Emotion and Motivation

Part 1: The Hypothalamus, the Amygdala, and the Midbrain

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2023-09-01

Contents

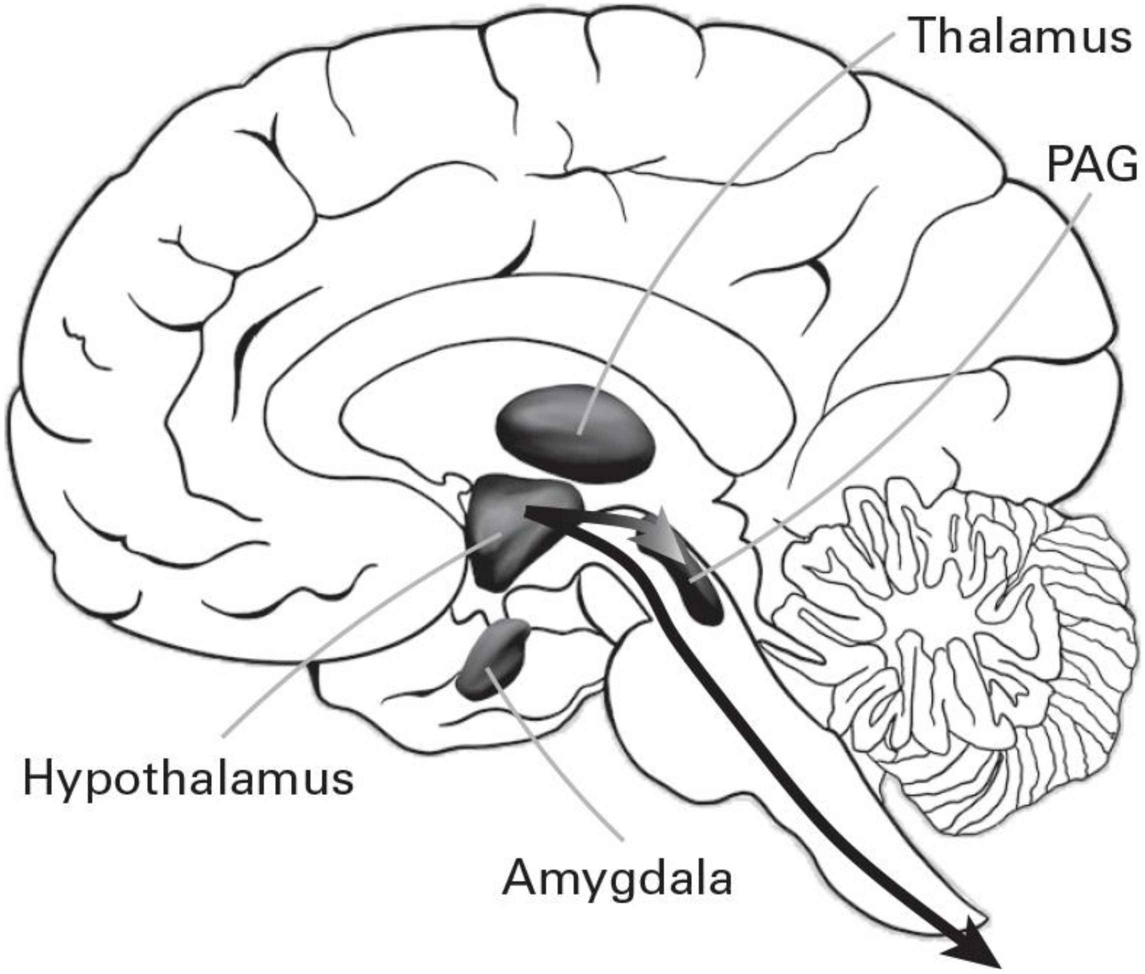
Introduction

- The ***hypothalamus*** and the ***amygdala*** were believed to be central to processing emotion.
- The ***striatum*** and regions in the ***midbrain*** that produce **dopamine** play an essential role in reward and motivation.
- But we will see that there is no single “emotion brain region”, and that all mental functions rely on distributed circuits.

“Higher” Cortex, “Lower” Subcortex

- 19C thinking was that ***emotion*** was a “***below the cortex***” function
- **Friedrich Goltz**’s finding that animals with an excised cortex still exhibited uncontrolled “rage” reactions was consistent with this hierarchical way of thinking
- **John Hughlings Jackson** embraced a ***hierarchical view*** of brain organization rooted in a logic of evolution as a process of the gradual accrual of more complex structures atop more primitive ones
- **Sigmund Freud**’s framework of the ***id*** (the lower level), the ***superego*** (the higher level), and the ***ego*** (in-between role between the other two) reflected this view

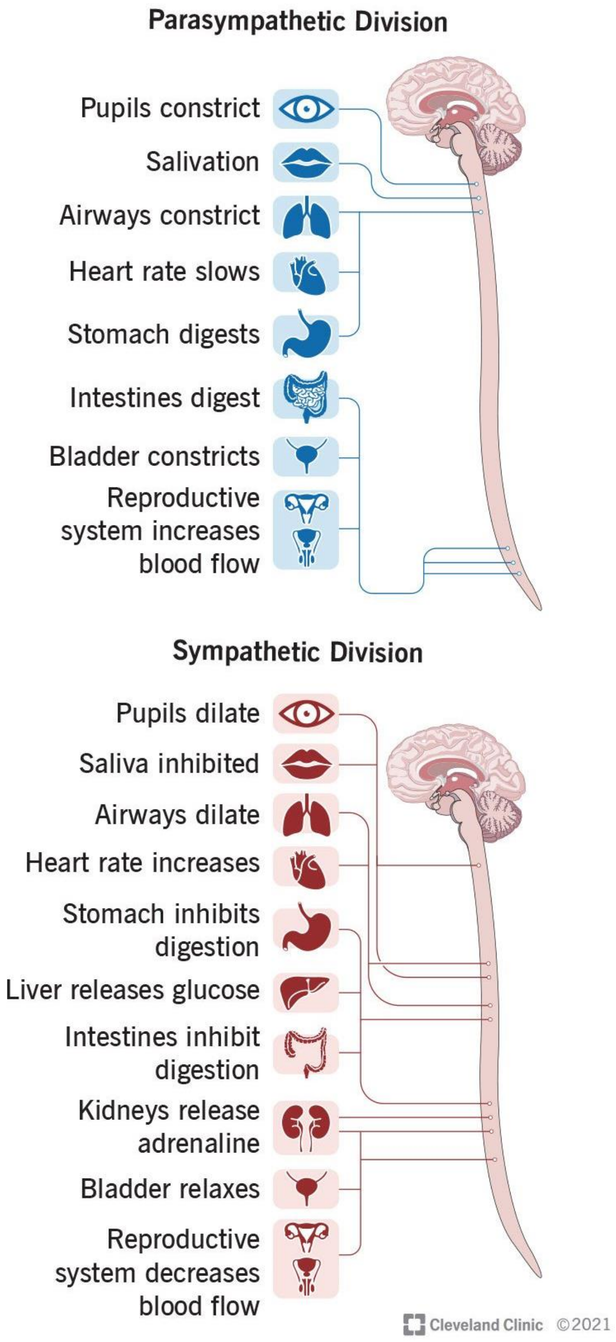
The Hypothalamus



- Participates in homeostatic mechanisms
- Contributes to neuroendocrine outputs
- Contributes to circadian rhythm, wakefulness, sleep, stress responses, temperature regulation, food intake, thirst, sexual and defensive behaviors.
- Projections from the hypothalamus contact brainstem sites (including ***PAG***) and the spinal cord

The Autonomic Nervous System

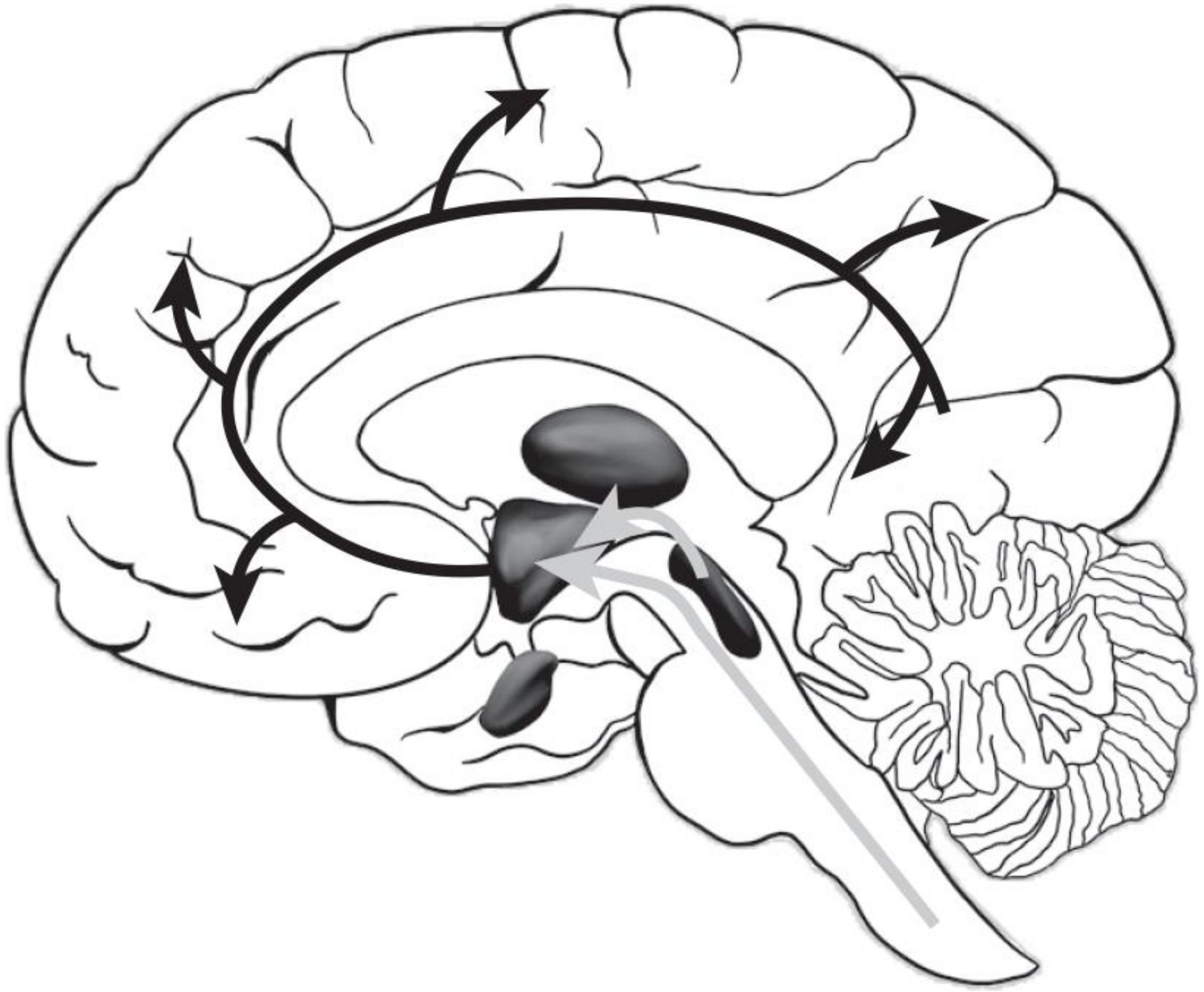
- The ***Peripheral Nervous System*** contains the nervous system other than the brain and spine
- The ***Autonomic Nervous System*** consists of the neurons that innervate the internal organs, the bloods vessels, and the glands
  - The ***Sympathetic Subdivision*** triggers responses during a crisis: fight, flight, fright, and sex
  - The ***Parasympathetic Subdivision*** facilitates digestion, growth, immune responses, and energy storage

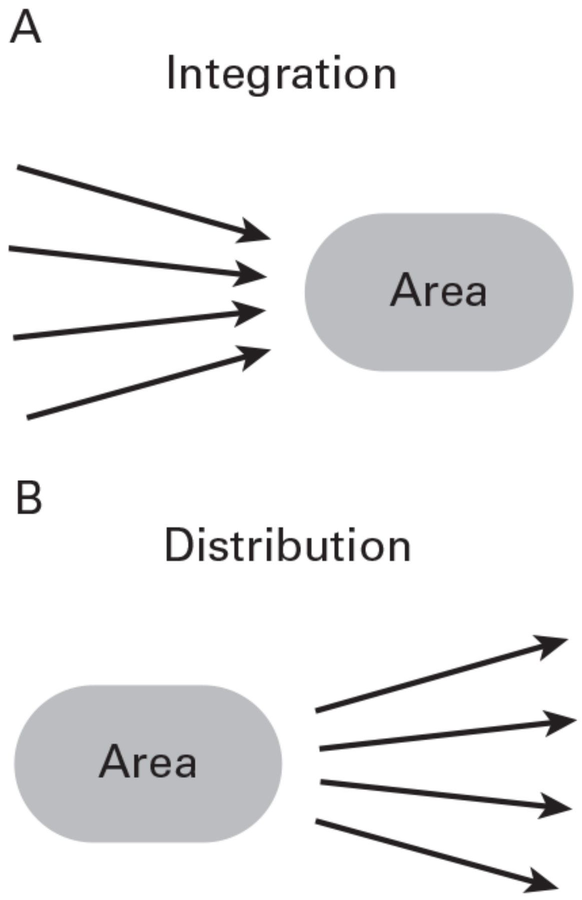


The Hypothalamus is Multifaceted

- So, the textbooks picture the hypothalamus as a sort of ***master controller*** that ***governs*** structures of the brainstem and spinal cord.
  - A hierarchical, class-based view of brain functions!
  - The image in the previous slide illustrates outgoing connections of the hypothalamus
- However, connections in the brain have a general tendency to be ***bidirectional***.
- While signals from the hypothalamus go everywhere along the cortex, ***the hypothalamus also listens*** to what is happening in the cortex and the brainstem
  - Recall) it provides internal contextual input to the superior colliculus in the ***minimal brain***

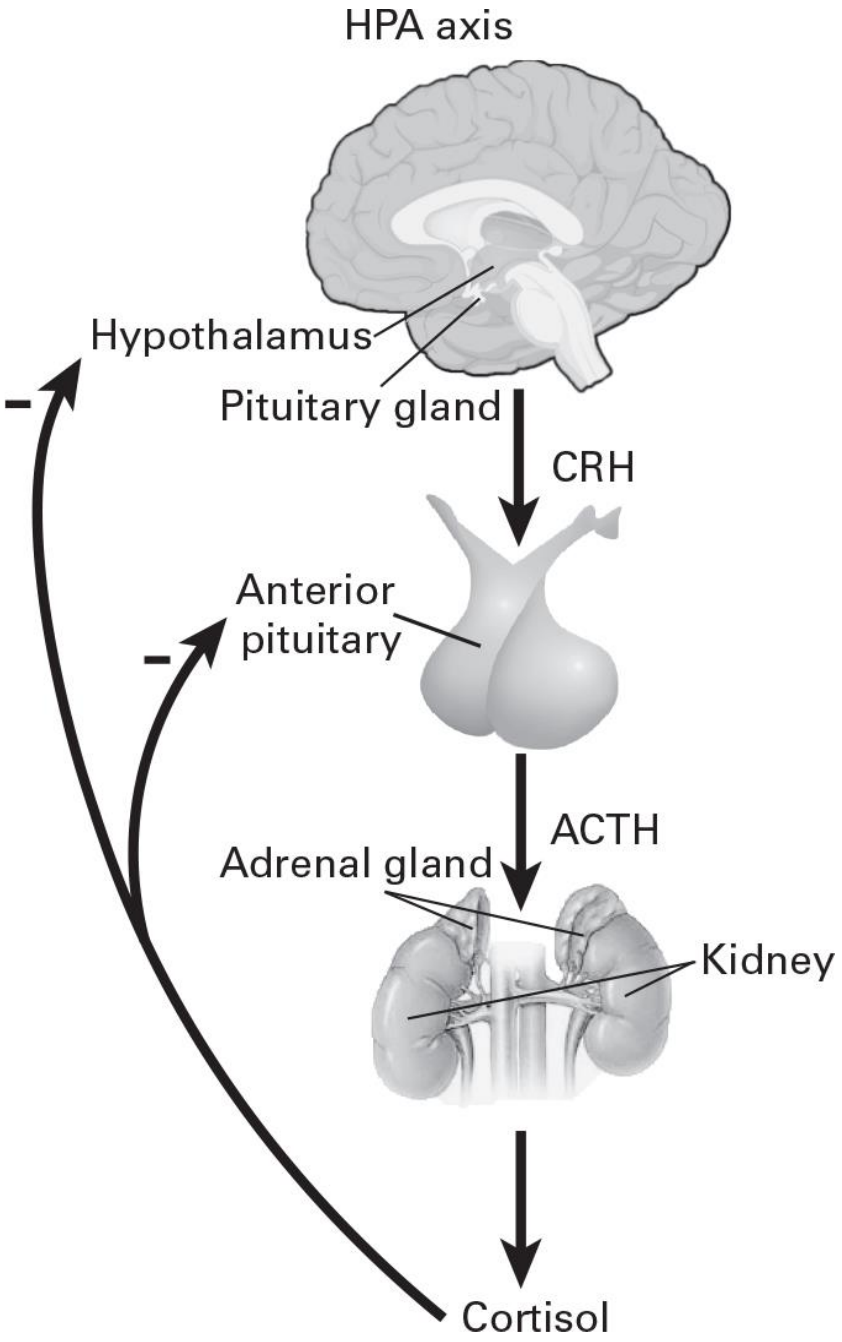
The Better Picture: Integration & Distribution





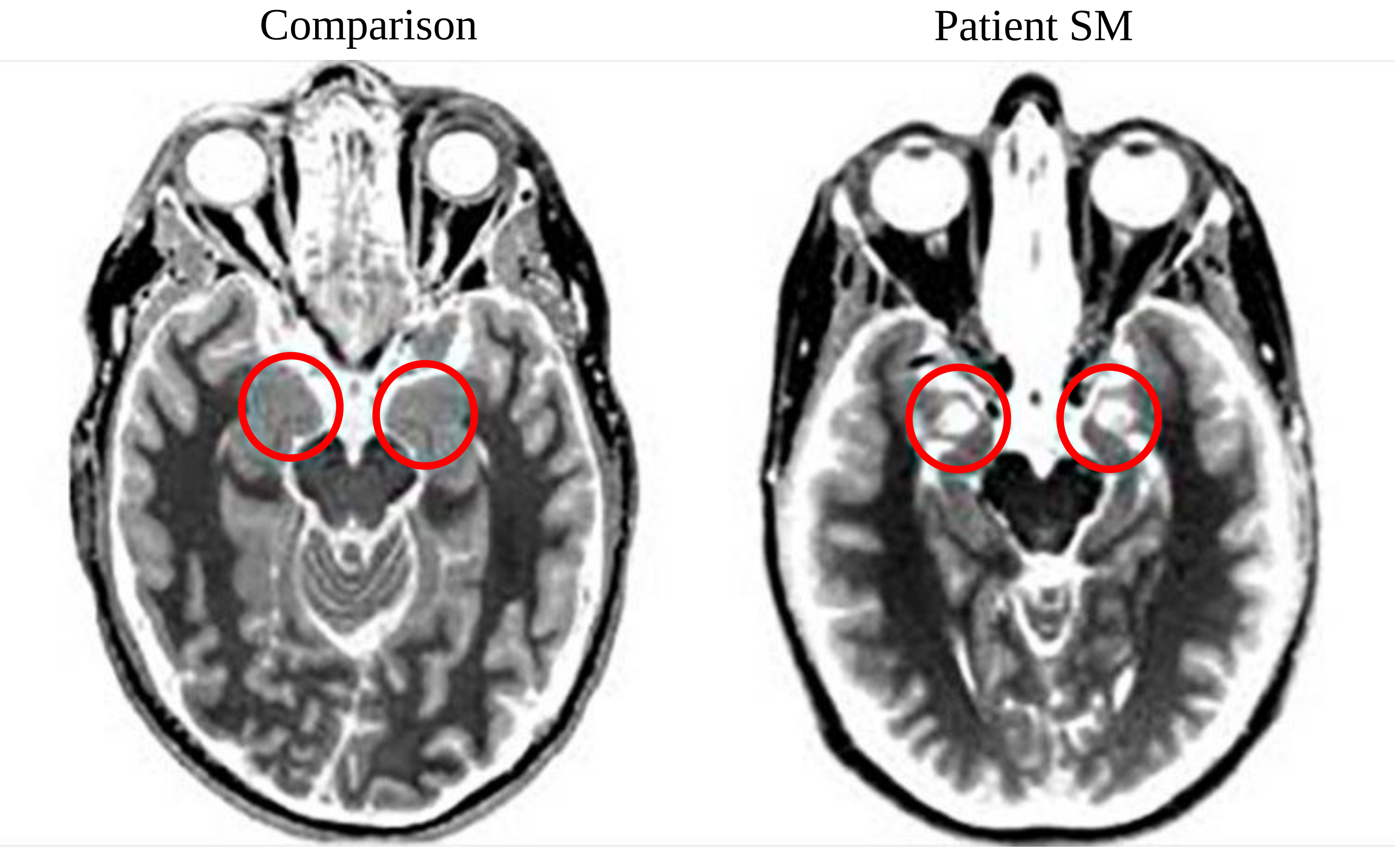
Stress Response

- Neurons in the hypothalamus ***synthesize*** corticotropin-releasing hormone
- The same neurons ***integrate*** stress-relevant signals and ***launch*** the stress response
- CRH → ACTH → cortisol, corticosterone
  - ACTH is released from the Anterior pituitary
  - Glucocorticoids are released from Adrenal glands.
- Blood pressure and glucose levels increase while inflammatory and immune responses are suppressed

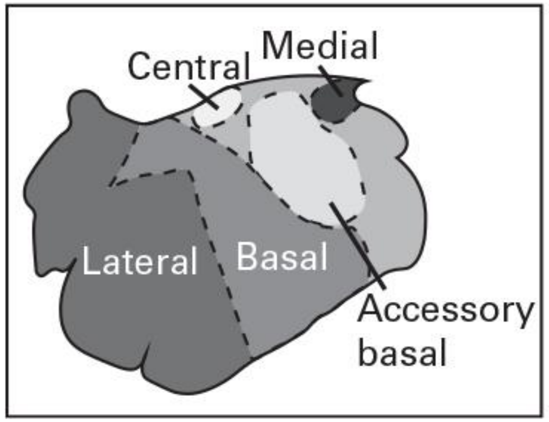


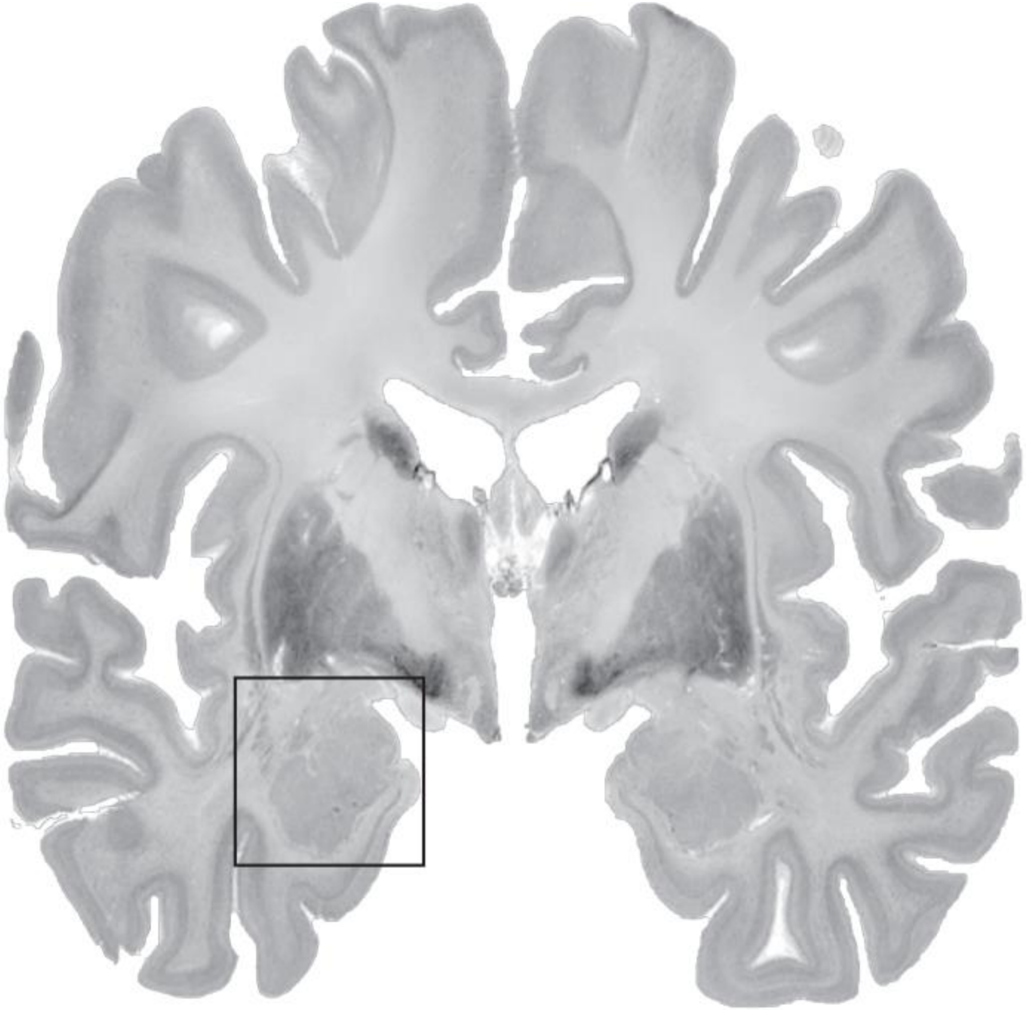
Patient S.M.

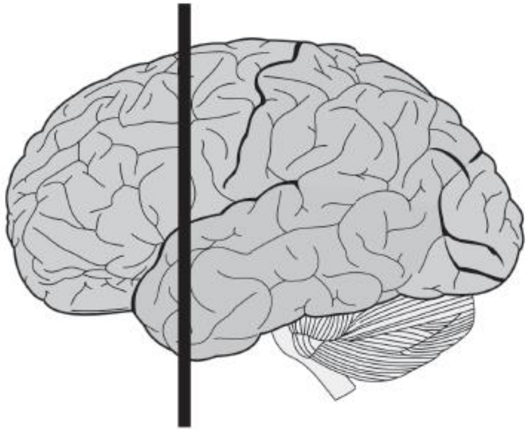
- A nearly complete natural lesion of the ***amygdala*** in both brain hemispheres
- Patient S.M.'s ***first experience*** of fear was in her mid-forties
- 14 seconds after inhaling CO_2, she exclaimed, "Help me!"



The Amygdala







The Amygdala: Media Star

≡ 강사뉴스 책과 사람 북세미나 인터뷰 칼럼 검색어를 입력해주세요

홈 > 칼럼

[강은영의 뇌공학 이야기] 부정적인 당신, 긍정의 힘을 얻고 싶다면? 편도체의 흥분을 억제해라!

강은영 칼럼니스트 | 입력 2021.10.08 07:58

가 가

The Amygdala: Media Star

동아사이언스

인간

감정을 담당하는 뇌 부위 편도체가 '식탐'도 조절해

2023.07.08 08:00

과학

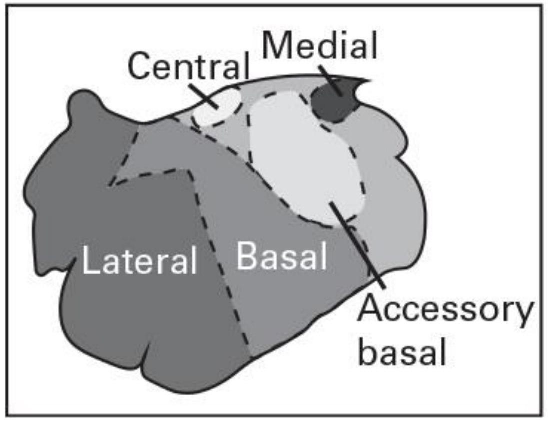
편도체 무디면, 공포영화 마니아 될 수도

2023.07.07 13:31

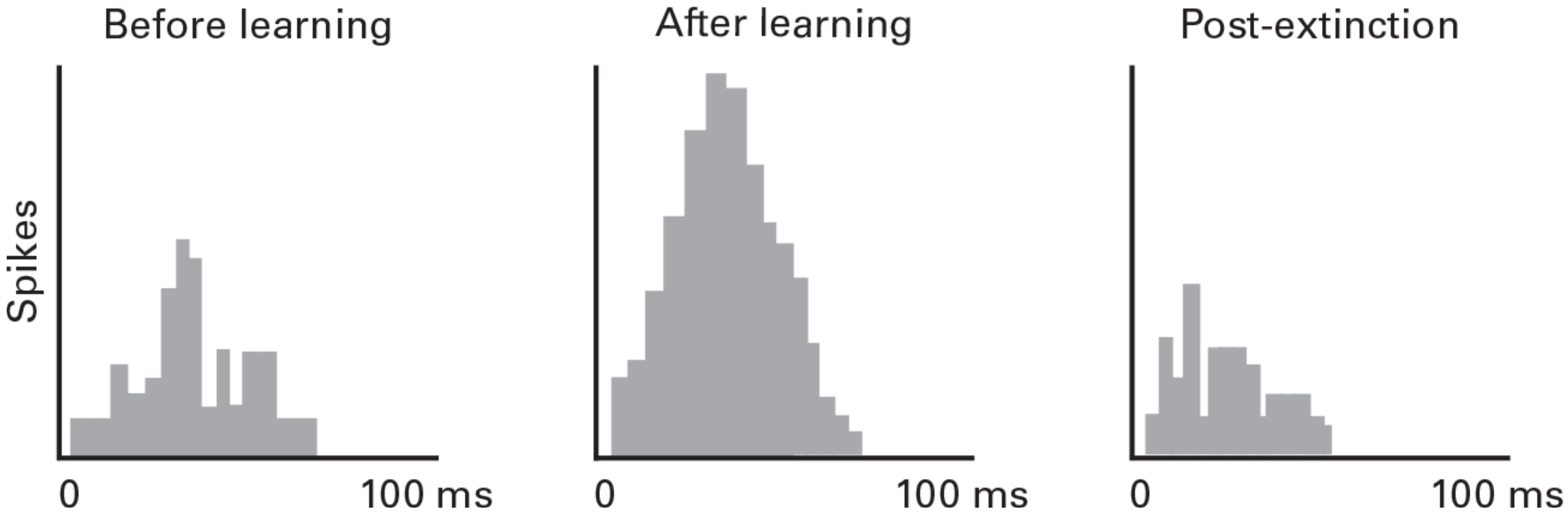
김원 상계백병원 교수, "편도체 예민도 사람마다 달라"

The Basolateral Amygdala: Aversive Learning

- The ***basolateral amygdala*** is critical for learning the aversive significance of an initially neutral stimulus
  - o The process can be studied by employing Pavlovian conditioning techniques or lesion studies
  - o Modern genetic techniques confirm that plasticity in the basolateral amygdala is necessary



Amygdala cell responses →



Classical Conditioning Rules

- A simple linear prediction of reward/punishment: the ***Rescorla-Wagner rule***
- Stimulus $\boldsymbol{u}$, expected feedback v, weight $\boldsymbol{w}$ has the relation,

$$v = \boldsymbol{w} \cdot \boldsymbol{u}$$

where the weights evolve to minimize the difference between v and the actual feedback r

- The weights evolve according the following algorithm,

$$\boldsymbol{w} \to \boldsymbol{w} + \epsilon \delta \boldsymbol{u}, \qquad \delta = r - v$$

- We can develop the model further, such as by introducing ***temporal differences*** so that the network learns to predict future reward. (the field of reinforcement learning)

The Central Amygdala: Emotional Responses

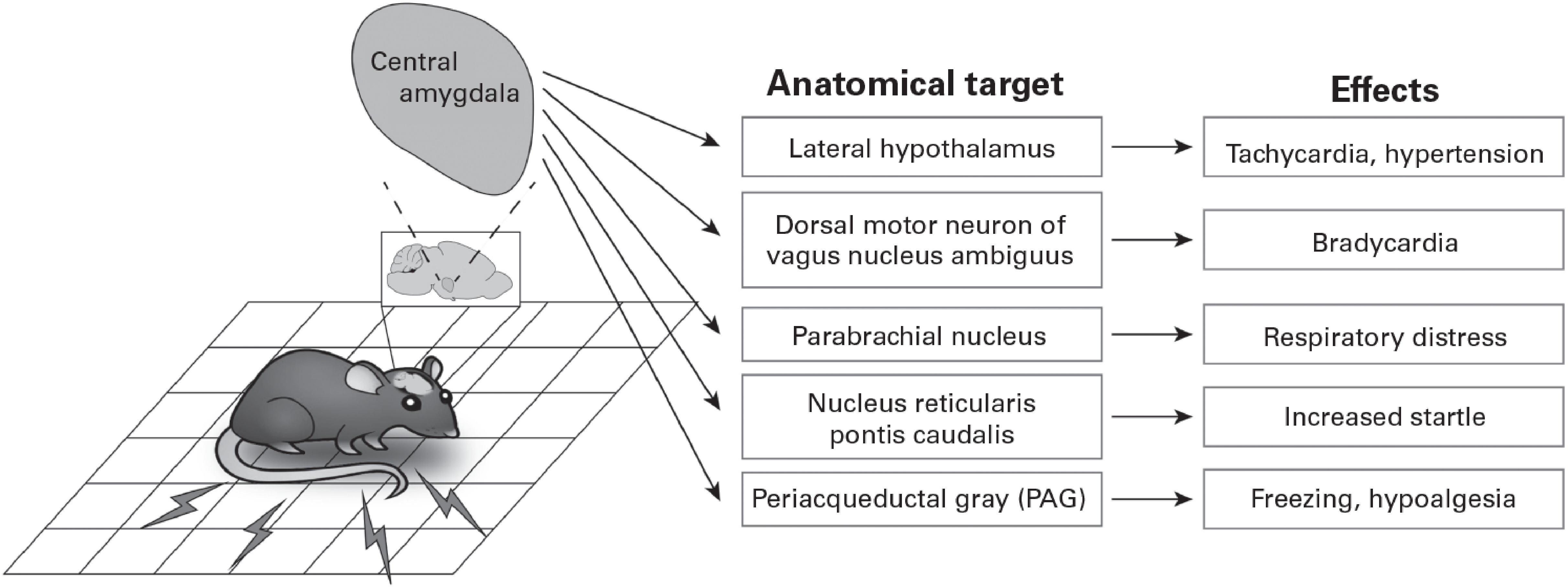
- Central Amygdala → PAG (which contributes to defensive behaviors)

  → hypothalamus (which contributes to autonomic systems)

  → parts of the brainstem (which potentiate motor responses)

- The central amygdala also projects to the ***locus coeruleus*** and other brainstem sites
  - Norepinephrine, dopamine, serotonin, acetylcholine
  - Augments the signal processing of motivationally relevant stimuli
  - A neutral stimulus may acquire affective significance

The Central Amygdala: Emotional Responses



Extra-Amygdalar Fear Circuits

- How did patient S.M. experience fear when breathing CO_2?
- CO_2-sensitive chemoreceptors engage sensory pathways that project to the brainstem
  - A likely scenario implicates the PAG
- As important is it is for fear learning, the amygdala is ***not the sole region*** critical for it.
- Sites like the ***thalamus and the cortex*** undergo changes during aversive conditioning.
- Fear conditioning engages a ***broader and more complex circuit*** than initially thought.

Automaticity of the Amygdala

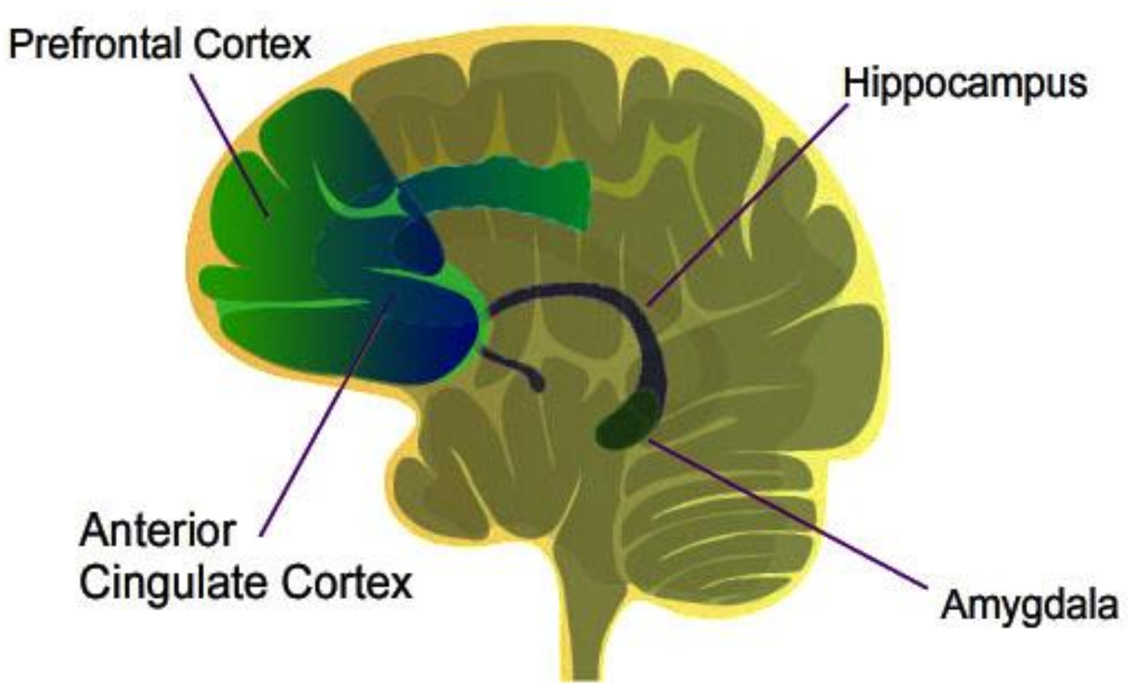
- Researchers measured responses in the amygdala even when the participants where not consciously aware of them.
- Then, are amygdala responses ***automatic***? i.e., effortless, nonconscious, involuntary
  - Defects in this system might underlie phobias, mood disorders, and PTSD
- The current answer: There is evidence that emotion-laden stimuli are more potent than neutral ones, but ***not as strong as "no matter what"***
  - Advice for anxiety: Focus on something challenging.
  - If your attention is consumed by a challenging task, emotional content in unattended stimuli do not produce detectable differences in response

Perception is Not Passive!

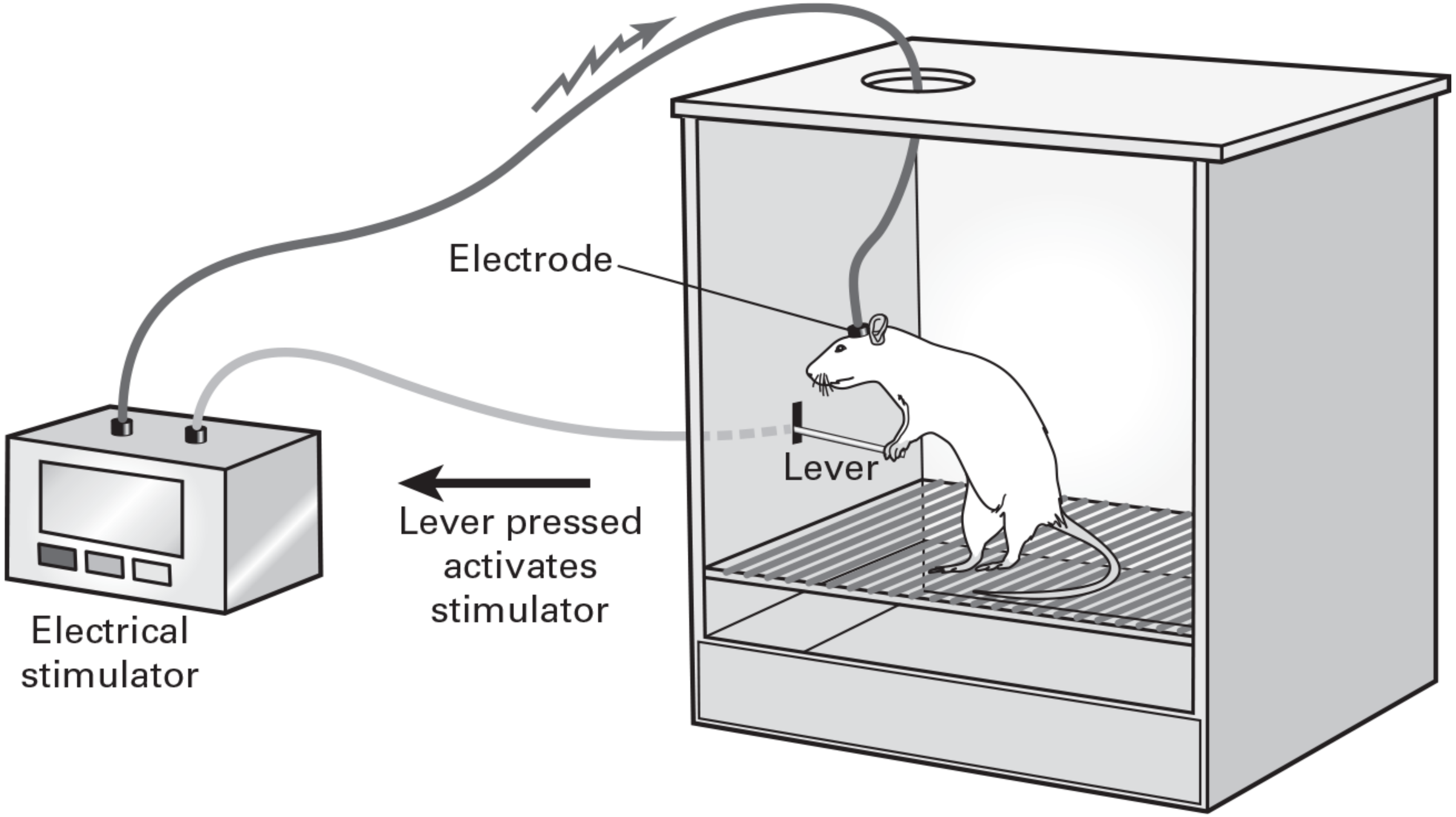
- Areas in the occipital and temporal cortex (visual processing) are strongly engaged by emotion-laden stimuli
  - But many other circuits are likely involved (Pessoa 2013).
- Participants detected emotionally significant pictures better than neutral ones
  - Pictures of houses and skyscrapers were shown, and a mild electric shock was used for conditioning
  - The amygdala seems intimately involved in ***selective information processing***
- Perception is not passive! What you ***see*** is what you ***value***.

The Amygdala is More than a Fear Module

- There are fMRI studies that demonstrate how the activity in the basolateral amygdala can predict decisions and actions of monkeys and saving plans of humans.



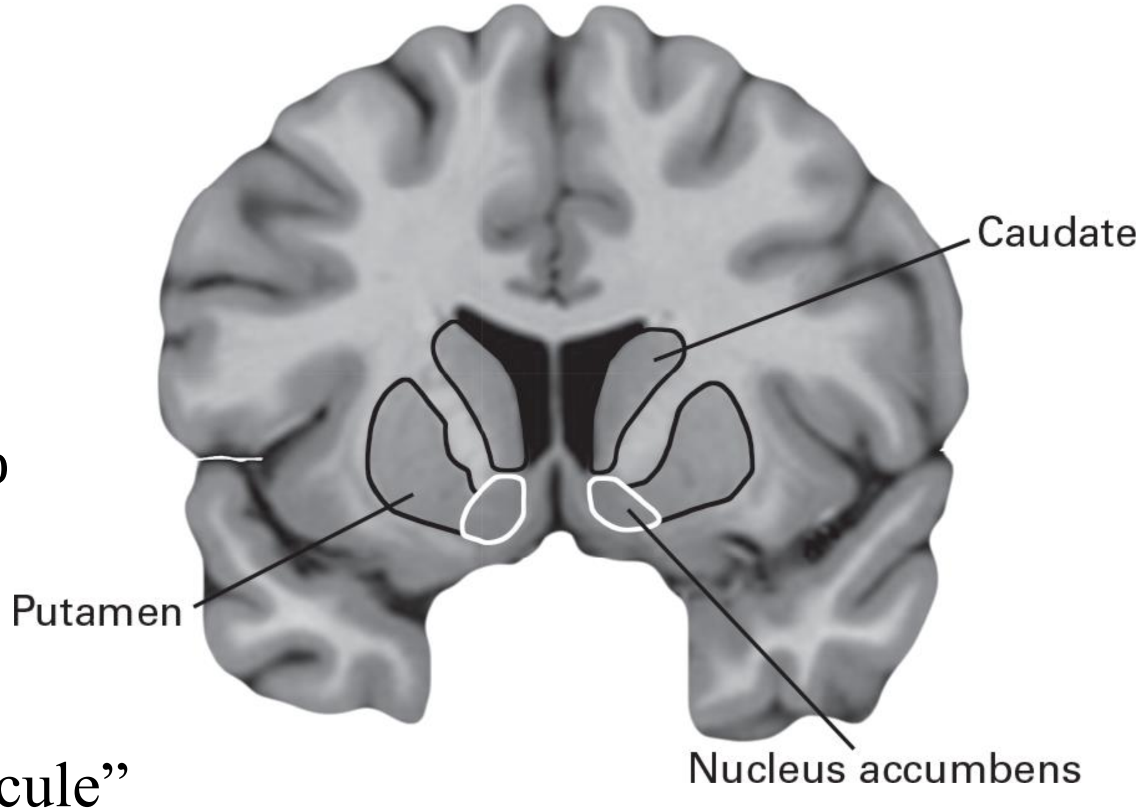
Motivation & The Midbrain



- The field of motivation focuses on understanding how animals seek rewards
- Olds and Milner, 1954
- Rats with electrodes placed in the ***hypothalamus*** would self-stimulate 2000 presses/hour
- When switched to parts of the ***midbrain***, 7000 presses/hour

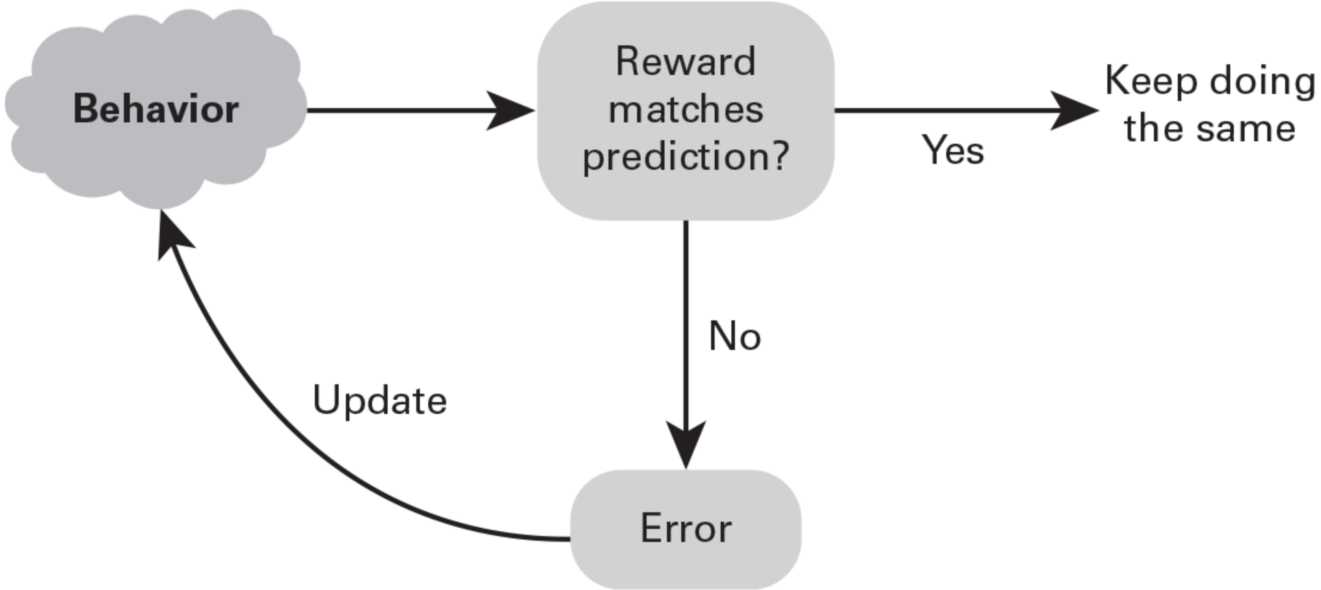
The Dopaminergic Midbrain

- The dendrites of neurons in the ***nucleus accumbens*** are full of dopamine receptors
  - Lower part of the ***striatum***
- The dopamine-containing neurons in the ***substantia nigra*** form a band that extends to adjacent parts of the midbrain
  - ***VTA (ventral tegmental area)***
- But remember that there is no "reward molecule"



Rewards Produce Learning

- Pavlovian Conditioning : stimuli predict reward
- Operant Conditioning : actions predict reward
- If there is a ***mismatch*** between the ***predicted value*** and the ***actual reward***, an error has occurred, signaling the need to update expectations about the future.



Predicting Reward

- Dopamine-containing neurons in the ***striatum*** signal a ***reward prediction error***
  - Firing increased if the actual reward was greater than anticipated, and decreased if it was smaller.
  - Here, dopamine does not signal reward itself!
- The prediction error signal precisely matched what was predicted in mathematical models of learning developed in the 1970s
  - A remarkable success story for neuroscience to hit on mathematically describable findings!
- The role of dopamine and reward prediction have major implications for understanding ***addiction*** and ***motivation disorders***

Predicting Total Future Reward

Temporal Difference Learning: How animals might use their predictions to optimize behavior when rewards are delayed

- The stimulus $u(t)$, the prediction $v(t)$, and the reward $r(t)$ are expressed as a function of $t \in [0, T]$
- Instead of $v(t)$ being the predicted reward at time t, define it as a prediction of the total future reward expected from t onward.

$$v(t) = \mathbb{E}\left[\sum_{t \leq \tau \leq T} r(\tau)\right]$$

  - This provides a better match to psychological and neurobiological data

Predicting Total Future Reward

- We approximate $v(t)$ by

$$v(t) = \sum_{0 \le \tau \le t} w(\tau) u(t - \tau)$$

- Then, find the weights by applying the stochastic gradient descent algorithm:

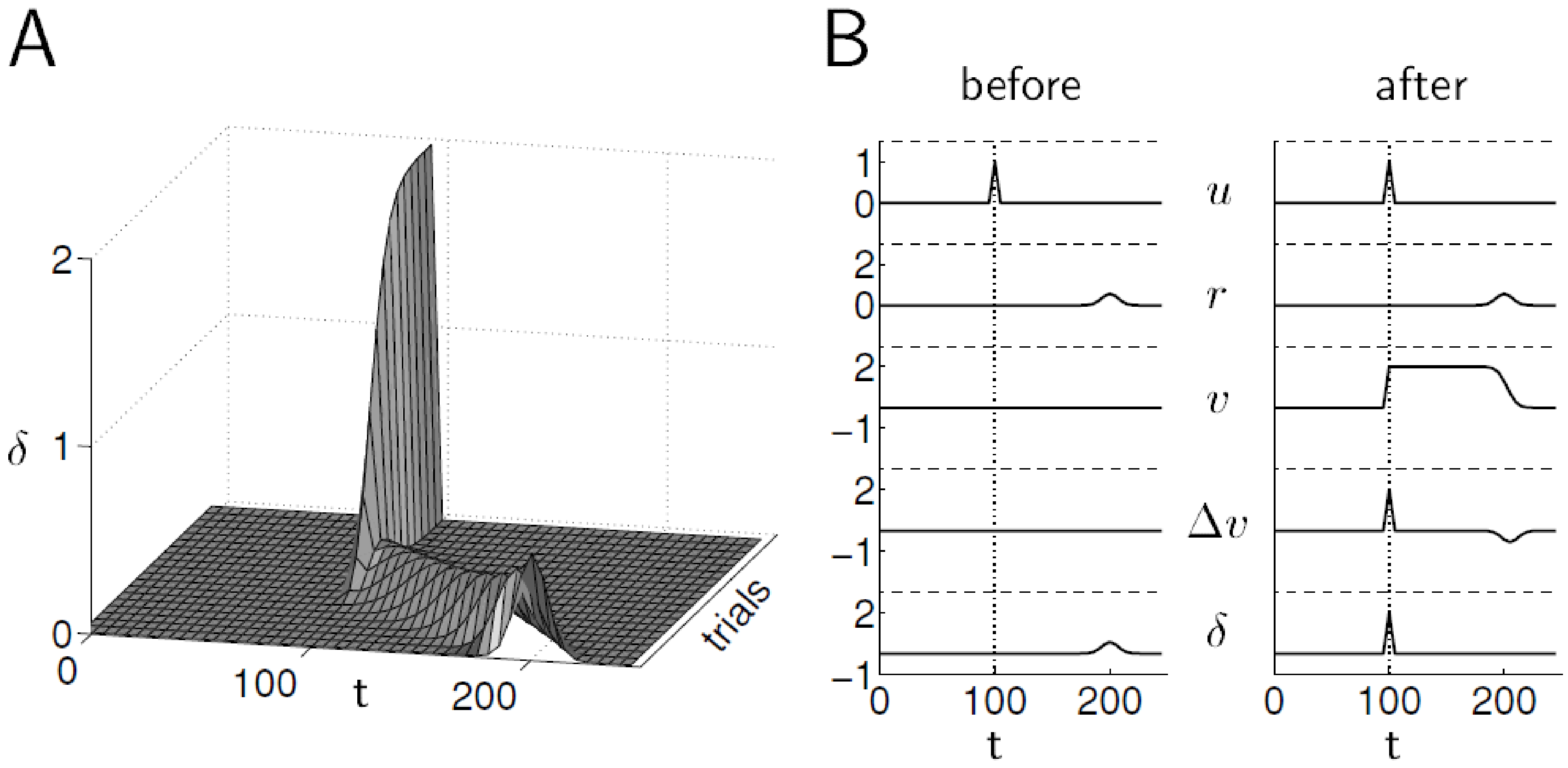
$$w(\tau) \rightarrow w(\tau) + \epsilon \delta(t) u(t - \tau)$$

with $\delta(t) = \left(\sum_{t \le \tau \le T} r(\tau)\right) - v(t)$being the ***difference*** between the actual and predicted total future reward.

- How do we compute $\delta(t)$ without the knowledge of the future?

Predicting Total Future Reward

- Stimulus appears at time $t = 100$, and a reward is given for a short interval at $t = 200$



Discussion

- How can we predict the total future reward without knowledge of the future?
  - Discuss whether the temporal difference learning rule makes sense:

$$w(\tau) \rightarrow w(\tau) + \epsilon\delta(t)u(t-\tau) \qquad \delta(t) = r(t) + v(t+1) - v(t)$$