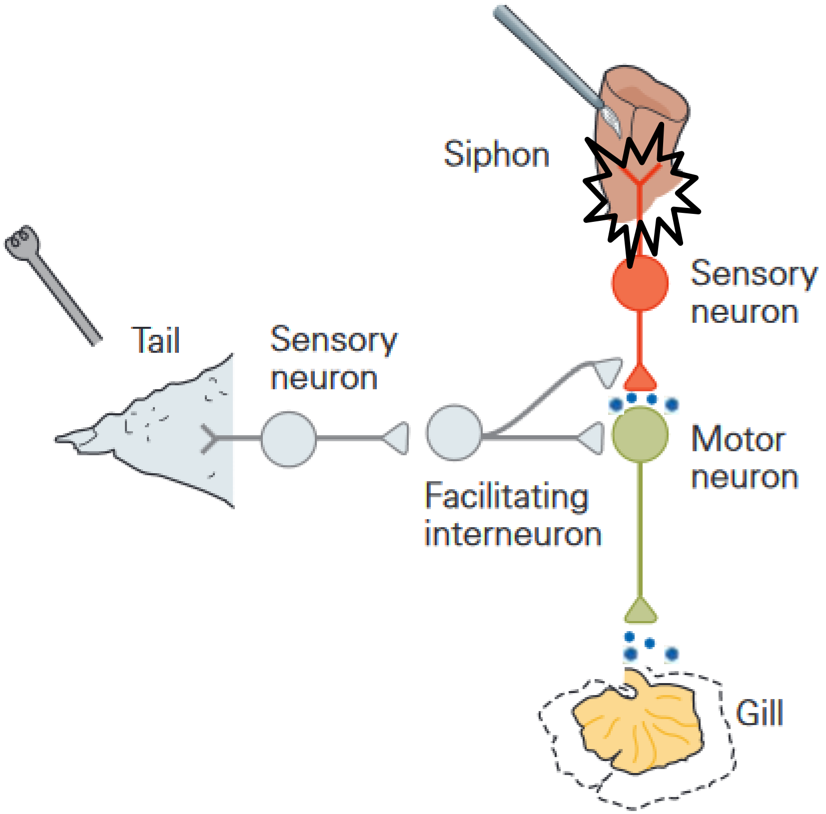

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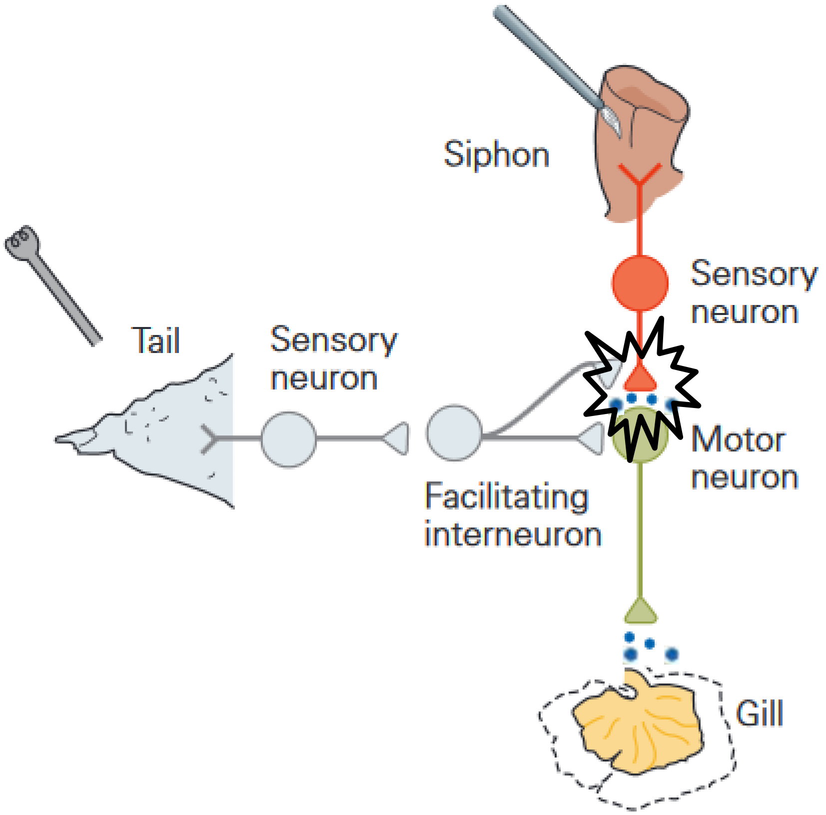

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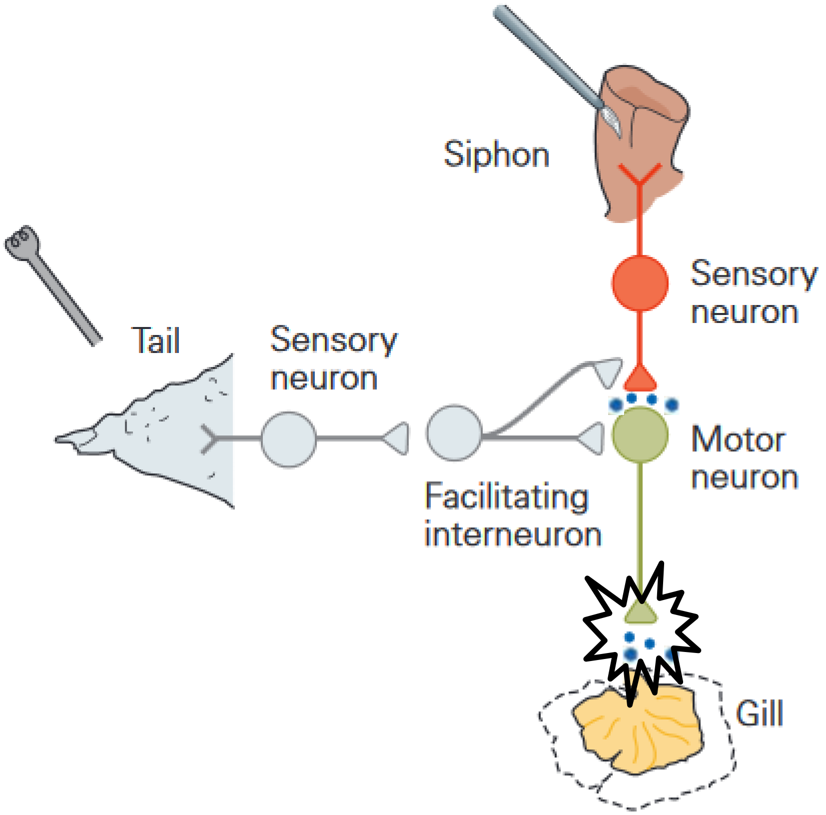

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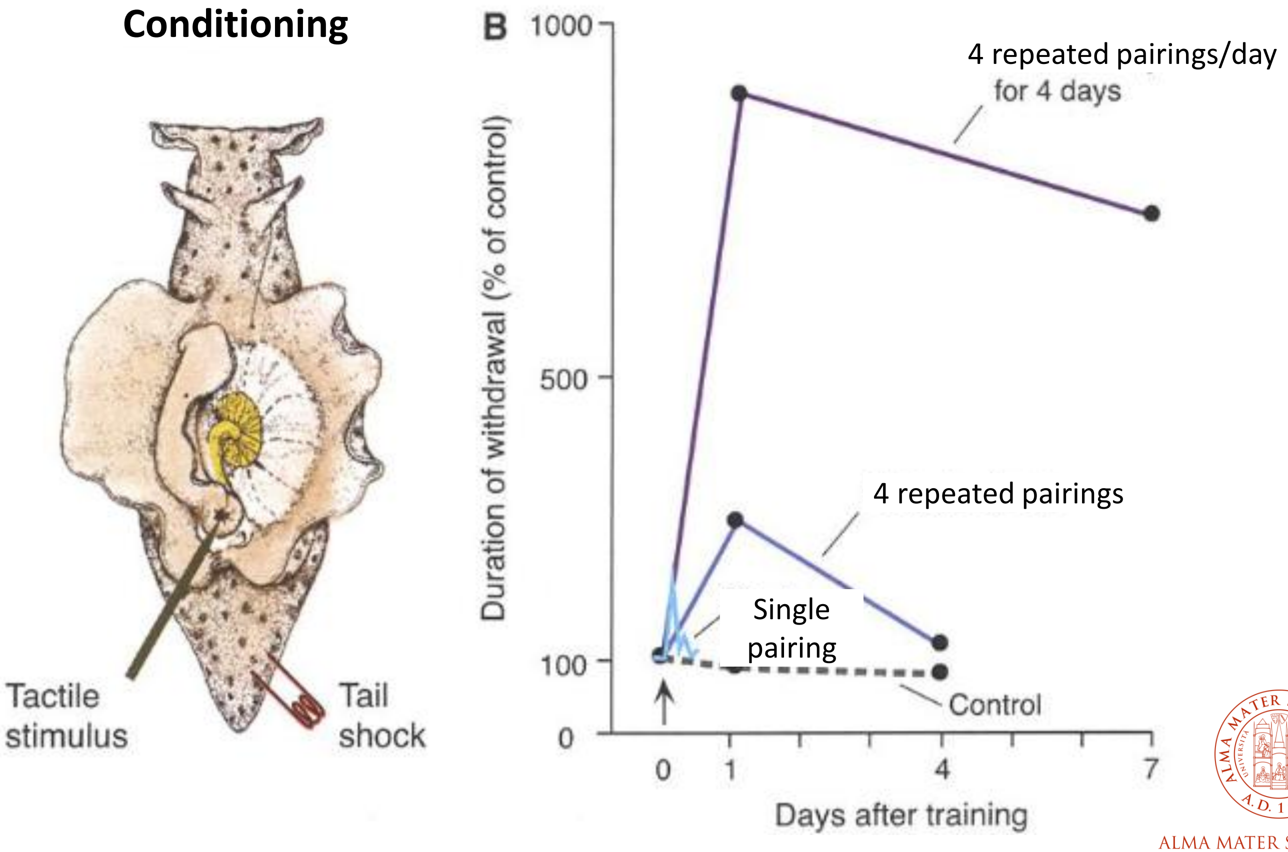

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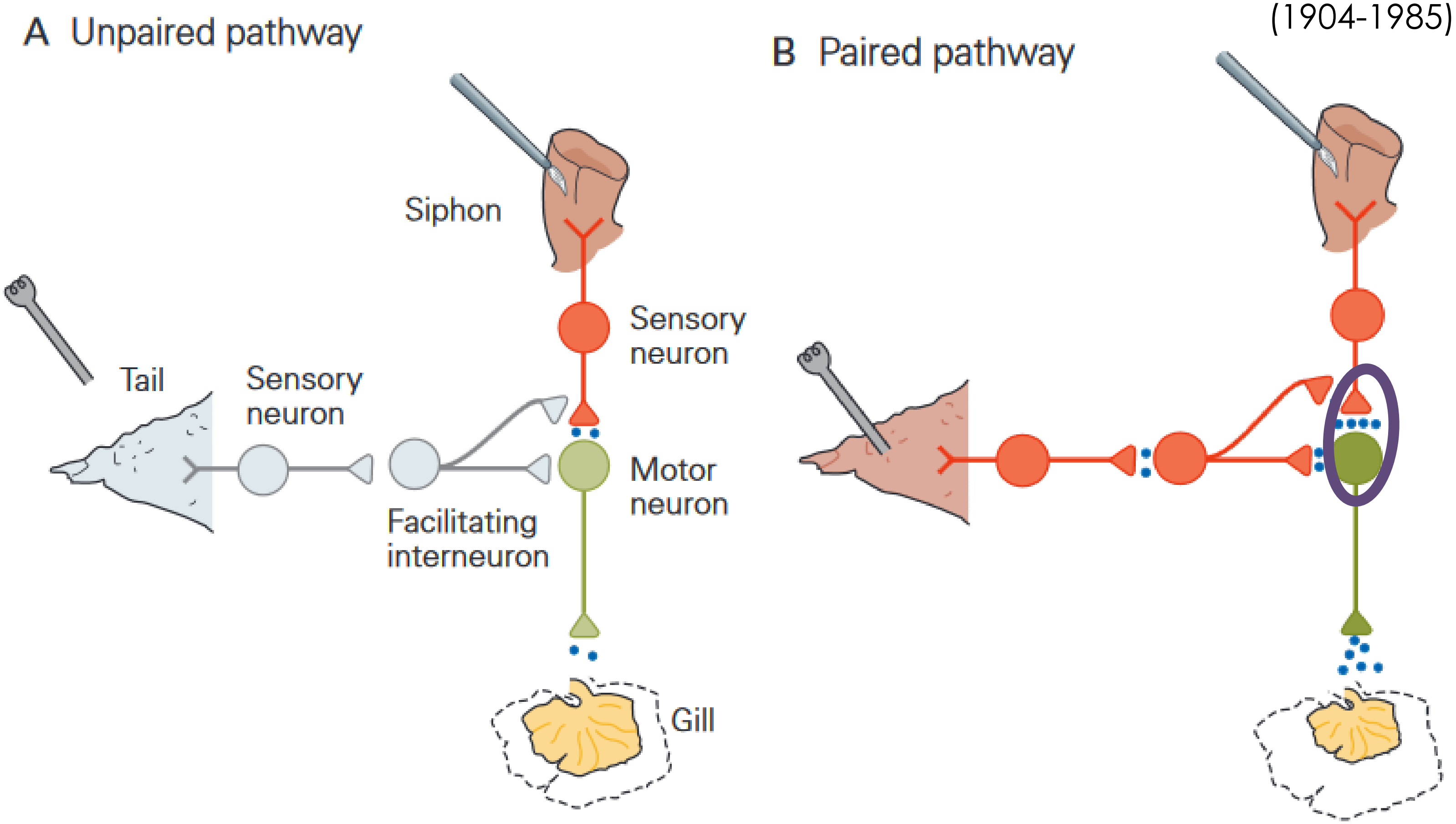
Learning is the result of changes in the strength of synaptic interactions among neurons in neural networks

Donald Hebb
(1904-1985)

Hebbian plasticity

- Hebb's Law: **Neurons that fire together, wire together**
- In "The Organization of Behaviour" (1949) Donald Hebb proposed a mechanism to explain synaptic plasticity
- It describes how when a cell persistently activates another nearby cell, the connection between the two cells becomes stronger



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In mammals, during Pavlovian conditioning, these changes occur in the amygdala.

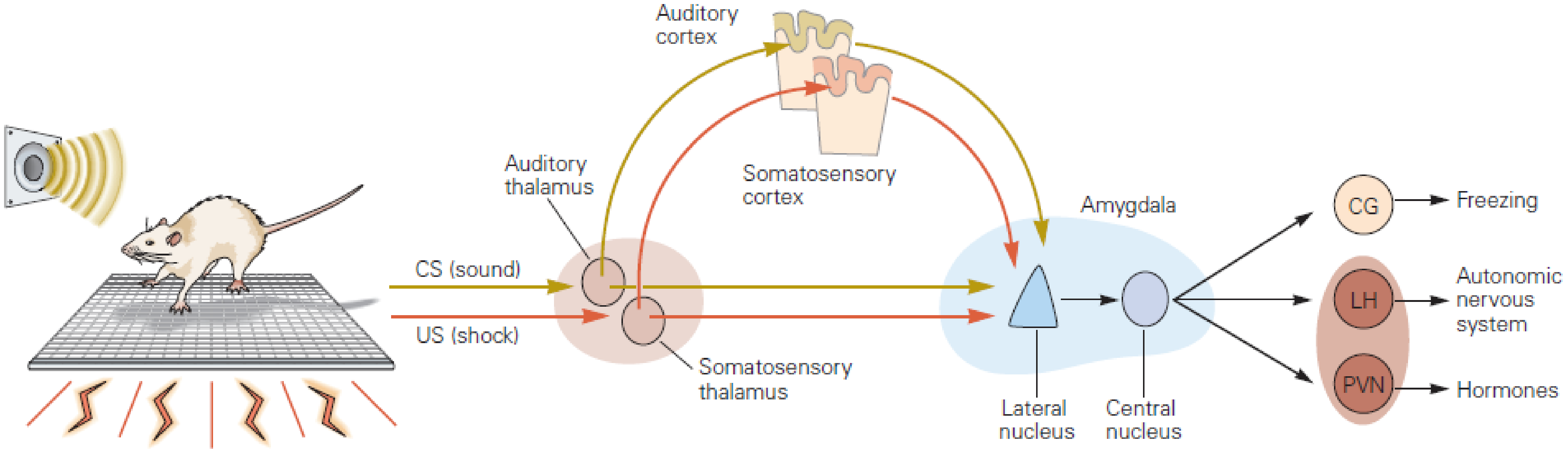

Figure 48–5 Neural circuits engaged during fear conditioning. The conditioned stimulus (**CS**) and unconditioned stimulus (**US**) are relayed to the lateral nucleus of the amygdala from the auditory and somatosensory regions of the thalamus and cerebral cortex. Convergence of the CS and US pathways in the lateral nucleus is believed to underlie the synaptic changes that mediate learning (see Figure 48–6). The lateral nucleus communicates with the central nucleus both directly and through intra-amygdala pathways (not shown) involving the basal and intercalated nuclei. The central nucleus then connects with regions that control various motor responses, including the central gray region (**CG**), which controls freezing behavior, the lateral hypothalamus (**LH**), which controls autonomic responses, and the paraventricular hypothalamus (**PVN**), which controls stress hormone secretion by the pituitary-adrenal axis. (Reproduced, with permission, from Medina et al. 2002.)

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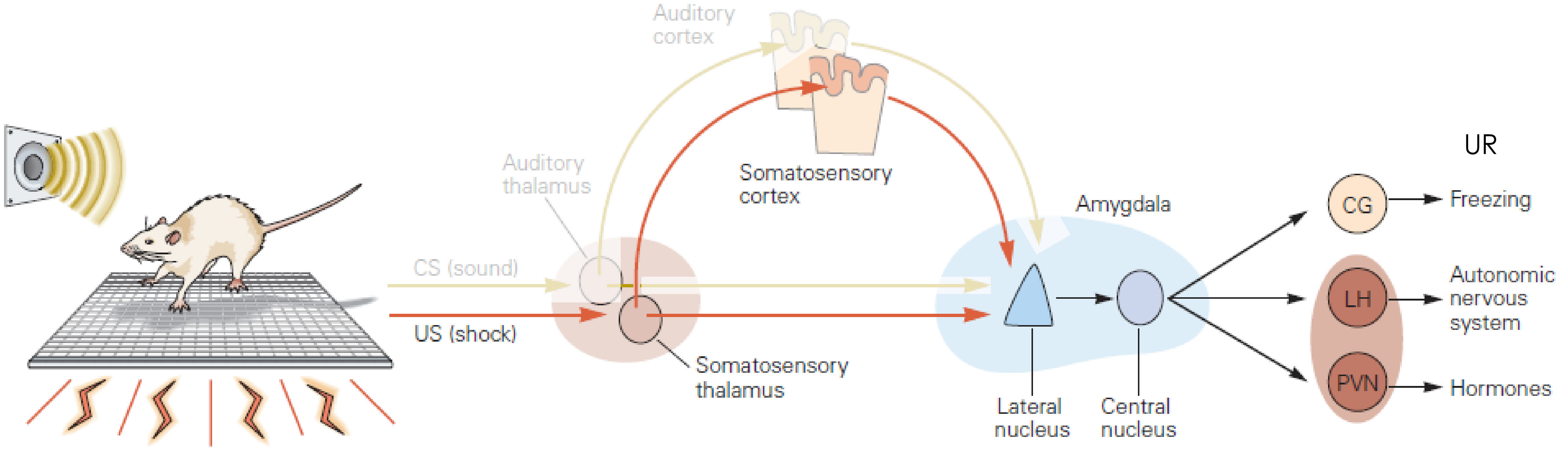
Before conditioning, the US alone activates the amygdala neurons, triggering the UR



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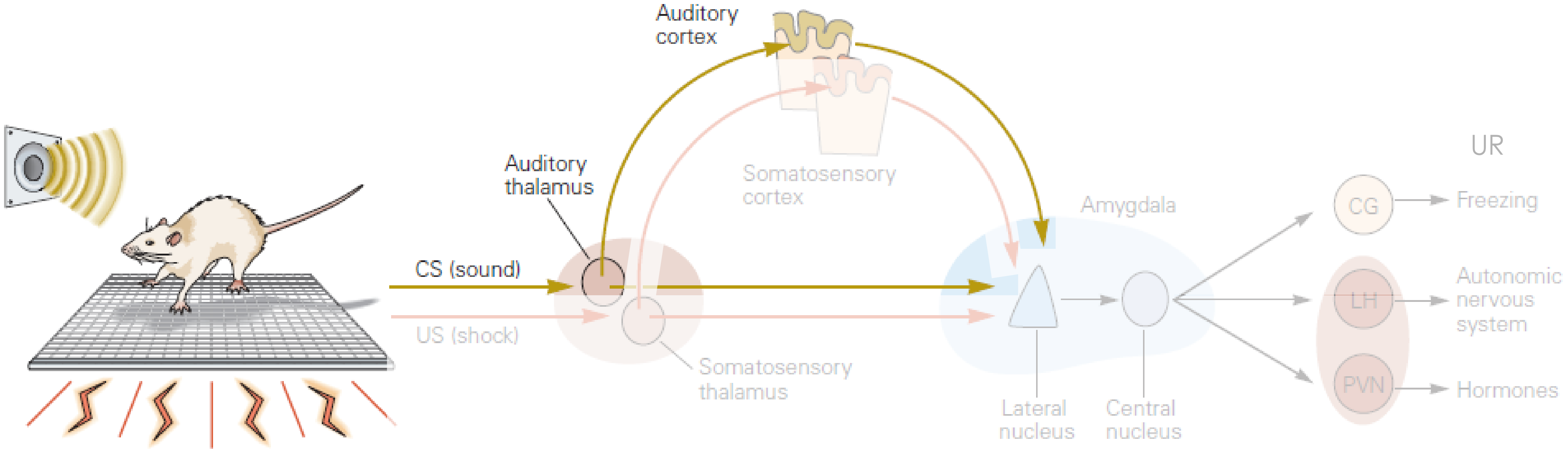
Before conditioning, the CS alone cannot activate the amygdala neurons



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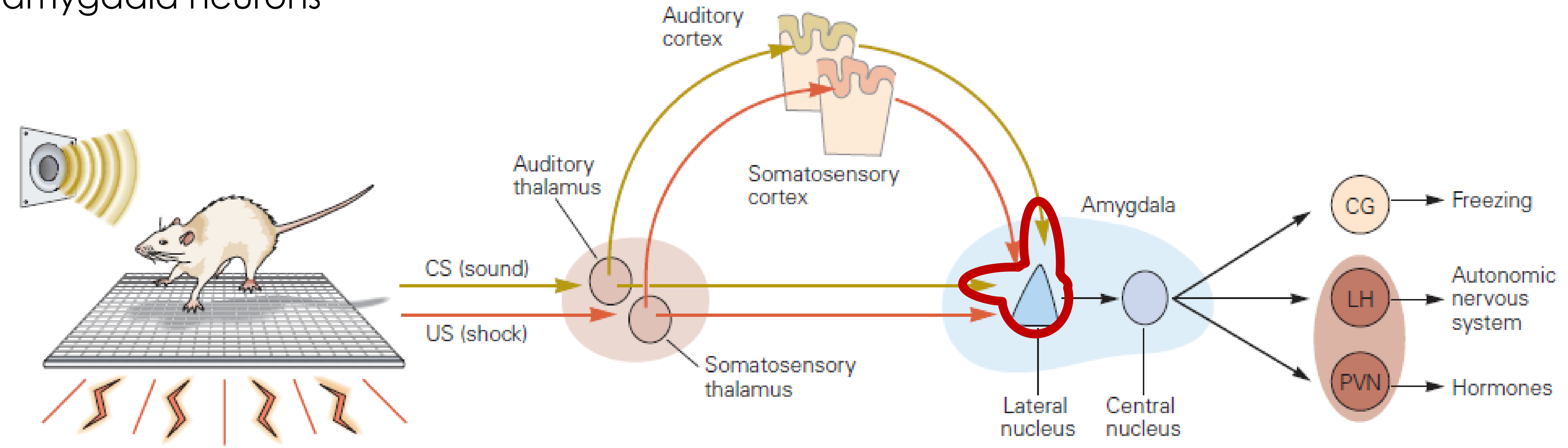
During Pavlovian conditioning, concurrent presentation of CS and US activates the amygdala neurons, thus strengthening the synaptic connections between neurons activated by the CS and amygdala neurons



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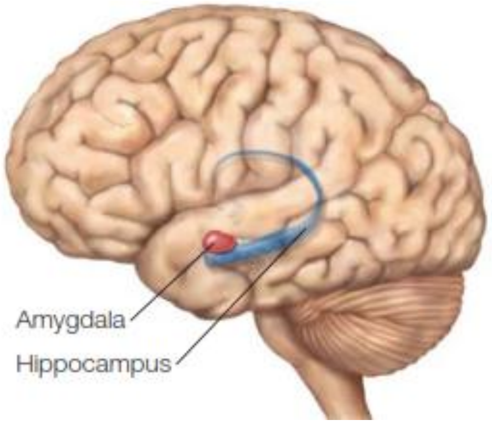
A lesion to the amygdala or hippocampus differently impair Pavlovian conditioning



2 experiments

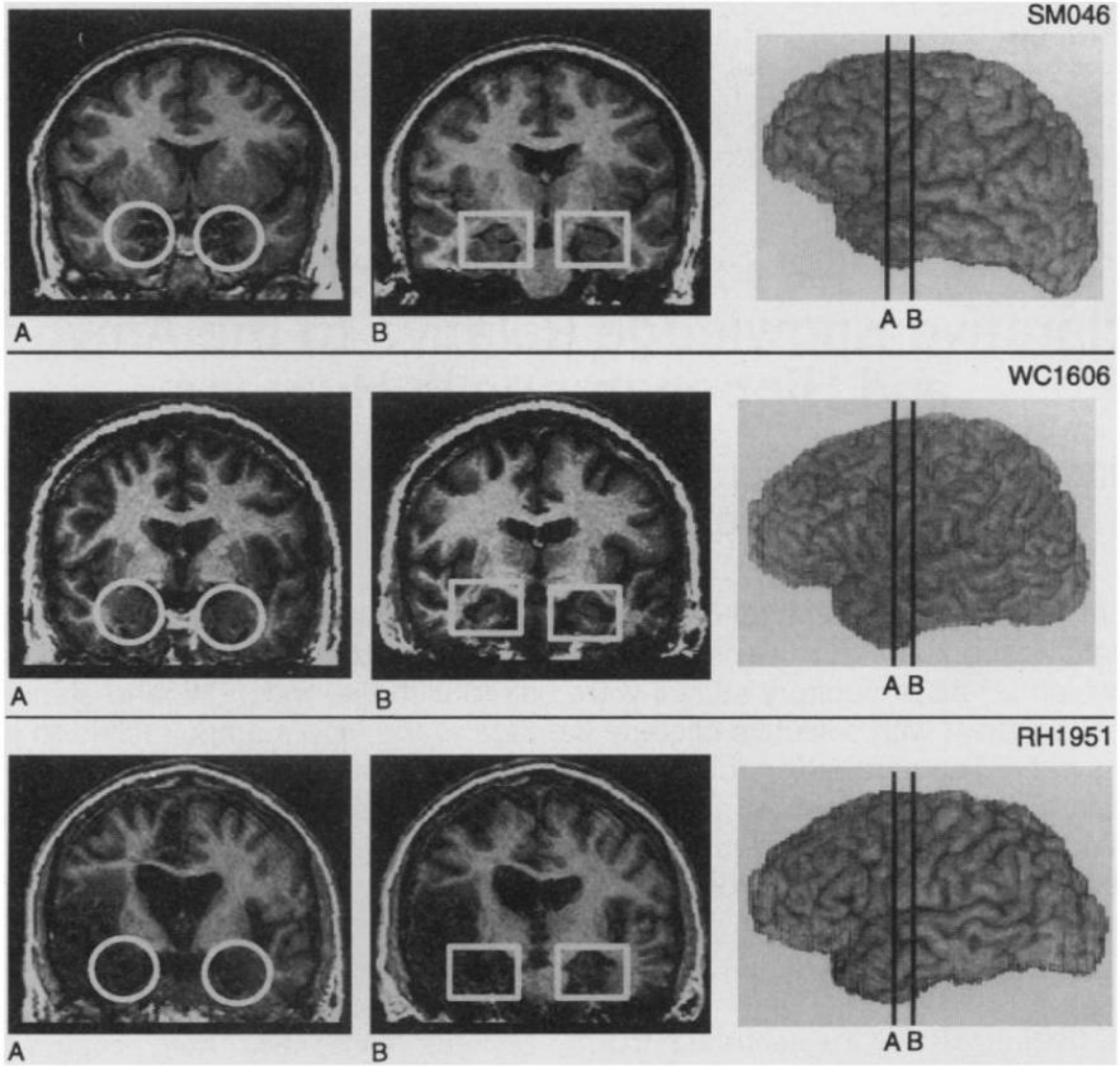
1. CS visual, US sound
2. CS sound, US sound

Participants

1. Patient with selective bilateral damage to the amygdala (SM046)
2. Patient with selective bilateral damage to the hippocampus (WC1606)
3. Patient with bilateral damage to both amygdala and hippocampal formation (RH1951)
4. 4 healthy control participants

Dependent measures

- SCR
- Verbal knowledge of CS-US association



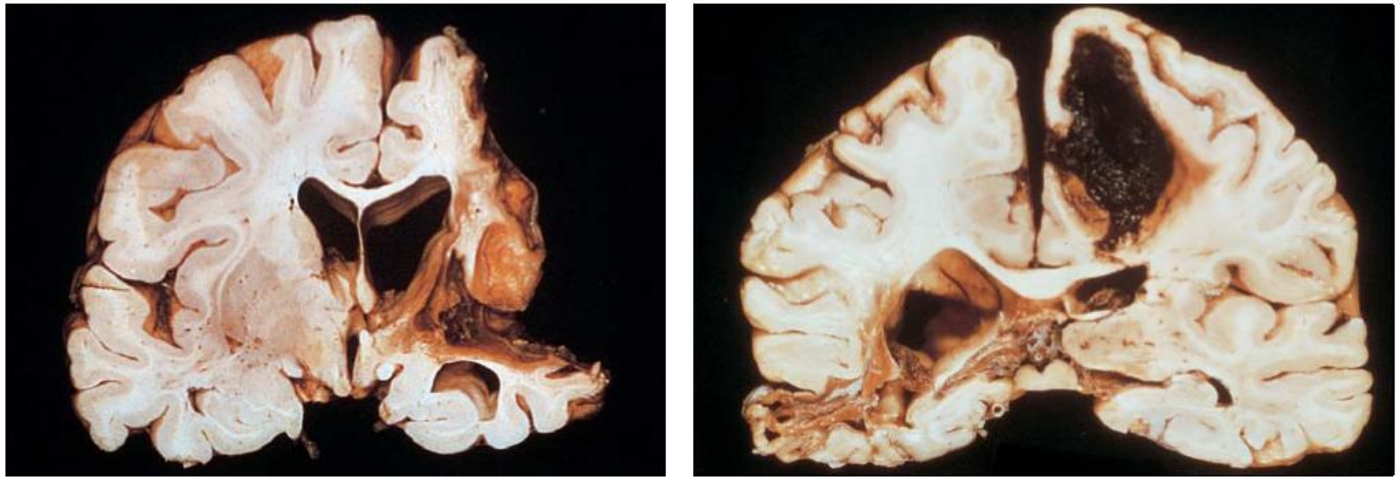
Bechara A, Tranel D, Damasio H, Adolphs R, Rockland C, Damasio AR. Double dissociation of conditioning and declarative knowledge relative to the amygdala and hippocampus in humans. Science. 1995 Aug 25;269(5227):1115-8. doi: 10.1126/science.7652558. PMID: 7652558.

Lesional method

Study of the consequences resulting from brain lesions

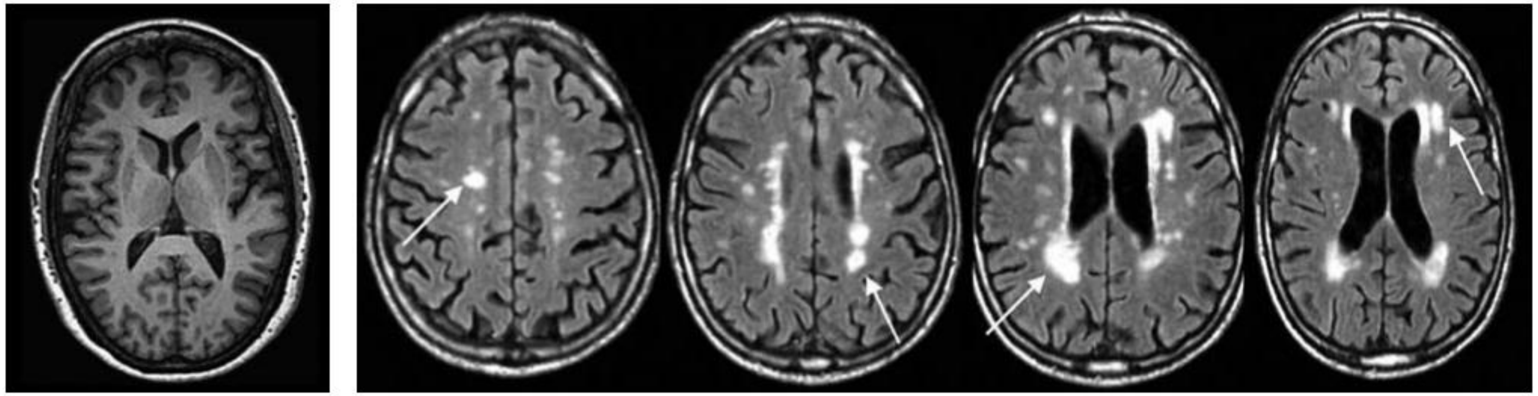
- Natural occurring (e.g. tumor, stroke, degenerative disease)
- Surgically induced to treat epilepsy
- Experimentally caused (only done in animals)

Causal evidence: which region is necessary for a given behavior or response



a b

FIGURE 3.7 Vascular disorders of the brain.
(a) Strokes occur when blood flow to the brain is disrupted. This brain is from a person who had an occlusion of the middle cerebral artery. The person survived the stroke. After death, a postmortem analysis shows that almost all of the tissue supplied by this artery had died and been absorbed. **(b)** Coronal section of a brain from a person who died following a cerebral hemorrhage. The hemorrhage destroyed the dorsomedial region of the left hemisphere. The effects of a cerebrovascular accident 2 years before death can be seen in the temporal region of the right hemisphere.



a b

FIGURE 3.8 Degenerative disorders of the brain.
(a) Normal brain of a 60-year-old male. **(b)** Axial slices at four sections of the brain in a 79-year-old male with Alzheimer's disease. Arrows show growth of white matter lesions.

A lesion to the amygdala or hippocampus differently impair Pavlovian conditioning

2 experiments

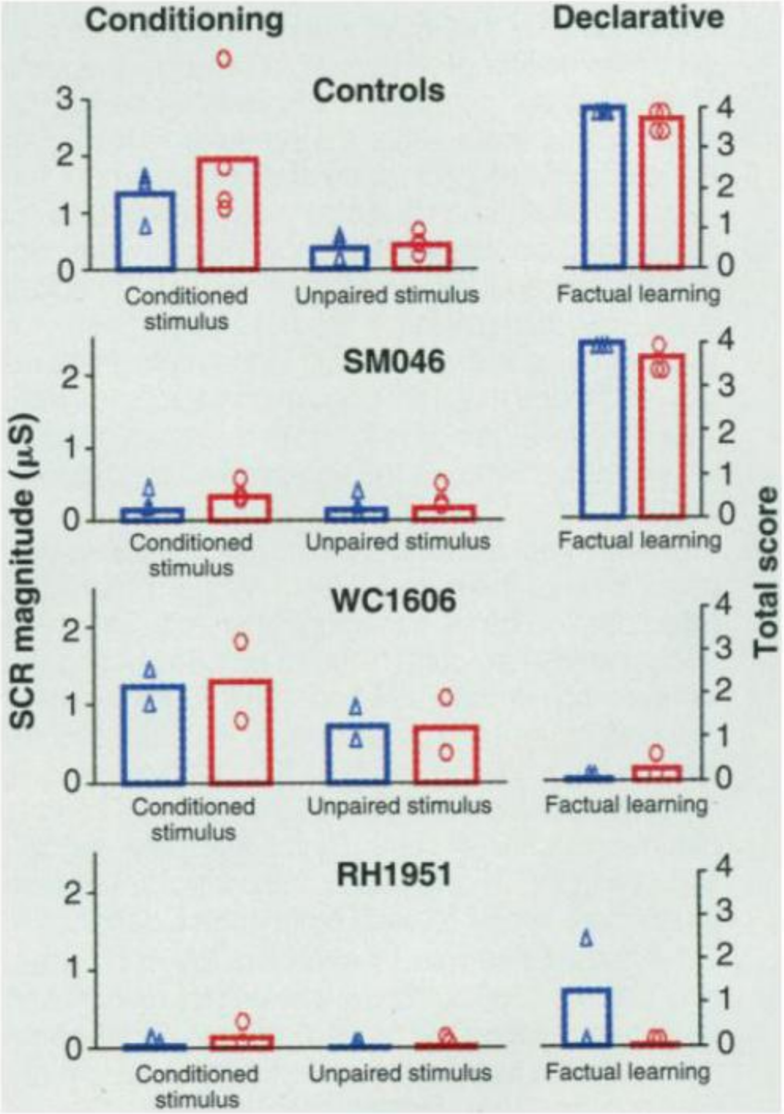
1. CS visual, US sound (blue bar)
2. CS sound, US sound (red bar)

Participants

1. Patient with selective bilateral damage to the amygdala (SM046)
2. Patient with selective bilateral damage to the hippocampus (WC1606)
3. Patient with bilateral damage to both amygdala and hippocampal formation (RH1951)
4. 4 healthy control participants

Dependent measures

- SCR
- Verbal knowledge of CS-US association



Bechara A, Tranel D, Damasio H, Adolphs R, Rockland C, Damasio AR. Double dissociation of conditioning and declarative knowledge relative to the amygdala and hippocampus in humans. Science. 1995 Aug 25;269(5227):1115-8. doi: 10.1126/science.7652558. PMID: 7652558.

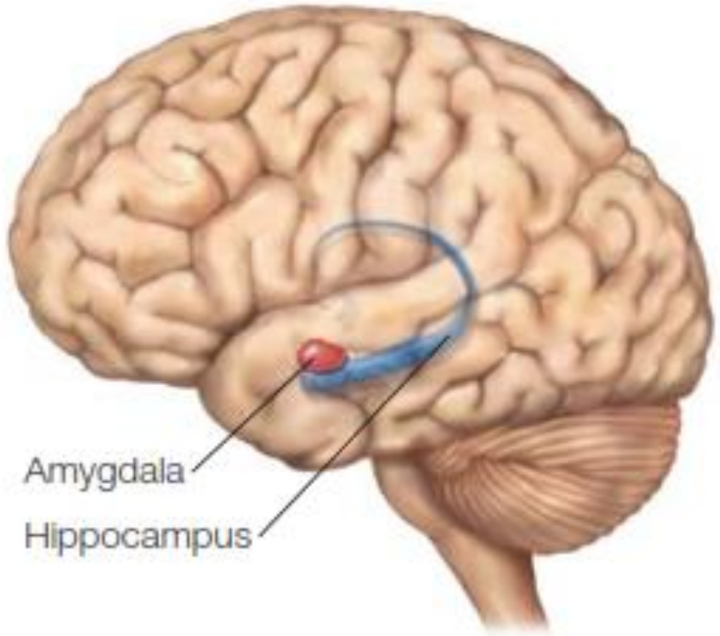
A lesion to the amygdala or hippocampus differently impair Pavlovian conditioning

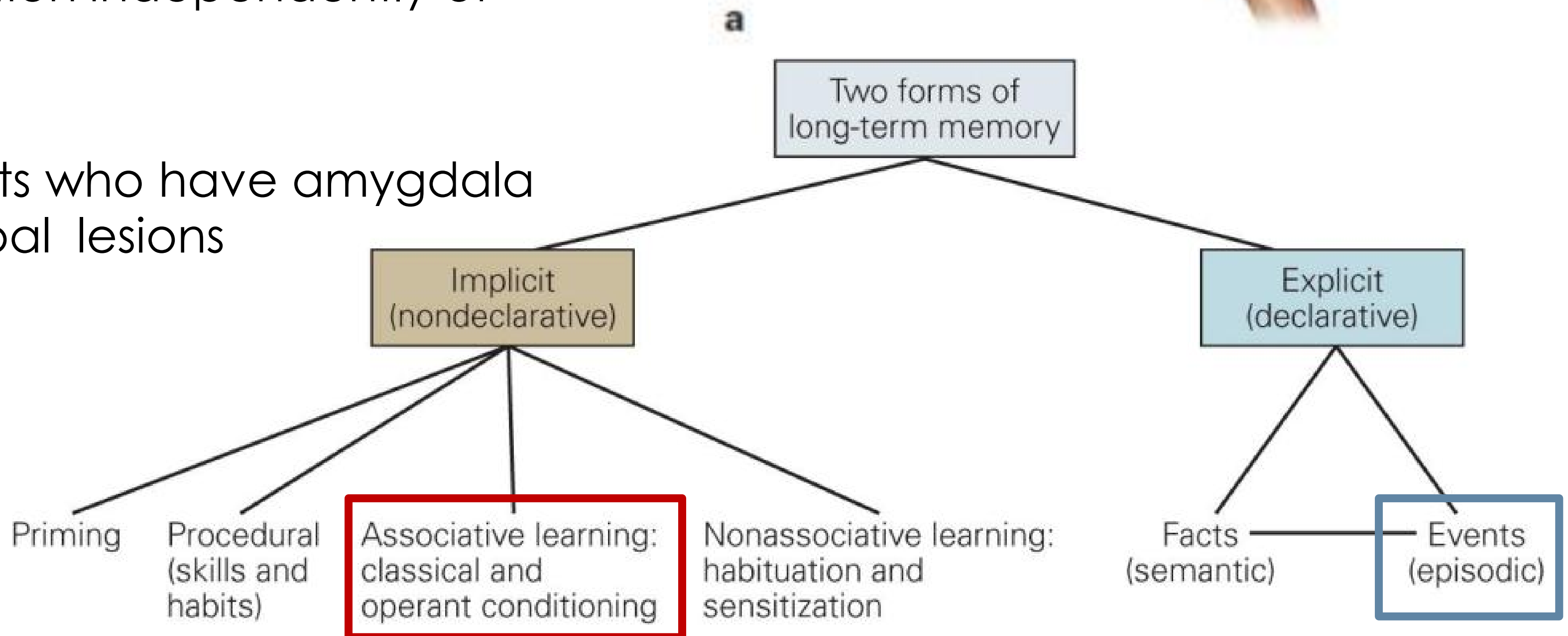
- The **amygdala** is necessary for the expression of the psychophysiological conditioned response (implicit memory)

- The **hippocampus** is necessary for the declarative expression of the CS-US association (explicit memory)

This is also an example of a "**double dissociation**": two related mental processes are shown to function independently of each other.

Double dissociation between patients who have amygdala lesions and patients with hippocampal lesions





Multiple systems contribute to learning and controlling decision-making in animals

Three learning systems enable organisms to draw on previous experience to **make predictions** about the world and to **select behaviors** appropriate to those predictions:

1. a **Pavlovian system** that learns to predict biologically significant events so as to trigger appropriate responses;

Instrumental system that comprises

2. a **habitual system** that learns to repeat previously successful actions;
3. a **goal-directed system** that evaluates actions on the basis of their specific anticipated consequences.

Pavlovian system

- Prediction learning
- Learns stimulus-outcome associations

Instrumental system

- Control learning
- Learns action-outcome associations

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Instrumental learning

Aka

Instrumental conditioning

Operant conditioning

https://youtu.be/5XUvm_smWHY

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Instrumental learning system

- Control learning
- Learns action-outcome associations
- Learn to predict
    - when reinforces are likely to occur
    - which action bring about those reinforcers
- These predictions enable the animal to produce specific actions in **anticipation** of reinforcers, instead of responding exclusively in a reactive manner once reinforcers have occurred

Instrumental learning involves associating an action with an outcome

Described by Edgar Thorndike and systematically studied by B. F. Skinner and others.

Thorndike's Law of effect:

"Of several **responses** made to the same situation, those which are accompanied or closely **followed by satisfaction** to the animal will, other things being equal, be more firmly connected with the situation, so that, when it recurs, they **will be more likely to recur**; those which are accompanied or closely **followed by discomfort** to the animal will, other things being equal, have their connections with that situation weakened, so that, when it recurs, they **will be less likely to occur**. The greater the satisfaction or discomfort, the greater the strengthening or weakening of the bond." (Thorndike, 1911)

Skinner Box

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The nature of the outcome shapes behavior

Positive reinforcement

- Delivery of rewarding outcome increases the probability of emitting the action

Positive punishment

- Delivery of aversive outcome decreases the probability of emitting the action

Negative reinforcement

- Omission of aversive outcome increases the probability of emitting the action

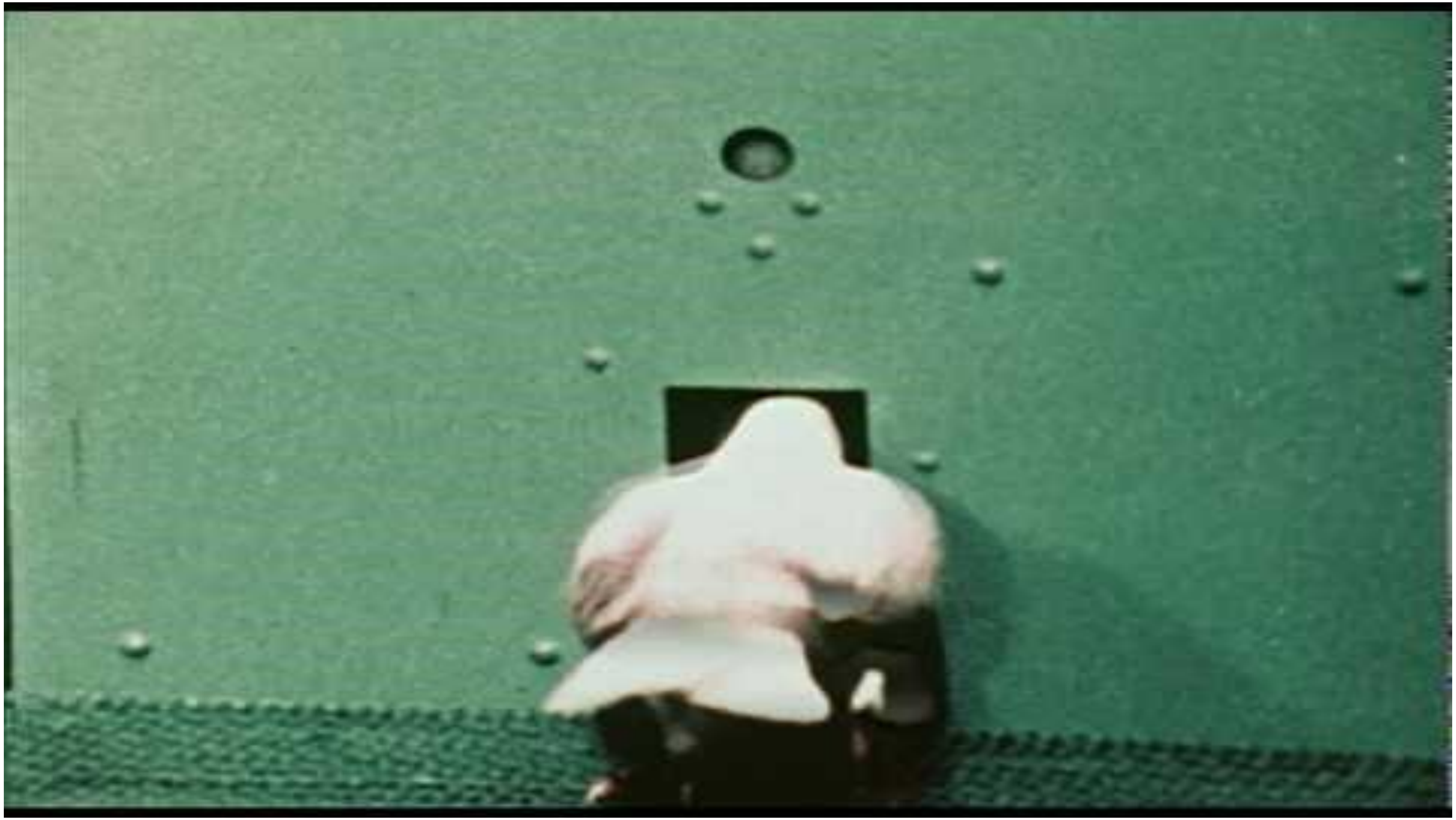
Negative punishment

- Omission of rewarding outcome decreases the probability of emitting the action

	Delivery	Omission
Appetitive	Positive reinforcement	Negative punishment
Aversive	Positive punishment	Negative reinforcement

	Delivery	Omission
Appetitive	Increases behavior	Decreases behavior
Aversive	Decreases behavior	Increases behavior

More complex behaviors can be conditioned through shaping



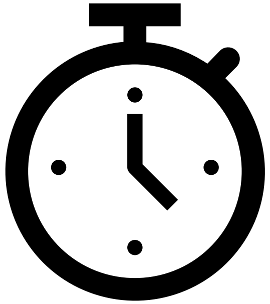
https://www.youtube.com/watch?v=TtfQlkGwE2U

Instrumental learning in everyday life

Can you come up with some examples?

Discuss in pairs:

- Examples of Instrumental learning
- Identify the
  - conditioned behavior
  - reinforcer/punishment



5 minutes

Instrumental learning in everyday life

Can you come up with some examples?

Discuss in pairs:

- Examples of Instrumental learning
- Identify the
  - conditioned behavior
  - reinforcer/punishment

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The frequency of the outcome also shapes behavior

Continuous schedule

- the desired behavior is followed by the outcome every single time it occurs
- most effective when trying to teach a new behavior

Partial schedule

- the desired behavior is followed by the outcome only part of the time it occurs
- Behaviors are acquired more slowly, but the response is more resistant to extinction

Four different partial schedules

1. **Fixed-ratio**

The outcome becomes available only after a **specified number of responses**.

This schedule produces a high, steady rate of responding with only a brief pause after the delivery of the outcome.

First learning ratio training, 2 lever presses for 1 food

Pressing the lever 10 times to get 1 reward

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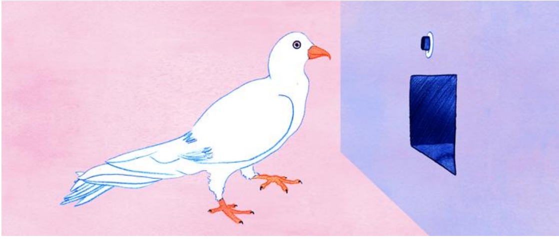
Four different partial schedules

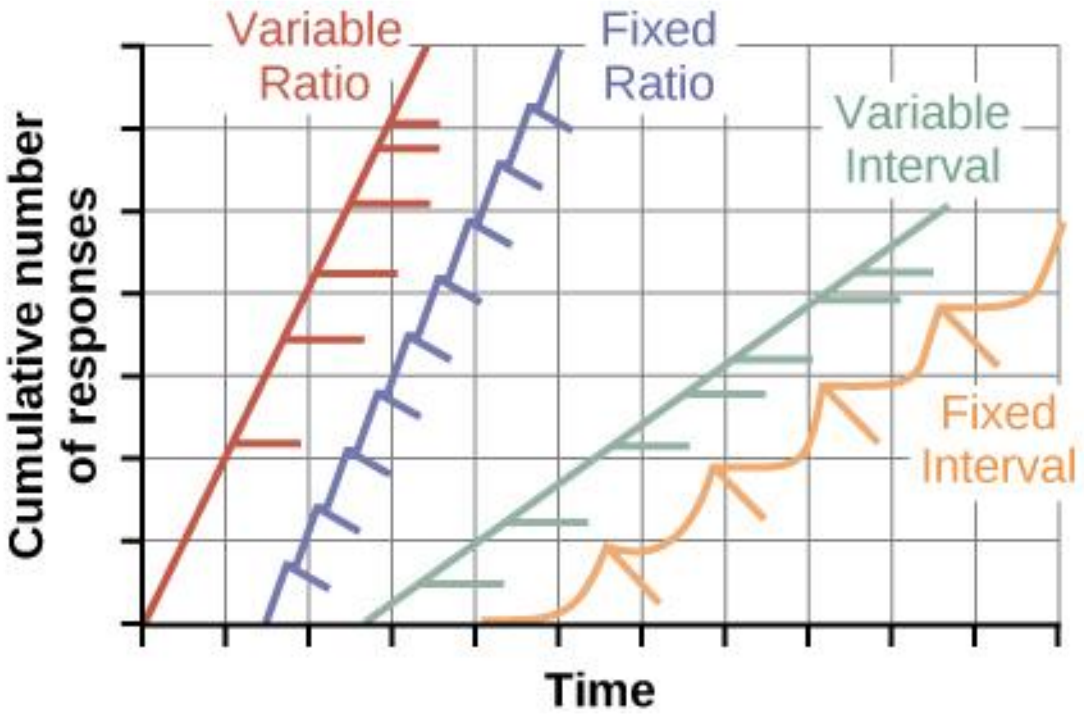


1. **Fixed-ratio**
- The outcome becomes available only after a **specified number of responses**.
- This schedule produces a high, steady rate of responding with only a brief pause after the delivery of the outcome.

2. **Variable-ratio**
- The outcome becomes available after an **unpredictable number of responses**.
- This schedule creates a high steady rate of responding.

3. **Fixed-interval**
- The outcome becomes available after a **specified interval of time**.
- This schedule causes high amounts of responding near the end of the interval but slower responding immediately after the delivery of the outcome.

4. **Variable-interval**
- The outcome becomes available after an **unpredictable interval of time.**
- This schedule produces a slow, steady rate of response.



An example in humans

https://www.youtube.com/watch?v=FuObgM9zPGc

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Different reinforcement schedules in everyday life

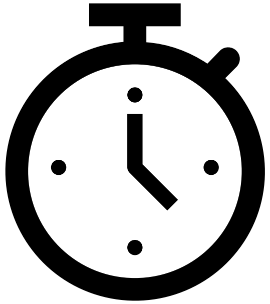
Can you come up with some examples?

Discuss in pairs:

- Examples of different reinforcement schedules

In instrumental learning

- Identify the
  - conditioned behavior
  - Reinforcer/punishment
  - Type of schedule



5 minutes

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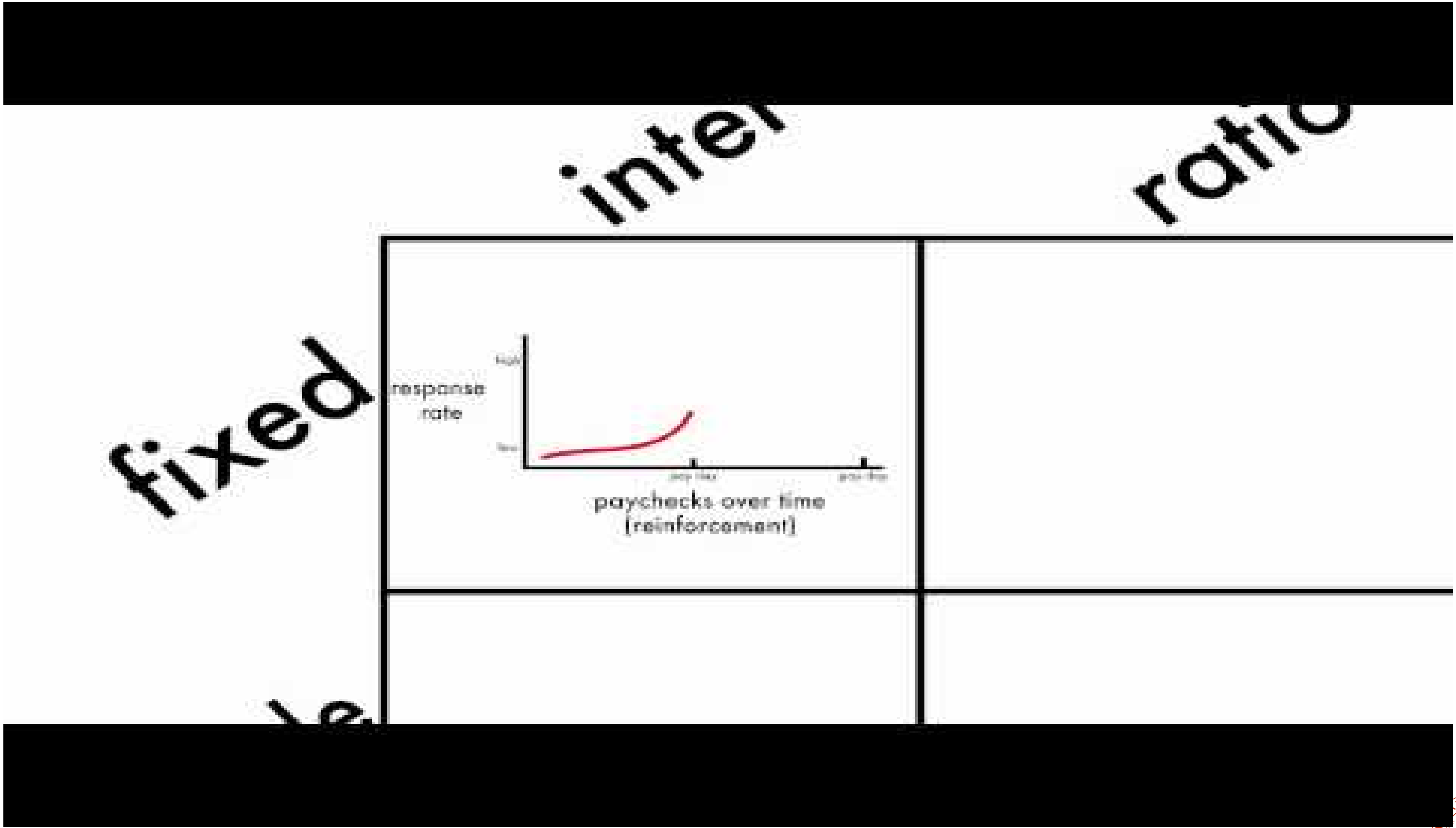
Partial reinforcement everyday life

1. Fixed-ratio
- Supermarket points
- Videogames

2. Variable ratio
- Gambling
- Lottery games



https://www.youtube.com/watch?v=GLx5yl0sxeM

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https://youtu.be/qG2SwE_6uVM

Recommended readings

- Daw, N. D., & O'Doherty, J. P. (2014). Multiple systems for value learning. In *Neuroeconomics* (Chapter 21, pp. 393-410). Academic Press.
- Gazzaniga, M. S., Ivry, R. B., & Mangun, G. R. (2014). Cognitive Neuroscience, The biology of the mind.
  - Page 393
- Kandel, E. R., Schwartz, J. H., Jessell, T. M., Siegelbaum, S., Hudspeth, A. J., & Mack, S. (Eds.). (2000). Principles of neural science. New York: McGraw-hill.
  - chapter 65 sections:
    - Implicit Memory Can Be Associative or Non-associative
    - Classical Conditioning Involves Associating Two Stimuli
    - Operant Conditioning Involves Associating a Specific Behavior with a Reinforcing Event

Revision questions

- Discuss the challenges associated with optimal decision-making, including delayed outcomes and the credit assignment problem. How do multiple learning systems in animals address these challenges?
- Compare and contrast Pavlovian and instrumental learning, providing examples of how each type of learning influences behavior in everyday life.
- Discuss how the processes of acquisition, extinction, generalization, and discrimination in Pavlovian conditioning demonstrate the flexibility of learning.
- How do conditioned responses, which are initiated in anticipation of the unconditioned stimulus, highlight the predictive nature of learning, and why is this predictive capacity advantageous for survival?
- Explain how the principles of neural plasticity underlie learning and memory. Discuss the role of synaptic changes and provide specific examples, such as the gill withdrawal reflex in Aplysia.
- Describe the process of extinction in Pavlovian conditioning. What evidence suggests that extinction is a form of new learning rather than simply forgetting? Discuss the implications of extinction for therapeutic interventions targeting maladaptive behaviors.
- Discuss the evidence related to how a lesion to the amygdala or hippocampus differently impair Pavlovian conditioning.
- Explain the different reinforcement schedules (fixed-ratio, variable-ratio, fixed-interval, variable-interval) and their effects on behavior in instrumental learning. Provide real-world examples of each schedule and discuss their implications for shaping and maintaining behavior.

Glossary of key terms

Associative Learning: A type of learning in which an association is formed between two stimuli or between a behavior and its consequence.

Classical Conditioning: (See Pavlovian Conditioning). A learning process in which an association is made between a neutral stimulus and a stimulus that naturally evokes a response.

Conditioned Response (CR): A learned response to a previously neutral stimulus (the conditioned stimulus) that occurs as a result of repeated pairings with an unconditioned stimulus.

Conditioned Stimulus (CS): A previously neutral stimulus that, after becoming associated with an unconditioned stimulus, eventually comes to trigger a conditioned response.

Continuous Schedule: A reinforcement schedule where the desired behavior is followed by the outcome every single time it occurs. This is most effective when trying to teach a new behavior.

Credit Assignment Problem: The difficulty in determining which specific actions or components are responsible for a particular outcome, especially when the outcome is delayed or depends on a series of actions.

Extinction: The process by which a conditioned response decreases or disappears when the conditioned stimulus is repeatedly presented without the unconditioned stimulus.

Glossary of key terms

Fixed-Interval Schedule: A reinforcement schedule in which the outcome becomes available after a specified interval of time.

Fixed-Ratio Schedule: A reinforcement schedule in which the outcome becomes available after a specified number of responses.

Goal-Directed System: A learning system that selects actions on the basis of their specific anticipated consequences.

Habitual System: A learning system that learns to repeat previously successful actions.

Habituation: A decrease in an innate response to a stimulus that is presented repeatedly.

Hebb's Law: Also known as Hebbian plasticity, it states that neurons that fire together, wire together.

Instrumental Conditioning: (See Operant Conditioning). A learning process in which behaviors are strengthened or weakened depending on their consequences (rewards or punishments).

Instrumental System: A learning system that learns action-outcome associations; this is also known as control learning.

Glossary of key terms

Learning: An enduring change in response or behavior that occurs as a result of experience.

Negative Punishment: The omission of a rewarding outcome that decreases the probability of emitting the action.

Negative Reinforcement: The omission of an aversive outcome that increases the probability of emitting the action.

Non-Associative Learning: A change in response or behavior that is caused by learning about the properties of a single stimulus.

Operant Conditioning: (See Instrumental Conditioning). A type of learning in which behavior is strengthened if followed by a reinforcer or diminished if followed by a punisher.

Partial Schedule: A reinforcement schedule where the desired behavior is followed by the outcome only part of the time it occurs.

Pavlovian Conditioning: (See Classical Conditioning). A learning process in which an association is made between a neutral stimulus and a stimulus that naturally evokes a response.

Pavlovian System: A learning system that learns stimulus-outcome associations; this is also known as prediction learning.

Glossary of key terms

Plasticity: The ability of neural connections to be modified by experience and learning.

Positive Punishment: The delivery of an aversive outcome that decreases the probability of emitting the action.

Positive Reinforcement: The delivery of a rewarding outcome that increases the probability of emitting the action.

Primary Reinforcer: A stimulus that is biologically prepared to elicit a response and is inherently rewarding or punishing.

Reinforcer: A stimulus or event that causes a change in response.

Secondary Reinforcer: A stimulus that comes to elicit a response following associative learning.

Sensitization: An increase in an innate response to a stimulus that is presented repeatedly.

Unconditioned Response (UCR): An unlearned, natural response to an unconditioned stimulus.

Unconditioned Stimulus (UCS): A stimulus that naturally and automatically triggers a response without any prior learning.

Variable-Interval Schedule: A reinforcement schedule in which the outcome becomes available after an unpredictable interval of time.

Variable-Ratio Schedule: A reinforcement schedule in which the outcome becomes available after an unpredictable number of responses.