Brain Intelligence and Artificial Intelligence

人脑智能与机器智能

Lecture 11 – **Sleep, Dream, & Hibernation**

Quanying Liu （刘泉影）

SUSTech, BME department

Email: liuqy@sustech.edu.cn

Lecture 11 – Sleep, Dream, & Hibernation

- **Five sleep stages**
  - Non-REM sleep: stage 1 – stage 4
  - REM sleep
- **Functions of sleep**
- **Circadian and Ultradian rhythms**
  - SCN in hypothalamus for Circadian rhythms
  - Brain stem for Ultradian rhythms
- **Hypnosis 催眠**
- **Hibernation 冬眠**
- **Sleep disorders**
  - Insomnia (失眠); Sleep Apnea (呼吸暂停症); Narcolepsy (嗜睡症); Parasomnia (sleep walking, sleep talking)
- **Decoding dreams with AI**

Sleep

We spend about **1/3** of our lives sleeping, and **1/4** of that time in a state of active dreaming.

Sleep may be **universal** among higher vertebrates and perhaps among all animals. Research suggests that even the *fruit fly*, *Drosophila*, sleeps.

Sleep is essential to our lives, almost as important as eating and breathing.

不睡觉会怎么样?

sina 新浪财经

雷军凌晨2点下班、刘强东睡4小时，库克3点45起床，你呢?

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每周工作7天！53岁马斯克的日常：凌晨3点睡早上9点起

Jun 30, 2024 — 马斯克称，他曾在"午夜过后的推特总部"待过，也曾因工作被迫睡在特斯拉和SpaceX的工厂地板上，每周工作时长超过120小时，这让他感到筋疲力尽。据马斯克传记的 ...

Sleep Deprivation 睡眠剥夺

一、生理影响

免疫系统受损：睡眠剥夺会降低免疫系统的功能，使人更容易受到病毒和细菌的侵袭，从而增加患病的风险。

代谢异常：长期睡眠不足会导致血糖调节能力下降，增加患糖尿病的风险。同时，还可能引起高血压、心脏病等心血管疾病。

神经系统改变：睡眠剥夺会引起一系列神经系统和血液生化方面的改变，如手指震颤、发音困难、动作协调性差、肌肉松弛等。此外，还会影响大脑神经递质平衡，导致神经元过度兴奋性。

生长发育受阻：对于青少年来说，睡眠剥夺还会影响生长发育，导致身高矮小、智力发育迟缓等问题。

二、心理影响

认知功能下降：睡眠剥夺会导致注意力不集中、记忆力减退、思维迟钝等症状，严重影响个体的认知功能。

情绪波动：缺乏睡眠会使人情绪不稳定，容易出现焦虑、抑郁等心理问题。长期睡眠不足还可能引发精神分裂症等严重精神疾病。

决策能力减弱：在睡眠剥夺的状态下，个体的决策能力会明显减弱，难以做出明智的选择。

三、行为影响

工作效率下降：在疲劳和困倦的情况下，个体的工作效率会显著下降，可能导致任务延误或错误增加。

安全隐患增加：睡眠剥夺会增加安全事故的风险。例如，疲劳驾驶是导致交通事故的重要原因之一。此外，在工作或生活中也可能因注意力不集中而发生意外。

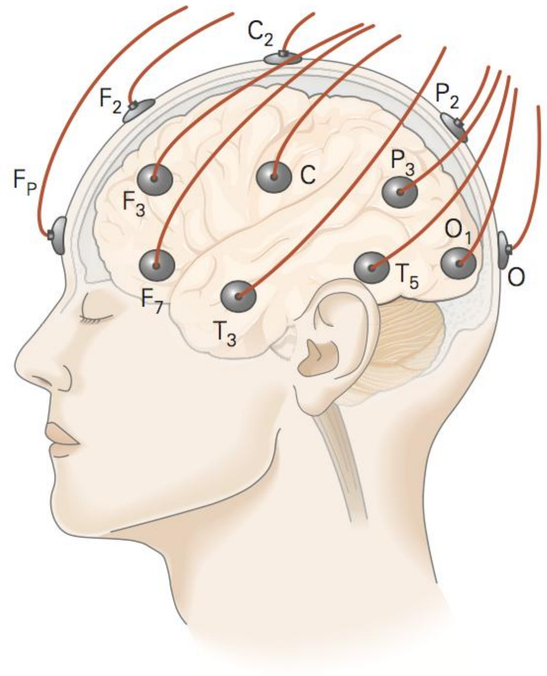
四、长期影响

精神疾病风险增加：长期睡眠剥夺可能增加患抑郁症、焦虑症等精神疾病的风险。这些疾病不仅会影响个体的生活质量，还可能给家庭和社会带来沉重的负担。

身体健康问题：长期睡眠不足还可能导致体重增加、糖尿病、高血压等健康问题，进一步影响个体的整体健康状况。

Sleep stages 睡眠分期

- **Awake**
- **Non-RME sleep**: from stage 1 to stage 4, an idling brain in a movable body
- **REM sleep** (Rapid eye movement sleep): an active, hallucinating brain in a paralyzed body

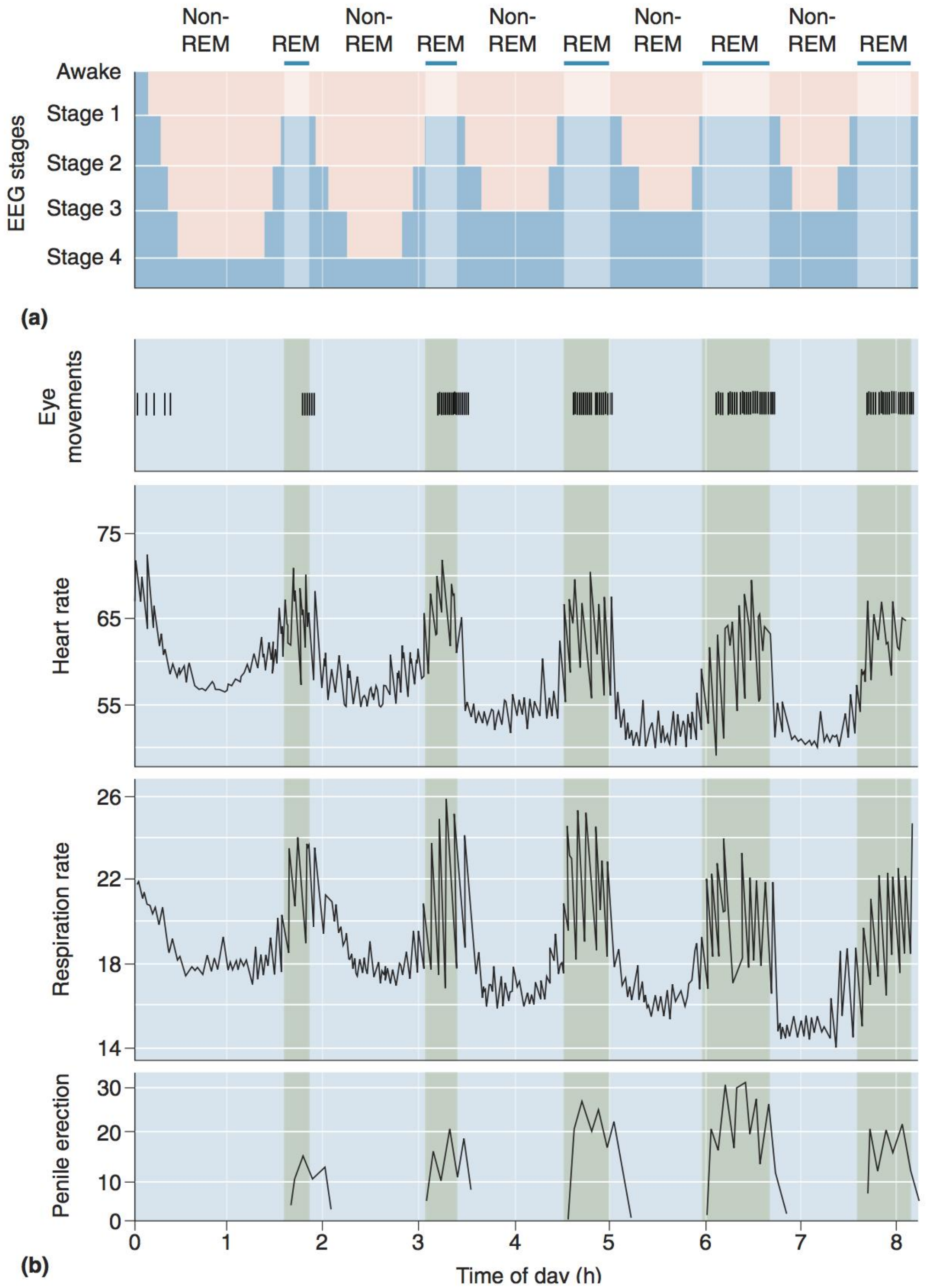


Behavior	Awake	Non-REM Sleep	REM Sleep
EEG	Low voltage, fast	High voltage, slow	Low voltage, fast
Sensation	Vivid, externally generated	Dull or absent	Vivid, internally generated
Thought	Logical, progressive	Logical, repetitive	Vivid, illogical, bizarre
Movement	Continuous, voluntary	Occasional, involuntary	Muscle paralysis; movement commanded by the brain but not carried out
Rapid eye movement	Often	Rare	Often

Characteristics of the Three Functional States of the Brain

Sleep Cycle

- **Physiological changes during non-REM and REM sleep.**
- (a) This graph represents one night of sleep, starting with a transition from awake to stage 1 non-REM sleep. The sleep cycle progresses through the deeper stages of non-REM sleep, then into REM sleep. It is repeated several times, but each cycle has shorter and shallower non-REM periods and longer REM periods.
- (b) These graphs show regular increases in heart rate, respiration rate, and penile erection during the REM periods of one night sleep

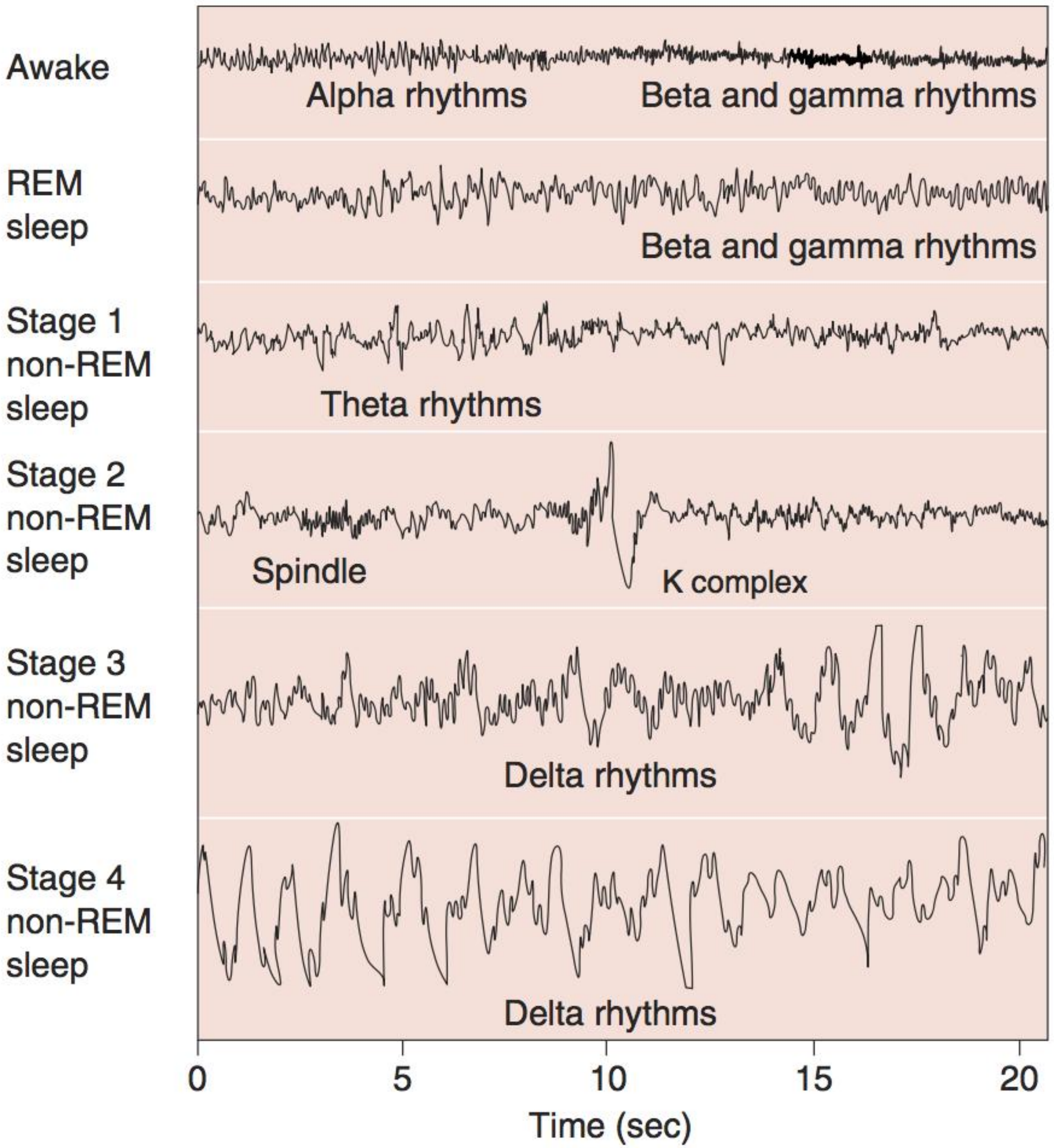


Sleep Cycle

EEG rhythms during the stages of sleep.

- **Stage 1** is transitional sleep, when the EEG alpha rhythms of relaxed waking become less regular and wane, and the eyes make slow, rolling movements. Stage 1 is fleeting, usually lasting only a few minutes. It is also the lightest stage of sleep, meaning that we are most easily awakened.

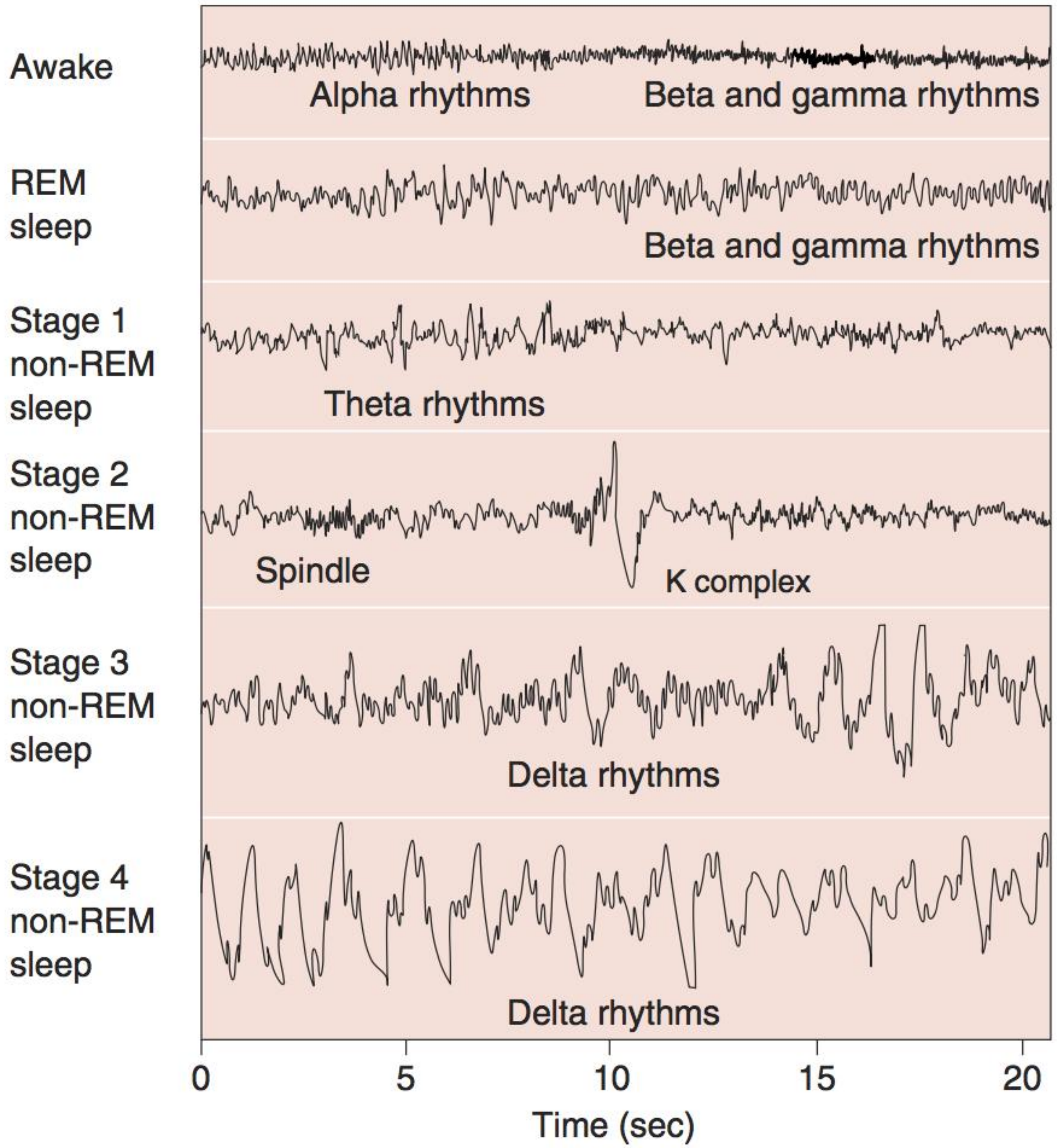
- **Stage 2** is slightly deeper and may last 5–15 minutes. Its characteristics include the occasional 8–14 Hz oscillation of the EEG called the **sleep spindle**, which is generated by a thalamic pacemaker. In addition, a high-amplitude sharp wave called the **K complex** is sometimes observed. Eye movements almost cease.



Sleep Cycle

EEG rhythms during the stages of sleep.

- Next follows **Stage 3**, and the EEG begins large-amplitude, slow delta rhythms. Eye and body movements are few.
- **Stage 4** is the deepest stage of sleep, with large EEG rhythms of 2 Hz or less. During the first cycle of sleep, stage 4 may persist for 20–40 minutes.
- Then sleep begins to lighten again, **ascends through stage 3 to stage 2** for 10–15 minutes, and suddenly enters a brief period of **REM sleep**, with its fast EEG *beta and gamma rhythms* and *sharp, frequent eye movements*. Postural muscles of the body are more **relaxed** than other stages in REM sleep.



REM sleep vs Non-REM sleep

- When one falls asleep, they progress through stages 1, 2, 3, and 4 **in sequential order**
- After about **an hour**, the person begins to cycle back through the stages from stage 4 to stages 3 and 2 and than REM.
- The sequence repeats with each cycle lasting approximately **90** minutes → **Ultradian rhythms**
- **REM sleep** is associated with an almost complete loss of muscle tone, owing to inhibition of the spinal motor neurons by descending pathways. Apparently the motor neurons in the *brain stem* that *control eye movements* are not inhibited, because the eyes move during REM sleep.
- **REM is strongly associated with dreaming**, but people also report dreaming in other stages of sleep.
- The characteristics of REM and non-REM dreams **differ**.

Dreams during REM sleep vs Non-REM sleep

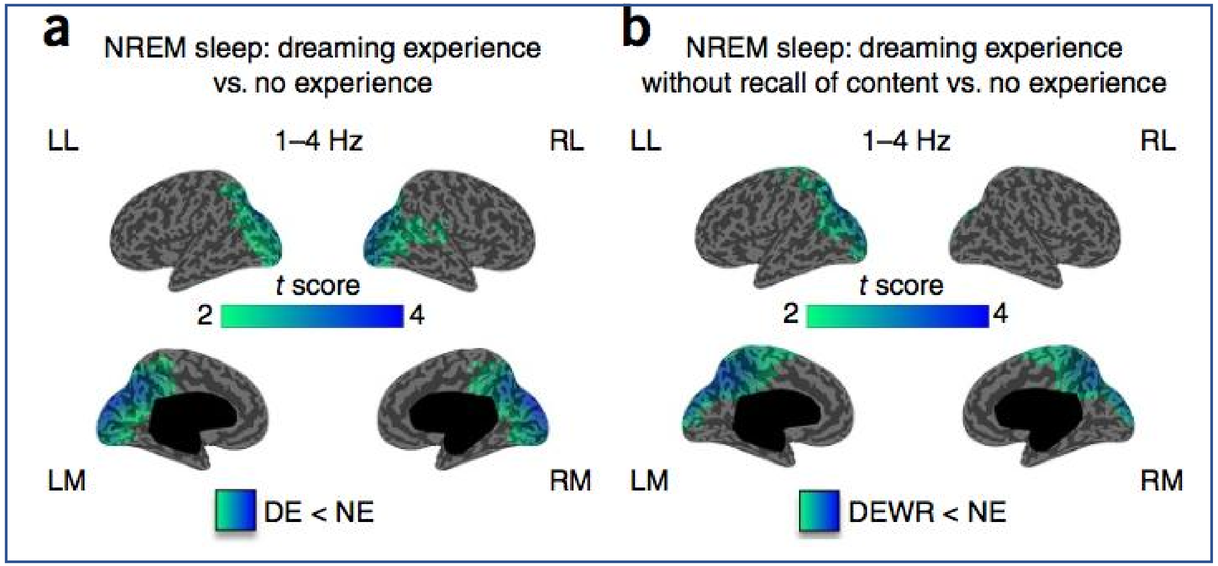
- *REM dreams* are relatively **long**, primarily visual, somewhat emotional, and usually *not* connected to the immediate events of the everyday life of the dreamer.
- *Non-REM dreams* are **shorter**, less visual, less emotional, more conceptual, and usually related to the current life of the dreamer.

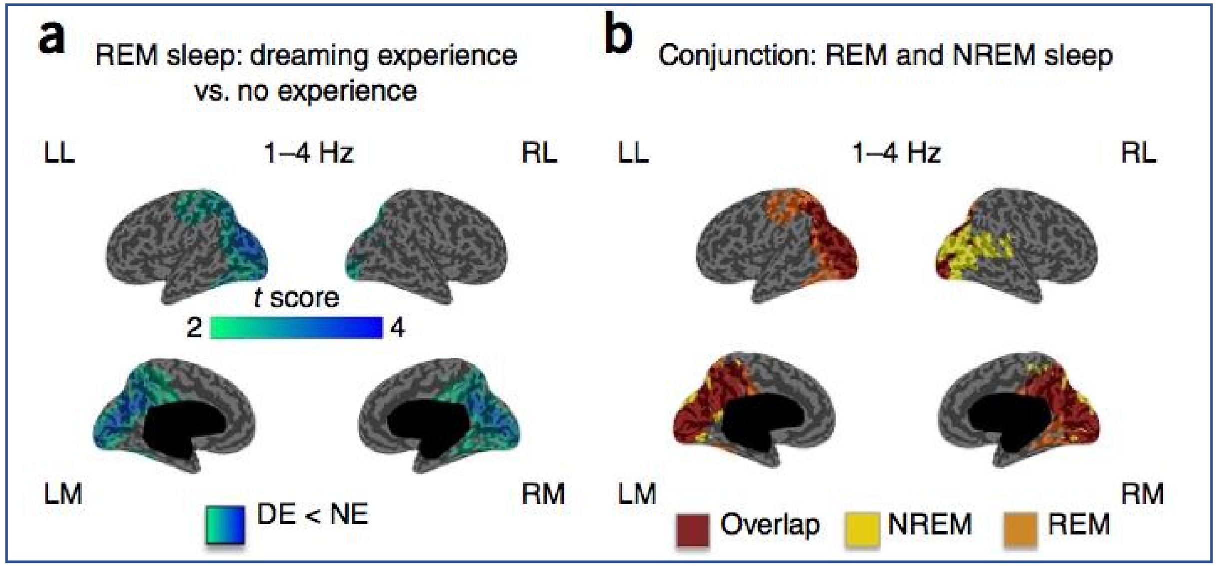
- **What sensory modalities are experienced during dreams in REM sleep?**
- **Vision** is preeminent, occurring in all dreams (except, of course, in the congenitally blind), whereas **auditory** events occur in approximately 65%, **vestibular** 8%, and **temperature** 4%; tactile, olfactory, and gustatory experiences are rare (only 1% each).
- The **emotional** content of dreams varies from anxiety (14%), to surprise (9%), joy (7%), sadness (5%), and shame (2%).
- Men experience penile erections, and women experience the physiological counterparts of sexual arousal during REM sleep. The emotional content is organized at several levels of the central nervous system but is, for the most part, unrelated to the specific content of the dream.

The neural correlates of dreaming

Francesca Siclari[1,2,9], Benjamin Baird[1,9], Lampros Perogamvros[1,3,4,9], Giulio Bernardi[1,2,5], Joshua J LaRocque[6], Brady Riedner[1], Melanie Boly[1,7], Bradley R Postle[1,8] & Giulio Tononi[1]

Consciousness never fades during waking. However, when awakened from sleep, we sometimes recall dreams and sometimes recall no experiences. Traditionally, dreaming has been identified with rapid eye-movement (REM) sleep, characterized by wake-like, globally 'activated', high-frequency electroencephalographic activity. However, dreaming also occurs in non-REM (NREM) sleep, characterized by prominent low-frequency activity. This challenges our understanding of the neural correlates of conscious experiences in sleep. Using high-density electroencephalography, we contrasted the presence and absence of dreaming in NREM and REM sleep. In both NREM and REM sleep, reports of dream experience were associated with local decreases in low-frequency activity in posterior cortical regions. High-frequency activity in these regions correlated with specific dream contents. Monitoring this posterior 'hot zone' in real time predicted whether an individual reported dreaming or the absence of dream experiences during NREM sleep, suggesting that it may constitute a core correlate of conscious experiences in sleep.





Siclari et al., (2017) The neural correlates of dreaming, *Nature Neuroscience*

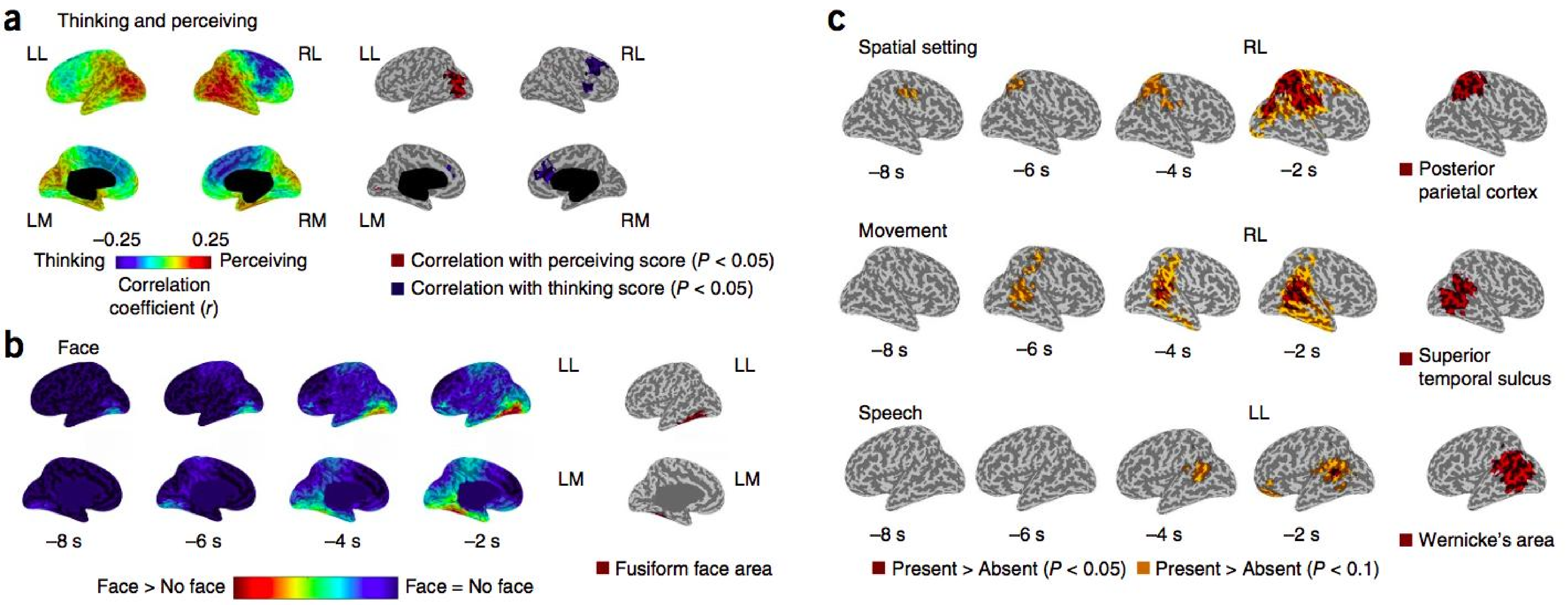


Figure 4 The content of dream experiences in REM sleep. (**a**) Correlation between the thinking–perceiving score and 25–50-Hz power (last 8 s, $n = 7$ subjects). Left: mean Spearman rank correlation coefficients ($n = 7$ subjects). Right: significant voxels ($P < 0.05$, one-tailed permutation test, $r > 0.14$). (**b**) Left: 25–50-Hz power differences (DE with face minus DE without face). ROI contrast in the fusiform face area (FFA) ($P = 0.023$; one-tailed paired t-test, $n = 7$ subjects, $t_6 = 2.52$). Right: FFA (red). (**c**) Upper row: 25–50 Hz average power differences between DEs with and without a spatial setting ($n = 6$ subjects, $t_5 > 2.57$). Right: right posterior parietal cortex. Middle row: movement vs. no movement ($n = 7$ subjects, $t_6 > 2.45$). Right: superior temporal sulcus. Bottom row: speech vs. no speech ($n = 7$ subjects, $t_6 > 2.45$). Right: Wernicke's area. Two-tailed paired t-tests; $P < 0.05$ (red) and $P < 0.1$ (yellow).

Siclari et al., (2017) The neural correlates of dreaming, *Nature Neuroscience*

Brain function of REM sleep

During REM sleep:

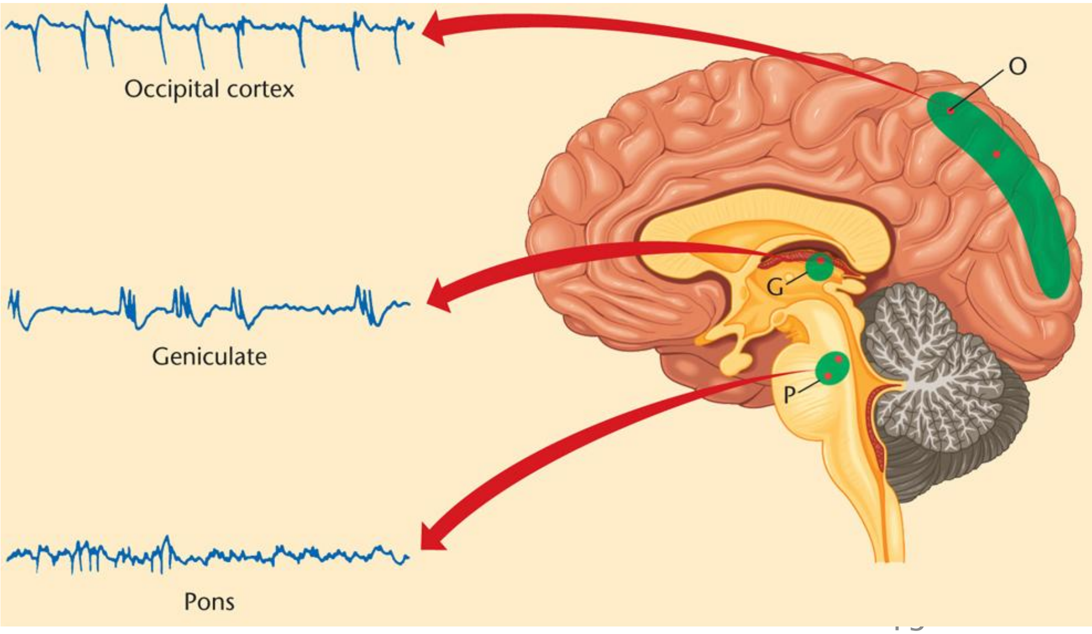
- Activity increases in the **pons** (triggers on set of REM sleep) and limbic system (emotional systems), parietal cortex, and temporal cortex
- Activity in the pons triggers onset of REM sleep
- Activity decreases in the primary visual cortex, the motor cortex, and the dorsolateral prefrontal cortex

Sleep can be local within the brain

Sleepwalkers are awake in one part of the brain and asleep in others

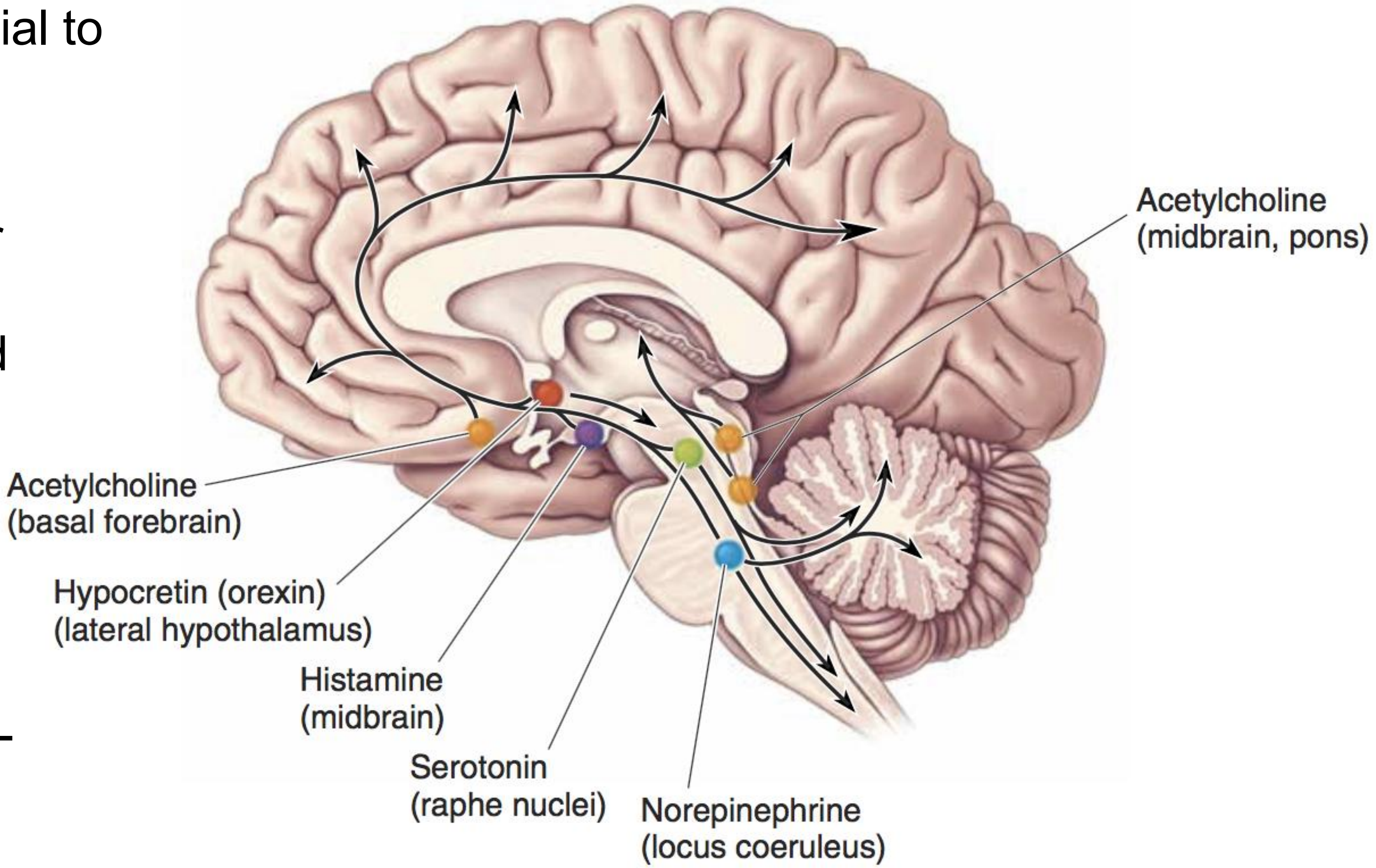
Lucid dreaming is also another example of this

When the pons remains in REM and other brain areas wake up, it causes the inability to move.



Wakefulness & Ascending Reticular Activating System

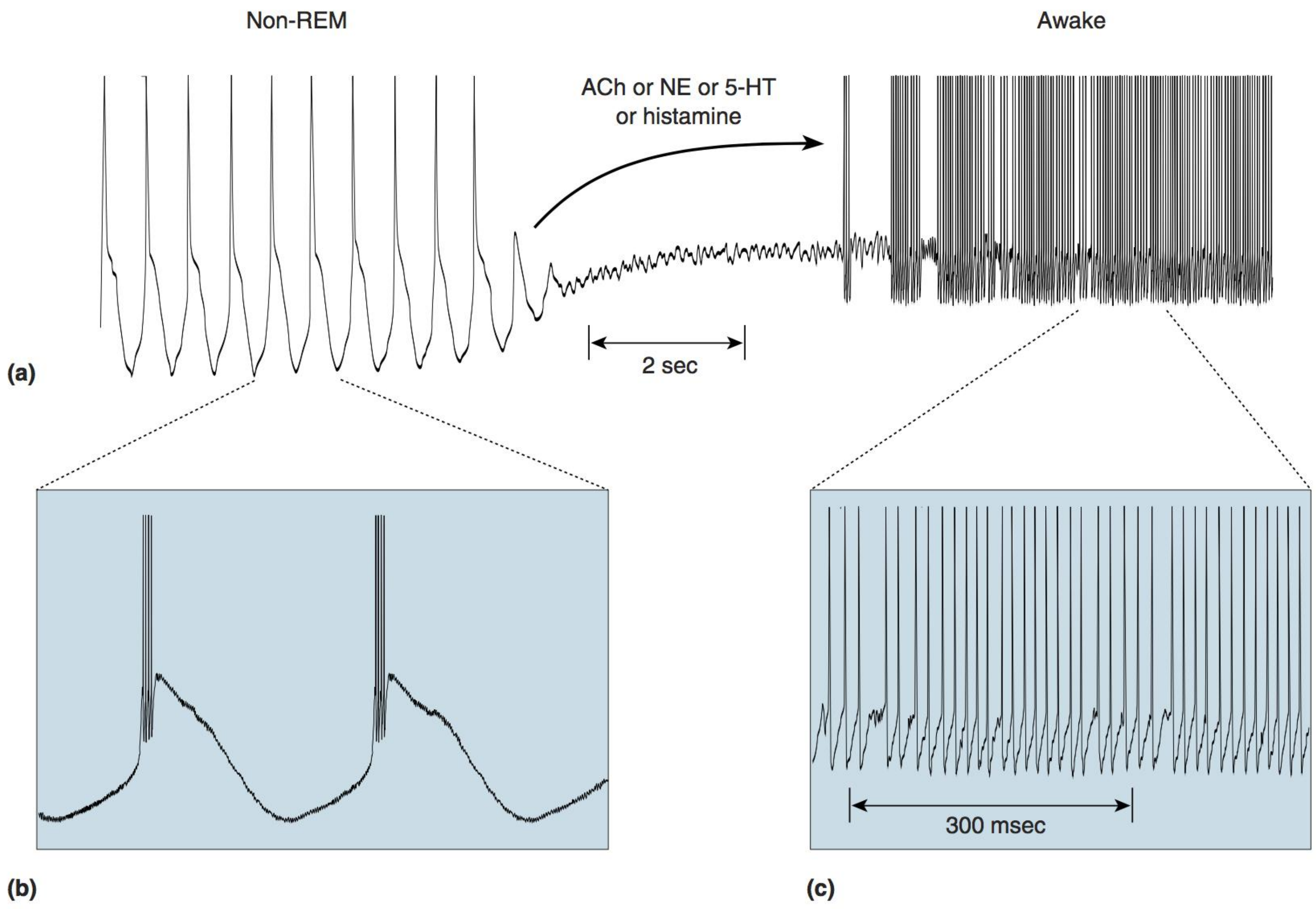
- Lesions in the **brain stem** of humans can cause sleep and coma, suggesting that the brain stem has neurons whose activity is essential to keeping us awake.
- Lesions in the **midline** structures of the brain stem caused a state similar to non-REM sleep, but lesions in the **lateral** tegmentum, which interrupted ascending sensory inputs, did not.
- Conversely, electrical stimulation of the midline tegmentum of the midbrain, within the reticular formation, **transformed** the cortex from the slow, rhythmic EEGs of non-REM sleep to a more **alert and aroused state** with an EEG similar to that of waking.



Thalamic rhythmicity during waking and sleeping

(a) Thalamic neurons at rest have a tendency to generate slow, delta frequency rhythms of intrinsic burst-firing (left), and switch to a more excitable single-spiking mode (right).

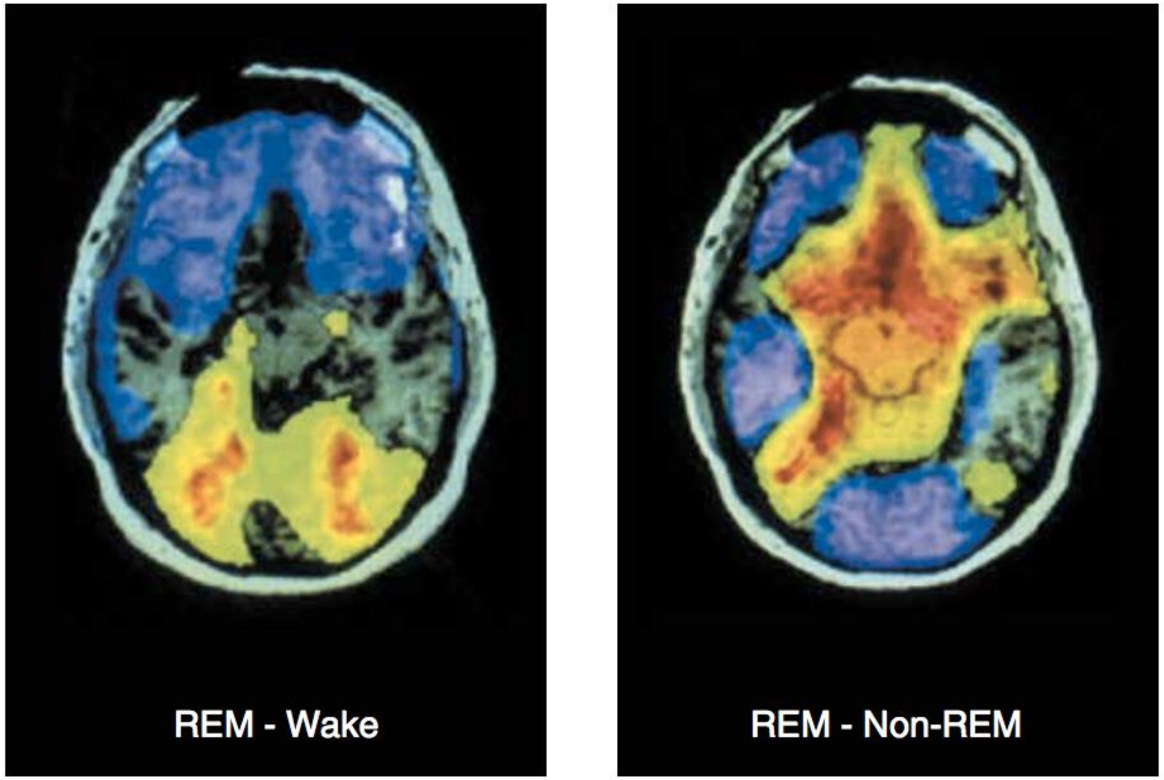
Expanded views of rhythmic bursting (b) and single-spiking (c)



PET images of the waking and sleeping human brain

(a) Colors represent differences in activity between REM sleep and waking; green, yellow, and red indicate higher activation during REM, and purples indicate lower activation during REM. Note the dark notch at the bottom (posterior) edge of the section, indicating that **striate cortex** is equally active in the two states.

(b) REM sleep compared with non-REM sleep. In REM, **striate cortex** is less active.



(a) (b)

Dolphins and whales live their life in deep or turbulent water, yet needing to breathe air every minute or so.

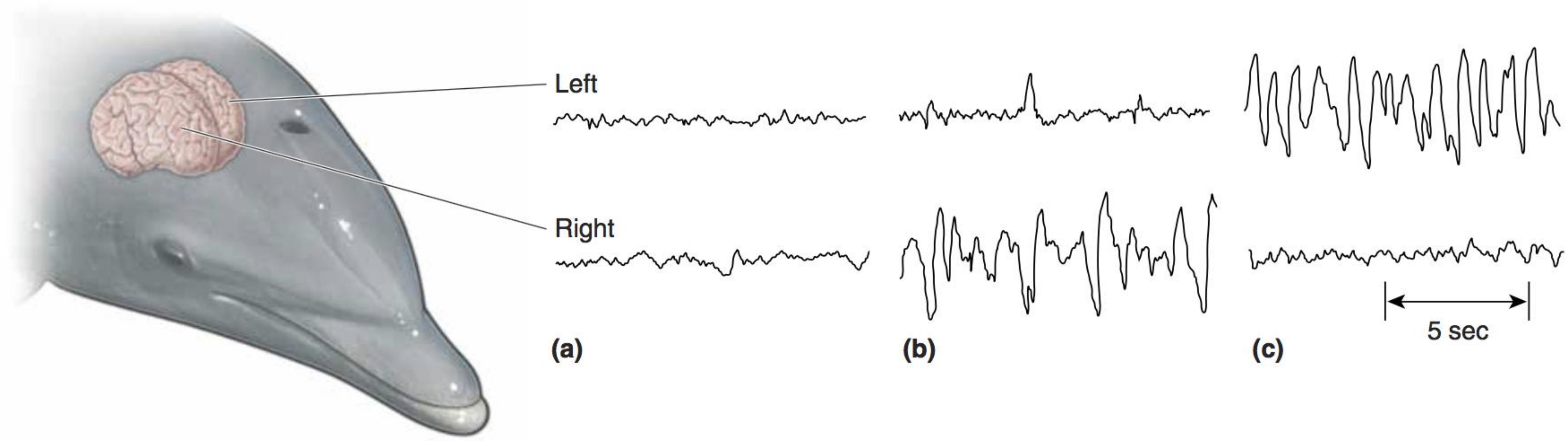
Do dolphins sleep?

Do dolphins sleep?

Yes.

How do dolphins sleep?

Bottlenose dolphins sleep with only **one cerebral hemisphere at a time**: about 2 hours of non-REM sleep on just one side, then 1 hour awake on both sides, 2 hours of non-REM sleep on the other side, and so on, for a total of about 12 hours per night.



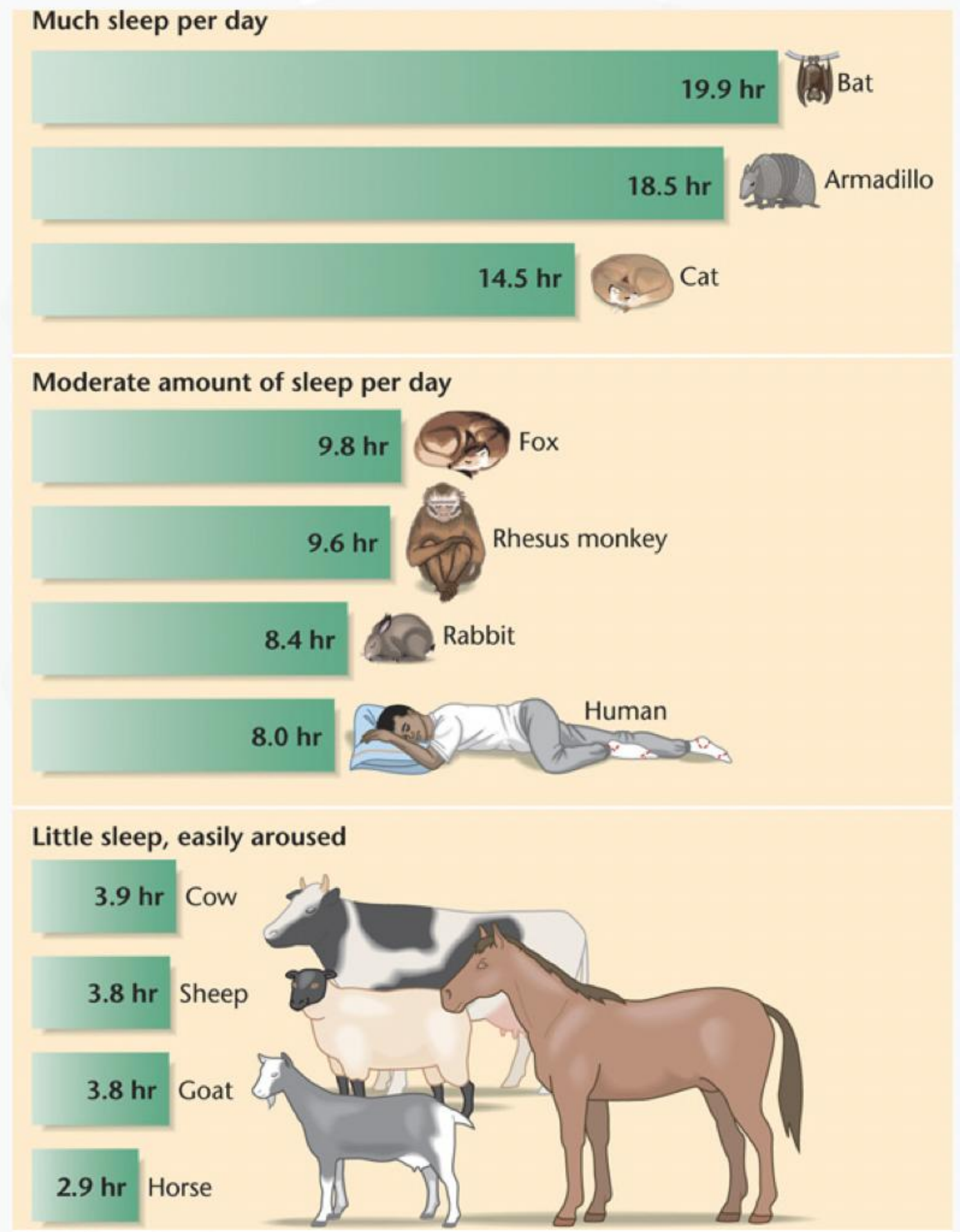
Why do we sleep?

- All mammals, birds, and reptiles appear to sleep, although only mammals and some birds have a REM phase.
- Many people argue that a behavior as pervasive as **sleep must have a critical function**; otherwise, some species would have lost the need to sleep through evolution.
- Whatever the function, there is good reason to believe sleep is mainly for the **brain**.
- Cognitive impairment is the most immediate and obvious consequence of sleep deprivation.
- A restful 8 hours in bed without sleep might allow your body to recover from physical exertion, but you would **not** be at your best mentally the next day.

Function of sleep

1. Energy conservation
   - Decrease in body temperature of about 1-2 Celsius degrees in mammals
   - Decrease in muscle activity
   - Animals also increase their sleep time during food shortages (Analogous to the hibernation of animals)
2. Restoration of the brain and body

3. Enhancing learning and strengthening memory (Memory consolidation)



Function of sleep – learning and memory

Performance on a newly learned task is often **better** the next day, if adequate sleep is achieved during the night.

Increased brain activity occurs in *the area of the brain* activated by *a newly learned task* while one is asleep.

Patterns of activity in the **hippocampus** during **learning** were similar to those shown during **sleep**

- Suggesting that the brain **replays** its daily experiences during sleep

The brain **strengthens** some synapses and **weakens** others during sleep

Sleep spindles increase in number after new learning: correlated with *nonverbal IQ*

睡眠的作用

睡眠在身体和大脑的恢复与运作中扮演了多重关键角色：

1. **身体修复和免疫增强**：在睡眠期间，身体细胞的修复和再生加速，包括肌肉和组织的修复、蛋白质合成和细胞生长。睡眠还支持免疫系统，通过产生细胞因子来增强免疫反应，这些分子有助于对抗感染和炎症 NIIGATA UNIVERSITY 。
2. **记忆巩固与学习**：睡眠尤其是深度睡眠和快速眼动睡眠（REM）阶段，对记忆的形成和巩固至关重要。在学习新的信息后，大脑会在睡眠中重现并强化这些记忆，提高知识的保持和回忆。研究表明，睡眠不足会影响记忆巩固和学习效果 HARVARD GAZETTE 。
3. **情绪调节**：睡眠在情绪和压力管理方面具有显著作用。缺乏睡眠容易导致情绪波动和易怒，长期缺乏优质睡眠会增加抑郁和焦虑的风险。睡眠帮助大脑处理情感信息，使人更能适应日常压力 NIIGATA UNIVERSITY 。
4. **新陈代谢与内分泌平衡**：睡眠调节与新陈代谢和激素分泌密切相关，如胰岛素和瘦素（控制饱腹感的激素）的调节。长期睡眠不足可能导致代谢紊乱，增加肥胖、糖尿病和其他代谢疾病的风险。
5. **清除脑部代谢废物**：在睡眠期间，大脑的**淋巴系统**会清除神经活动中产生的代谢废物，包括与阿尔茨海默症有关的β-淀粉样蛋白堆积。这一过程在深度睡眠时尤为活跃，帮助保持大脑健康 NIIGATA UNIVERSITY 。

总的来说，睡眠是身心恢复的不可或缺的生理过程，对身体健康、认知功能和情绪稳定起到关键支持作用。

Sleep deprivation

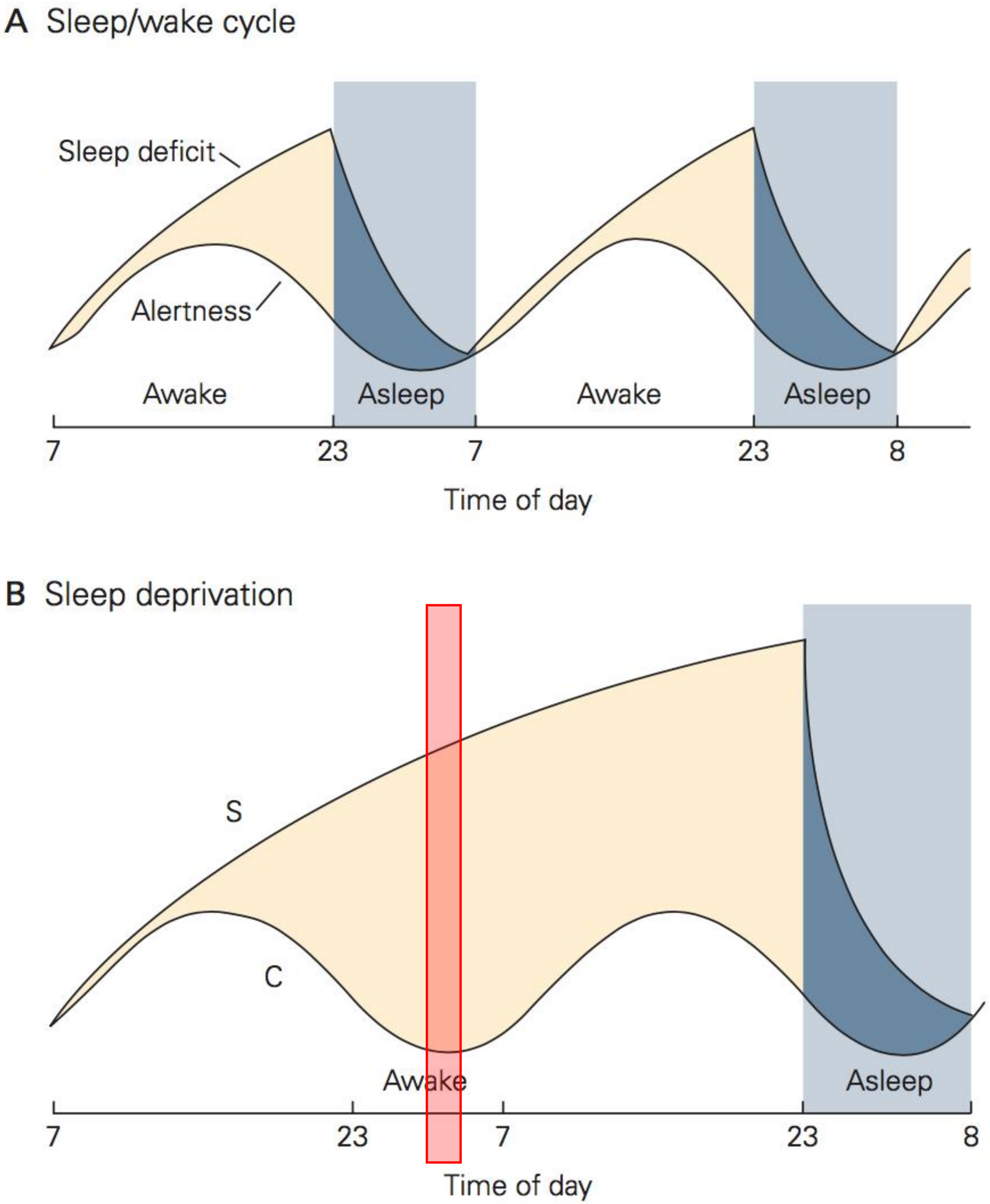
Sleepiness—the drive to sleep—depends on several factors.

Two of the strongest are the time since **the last full period of sleep** and **the circadian rhythm**.

If a night of sleep is missed, one is likely to find that at approximately **3–4 a.m**. it is nearly impossible to stay awake.

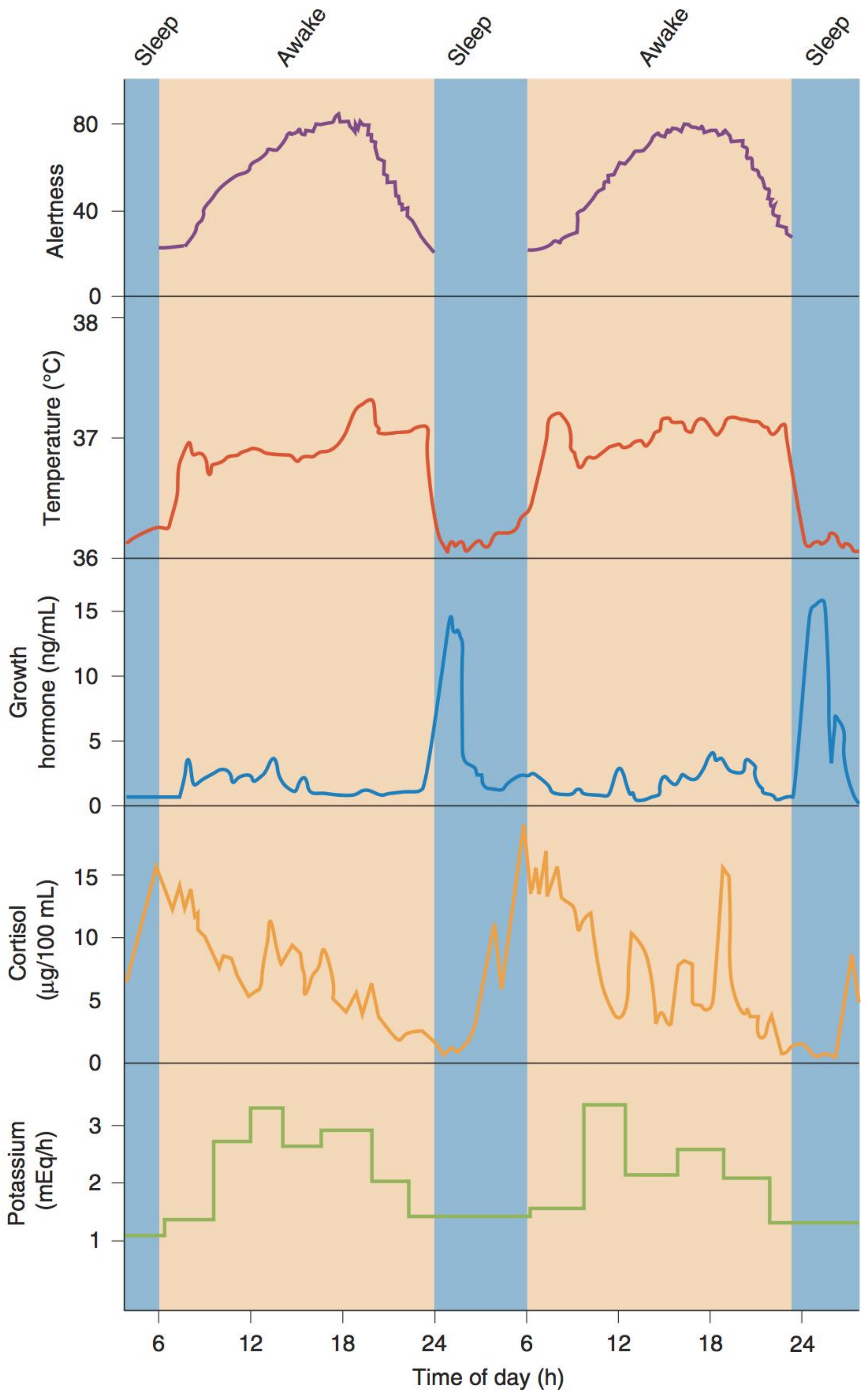
This is because the sleep deficit is high and continues to increase, while the circadian rhythm in arousal (and other body functions such as temperature) is at a low point. Thus the sleep drive is high.

Sleep once again **restores the balance**, relieving this built-up sleep pressure.



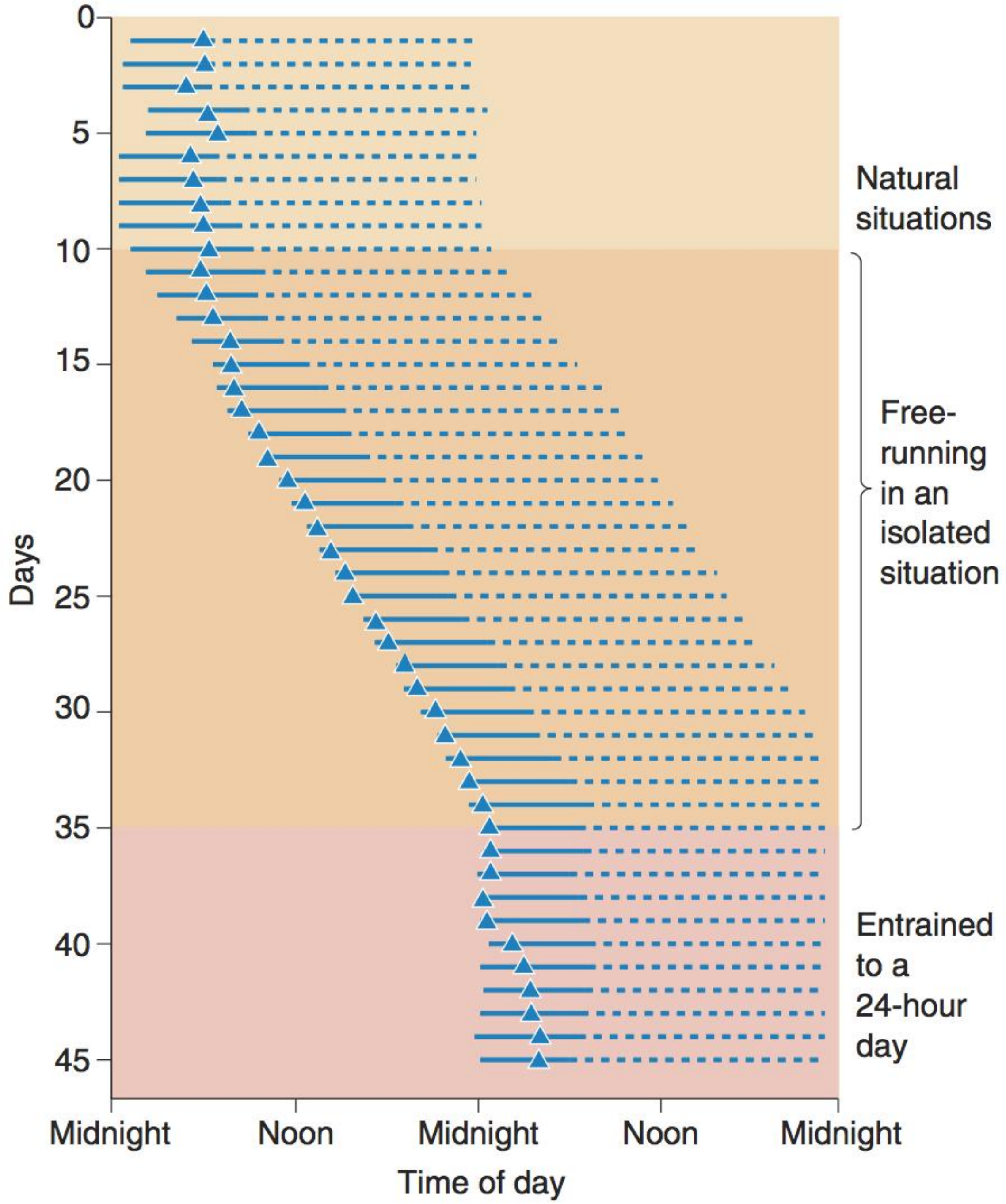
Circadian rhythms

- Almost ***all*** land animals coordinate their behavior according to **circadian rhythms**, the daily cycles of daylight and darkness that result from *the spin of the Earth*.
- Environmental time cues (light/dark, temperature and humidity variations) are collectively termed **zeitgebers** (German for "time givers").
- In the presence of *zeitgebers*, animals become **entrained** to the day–night rhythm and maintain an activity cycle of exactly 24 hours.
- When mammals are completely deprived of zeitgebers, they settle into a rhythm of activity and rest that often has a period more or less than 24 hours, in which case their rhythms are said to ***free-run***.
- In mice, the natural free-running period is about 23 hours, in hamsters it is close to 24 hours, and in humans it tends to be 24.5–25.5 hours.



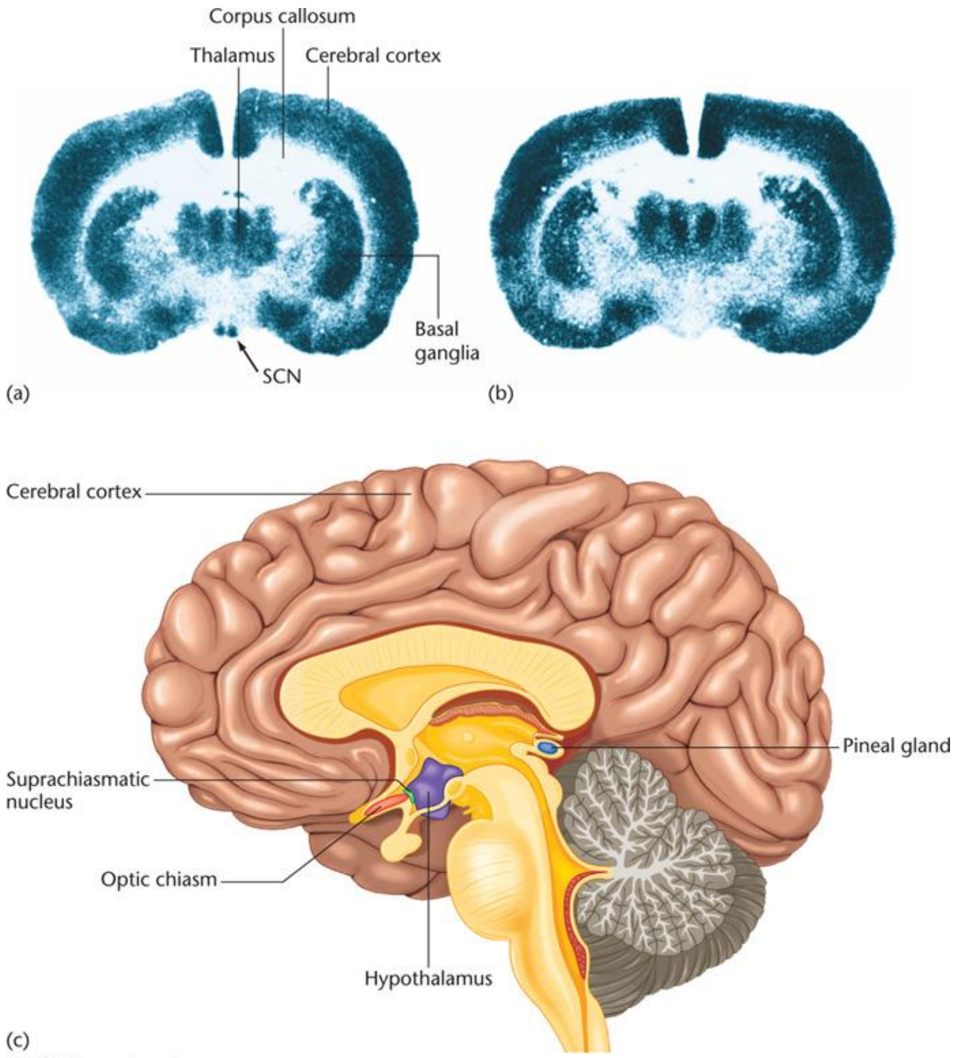
Circadian rhythms

- **Circadian rhythms of sleep and wakefulness.**
- The subject was first exposed to 9 days of natural 24-hour cycles of light and dark, noise and quiet, and air temperature.
- During the middle 25 days, all time cues were removed, and the subject was free to set his own schedule. Notice that the sleep–wake cycles remained stable, but each lengthened to about 25 hours.
- During the last 11 days, a 24-hour cycle of light and meals was reintroduced, the subject again entrained to a day-long rhythm, and body temperature gradually shifted back to its normal point in the sleep cycle.



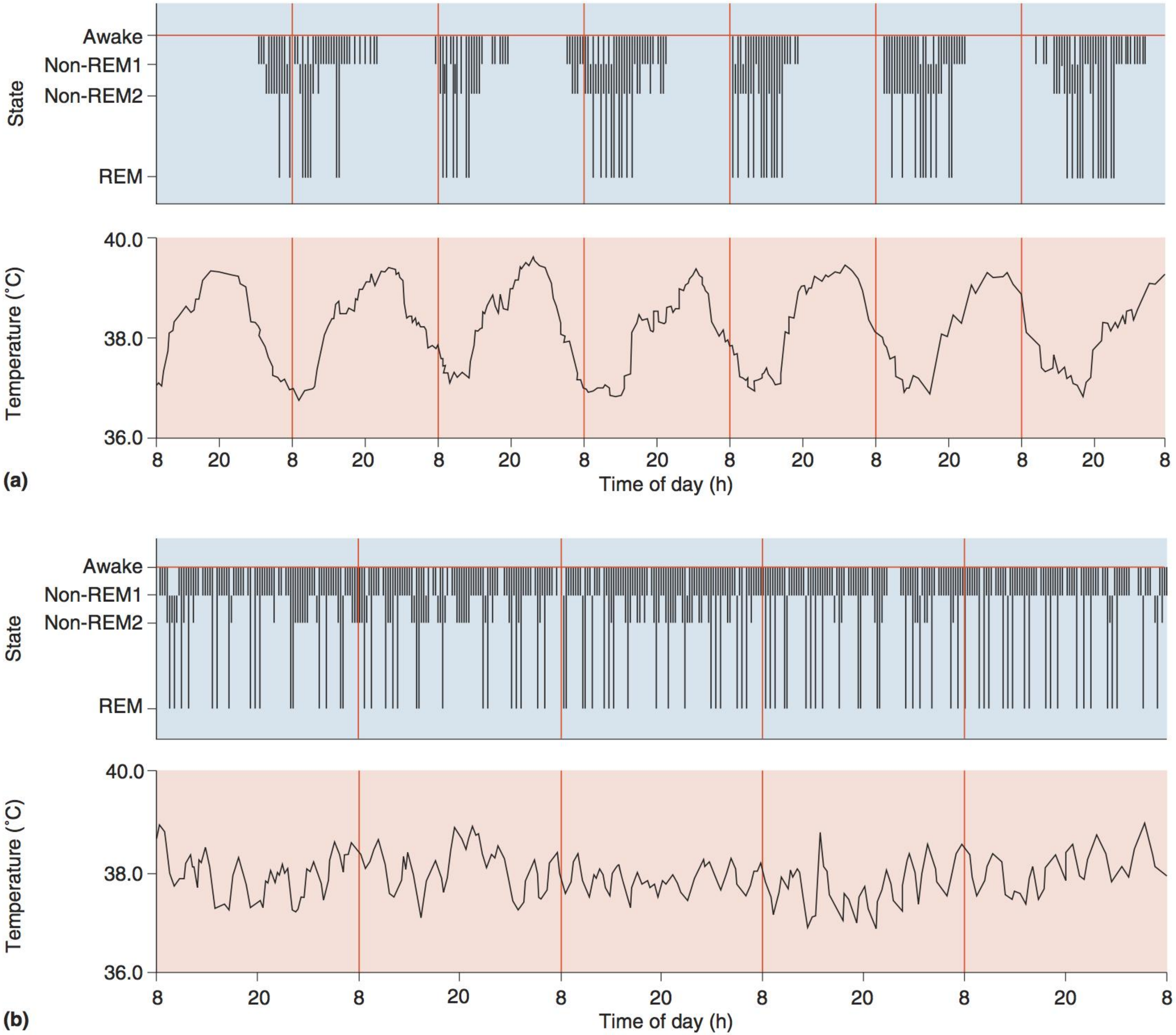
Suprachiasmatic Nucleus (视交叉上核，SCN): A Brain Clock

- When the cycles of daylight and darkness are removed from an animal's environment, circadian rhythms continue on more or less the same schedule because the primary clocks for circadian rhythms are not astronomical (the sun and Earth) but **biological in the brain**.
- **Brain clocks**, like all clocks, are imperfect and require occasional resetting.
- The SCN generates circadian rhythms in **a genetically controlled, unlearned manner.**
- Single cell extracted from the SCN and raised in tissue culture continues to produce action potential in a rhythmic pattern.
- Various cells communicate with each other to sharpen the circadian rhythm.



SCN & Brain Clock

(a) Normal squirrel monkeys kept in a constantly lit environment display circadian rhythms of about **25.5 hours**. The graph shows the stages of waking–sleeping and concurrent variations in body temperature. The animals' activity states were defined as awake, two levels of non-REM sleep (non-REM1 or non-REM2), or REM sleep.
(b) Circadian rhythms are **abolished** in monkeys with lesions in both SCN, kept in the same constant light environment. Notice that persistent high-frequency rhythms of both activity and temperature result from SCN lesions.

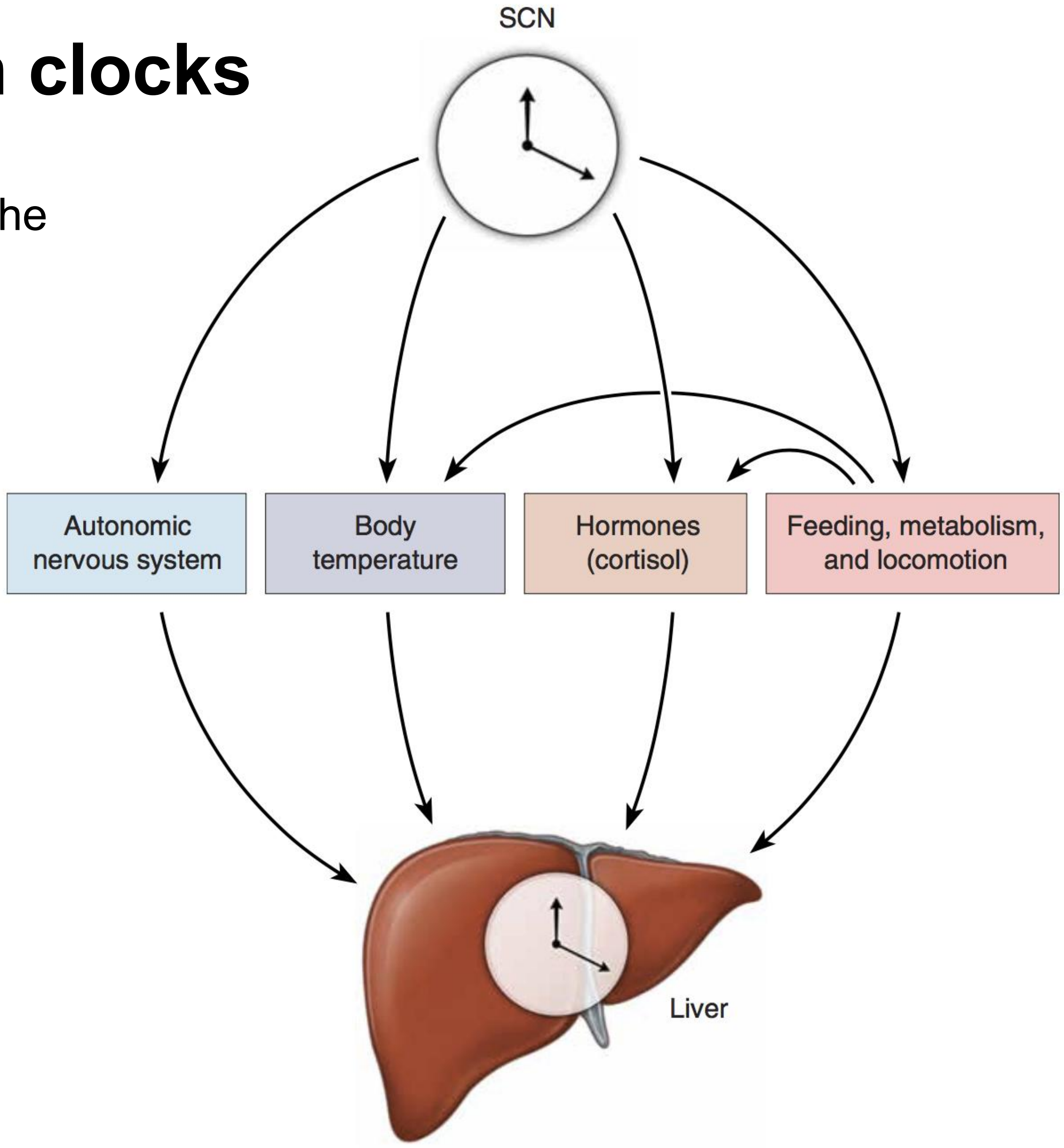


Mechanism of SCN to control Brain Clock

- The SCN regulates waking and sleeping by controlling activity levels in other areas of the brain.
- The SCN regulates the **pineal gland**（松果体）, an endocrine gland located posterior to the thalamus.
- The pineal gland secretes **melatonin** (褪黑素), a *hormone* that increases sleepiness.
- Melatonin secretion usually begins *two to three hours before bedtime.*
- Melatonin feeds back **to reset the biological clock** through its effects on receptors in the SCN.
- Melatonin taken in the afternoon can **phase-advance the internal clock** and can be used as a sleep aid.

SCN to peripheral circadian clocks

- Research has shown that nearly every cell of the body, including those in the liver, kidney, and lung, has a circadian clock.
- The same types of gene transcription feedback loops that drive the SCN clock also drive the clocks in these peripheral tissues.
- When cells from liver, kidney, or lung are grown in isolation, each exhibits a circadian rhythm of its own.
- Under normal conditions in an intact body, however, all cells' clocks are under the master control of the SCN.

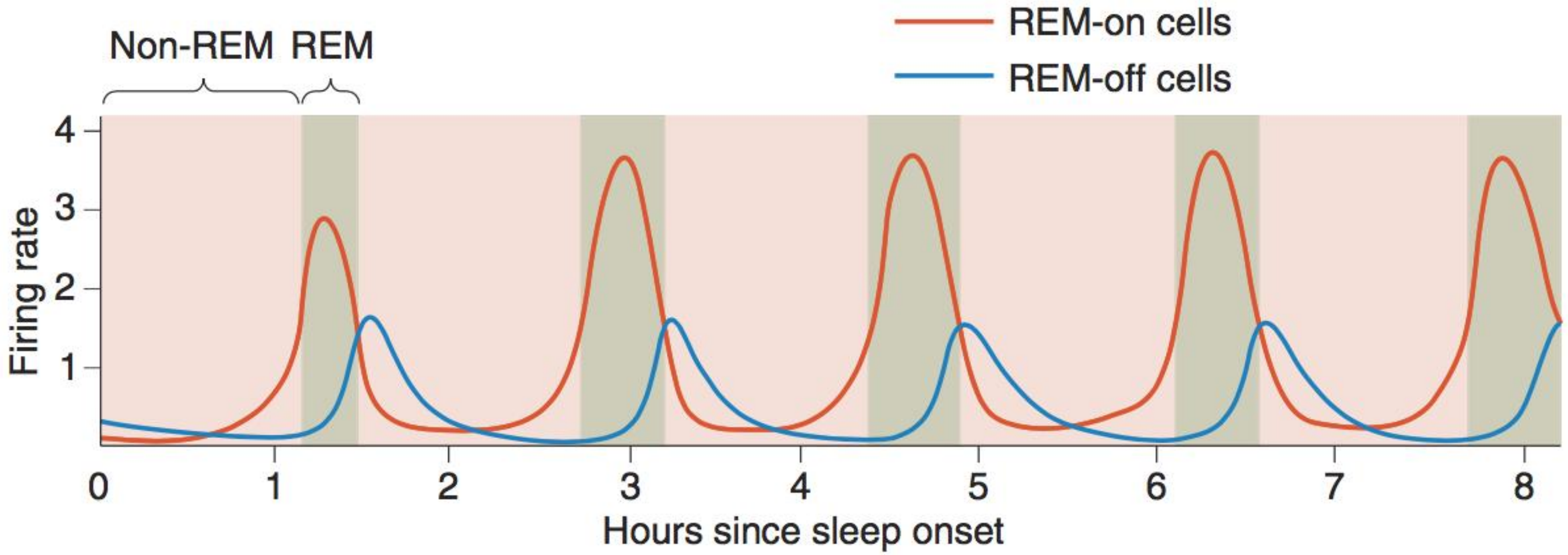


Ultradian Rhythms are controlled by the Brain Stem

An **ultradian rhythm** in the sleep period consists of a damped oscillation between non-REM and REM periods.

The control of REM sleep, as with the other functional brain states, derives from diffuse modulatory systems in the core of the brain stem, particularly the **pons**.

The firing rates of the two major systems of the upper brain stem, the *locus coeruleus* and the *raphe nuclei*, decrease to almost nothing before the onset of REM.



人工催眠可行吗？神经机制是？

人工催眠（或诱导性催眠）是一种通过外部方法引导大脑进入类似自然睡眠或催眠状态的过程，目前已有一些成功的研究和应用。人工催眠的神经机制主要涉及对大脑特定区域和神经递质系统的调控，以实现意识的改变、放松状态和睡眠。

1. 神经递质和神经环路的调控

- **GABA和谷氨酸系统**：催眠状态常涉及GABA（γ-氨基丁酸）递质系统的激活。GABA作为主要的抑制性神经递质，能降低中枢神经系统的活跃度，使大脑进入放松状态。通过调节GABA的释放，外部刺激可以诱导类似睡眠的深度放松状态 HARVARD GAZETTE 。
- **丘脑-皮层环路**：催眠状态中丘脑和皮层之间的连接有所改变，导致意识的调整和对外界刺激的敏感性降低。丘脑-皮层环路在促进放松和催眠中发挥重要作用，研究显示，通过特定频率的声音或视觉刺激可以影响这一区域的神经活动，进入半意识状态 NIIGATA UNIVERSITY 。

2. 脑电波和意识的改变

- **α波和θ波的增强**：研究发现，催眠过程中的脑电波会表现出较高的α波和θ波活动，表明大脑进入放松或轻度催眠状态。α波（8-13 Hz）常与清醒但放松的状态有关，而θ波（4-8 Hz）则与轻睡眠和深度放松状态相关，这两种脑电波的增强有助于催眠的发生 HARVARD GAZETTE 。
- **降低高频β波**：β波（13-30 Hz）通常与集中注意和清醒相关，催眠状态中β波的减少反映出注意力和清醒度的下降，有助于个体进入类似于放松或睡眠的状态。

3. 外部诱导技术

- **声音诱导**：通过特定频率的声音或白噪声，可以刺激大脑产生特定的脑电波活动，进而诱导放松和催眠状态。
- **视觉诱导**：快速闪烁的光刺激或视频内容能改变大脑的神经活动，诱发放松或深度集中，尤其是结合指导性言语或暗示时，可能进入类似催眠的状态。
- **磁刺激**：经颅磁刺激（TMS）和经颅直流电刺激（tDCS）等技术，通过外部电磁场刺激特定大脑区域，可以短暂改变神经活动，从而引发催眠效应。

诱导性催眠的实现方式多种多样，以下是几种常用的技术手段：

1. 言语暗示（Verbal Suggestion）

言语诱导是催眠最经典的手段之一，通常由训练有素的催眠师通过重复性、放松性指令来诱导个体进入放松或催眠状态。这种技术依赖于语言的节奏、语调和用词，通过指令引导被催眠者的注意力转向内在感知，逐渐进入深度放松状态。

2. 视觉诱导（Visual Induction）

视觉刺激常通过让被催眠者注视一个固定点（如灯光、指示物）或观看图像、闪烁的光来实现。视觉诱导方法常见于自我催眠中，通过聚焦视觉注意力使大脑逐渐进入放松状态。快速或有节奏的闪光可以改变大脑的神经活动，增加α波和θ波，有助于进入类似睡眠或深度放松状态 HARVARD GAZETTE 。

3. 声音诱导（Auditory Induction）

声音催眠技术包括白噪声、舒缓的音乐、自然音效（如雨声、海浪）以及双耳节拍（binaural beats）等，旨在通过特定的声音频率和节奏引导大脑进入催眠状态。双耳节拍是一种特殊的音频信号，通过左右耳播放微小频率差的声音，促使大脑产生特定频率的脑电波，从而引发放松和催眠 NIIGATA UNIVERSITY 。

4. 身体放松训练（Progressive Muscle Relaxation, PMR）

PMR是一种逐步放松全身肌肉的技术，常用于诱导性催眠和自我放松。通过按顺序紧张和放松身体的各个部位，帮助大脑逐渐放松，减少焦虑情绪并进入催眠状态。该方法常与言语暗示结合，以提高效果。

5. 呼吸调控（Breathing Control）

深呼吸和节奏性呼吸练习是帮助进入催眠状态的常用手段，通过缓慢而深长的呼吸降低心率和血压，有助于身体和大脑进入放松状态。许多催眠疗法会从呼吸调控开始，帮助个体快速进入放松状态 HARVARD GAZETTE 。

6. 经颅磁刺激（Transcranial Magnetic Stimulation, TMS）和经颅直流电刺激（tDCS）

TMS和tDCS是用于神经调控的非侵入性技术，通过电磁或电流刺激特定大脑区域，改变局部神经活动，从而引发类似催眠或深度放松的状态。例如，TMS可以刺激前额皮质，帮助抑制觉醒和焦虑反应，使人更容易进入放松或催眠状态 NIIGATA UNIVERSITY 。

7. 虚拟现实（Virtual Reality, VR）

VR技术通过沉浸式体验提供视觉、听觉和触觉的综合刺激，使个体进入深度放松或改变意识的状态。VR中的场景可设计为宁静、舒缓的自然环境，以帮助用户减轻压力，促进催眠效应。VR技术尤其适用于有焦虑倾向或难以集中注意力的个体，有助于其快速进入放松状态 NIIGATA UNIVERSITY 。

Hibernation 冬眠

哪些动物会冬眠？为什么冬眠？

冬眠是一种由许多动物在冬季低温、食物稀缺的环境下进入的低代谢状态，其目的在于节约能量并维持生存。冬眠的动物广泛分布在各种生态系统中，包括哺乳动物、两栖动物、爬行动物和一些昆虫等。

典型的冬眠动物

1. **小型哺乳动物**：许多小型哺乳动物，如**蝙蝠**、**地松鼠**、**仓鼠和刺猬**，是典型的冬眠者。这些动物在冬季食物短缺时，通过冬眠来大幅降低代谢率、心率和体温，以节省能量。
2. **熊**：熊（如棕熊和黑熊）在冬季会进入一种称为"冬眠"的低活跃状态，但与小型哺乳动物不同，熊的体温并不会显著下降。熊的这种状态通常被称为"滞育"（torpor），虽然不是真正的冬眠，但它们仍然会显著减少能量消耗。
3. **两栖动物和爬行动物**：例如，**青蛙**和**蛇**等冷血动物在冬季低温时也会进入冬眠状态。它们会找到泥土、落叶或水底等温暖的地方栖息，通过减缓新陈代谢来度过寒冷季节。
4. **昆虫**：一些昆虫，如**蝴蝶**和**甲虫**，会进入类似冬眠的滞育状态，以应对气温的剧烈变化或食物的缺乏。

冬眠的原因

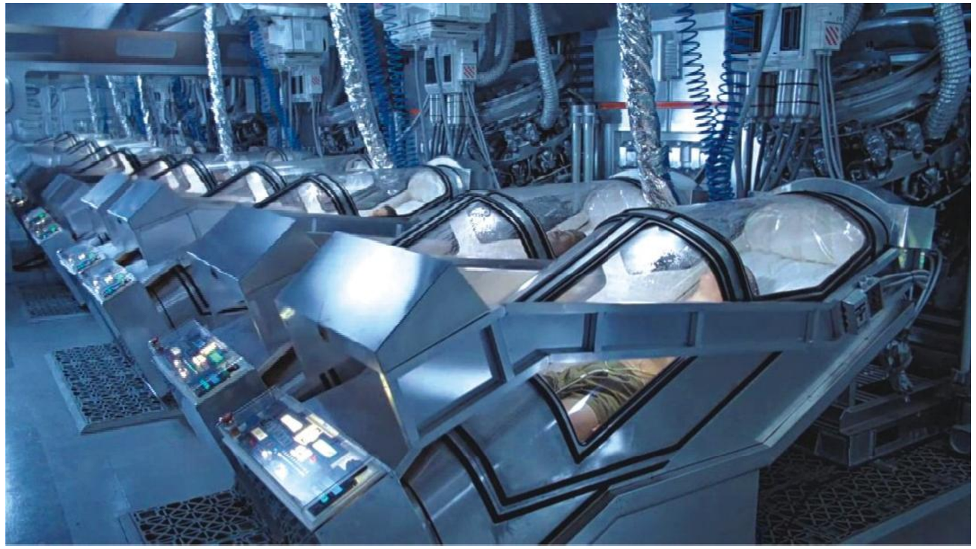
动物冬眠的主要原因是**节能和生存**。冬季的寒冷和食物稀缺使得维持正常的新陈代谢变得耗能且不具备优势。冬眠通过降低体温、心率、呼吸率和其他生理功能来减少能量消耗，这样动物就能在脂肪储备的支持下度过不利的季节。这种生理适应方式极大地提高了动物在极端环境中的生存能力，也帮助它们在冬季后有足够的能量去恢复正常生活和繁殖 HARVARD GAZETTE NIIGATA UNIVERSITY 。

土拨鼠在冬眠状态下，体温会从39℃降至7℃。心跳从原来的每分钟100下跌至2到3次。呼吸频率可以延至一小时一次。肠和肝的代谢产物会收集在肠的下部，并且在苏醒的时候被排出。

北极地松鼠冬眠时（从8月初到4月底），大脑温度会下降到冰点以上，而核心体温则会降到破纪录的零下3℃，心率下降到大约每分钟1次。

Question
人工诱导人类冬眠，有什么好处？

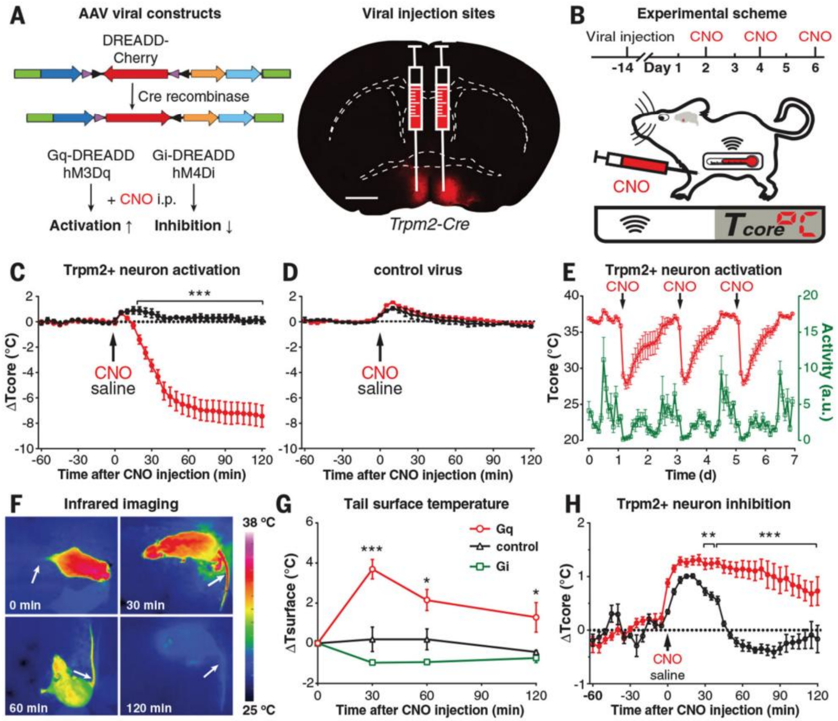
人工诱导冬眠



下丘脑中有20%的神经元对热有反应，它们都是表达TRPM2基因的神经元。为了验证TRPM2对小鼠体温的调控作用，学者们在正常的成年小鼠身上做了一个实验：

给小鼠的大脑注射特定药物和蛋白质，**激活TRPM2神经元**，同时记录小鼠的体温变化。 通过红外摄像仪发现，激活TRPM2神经元后，小鼠的体温在2小时内迅速从37℃**降低到了27℃**。

随着药物的代谢，十几个小时后，小鼠的体温又回归到正常水平，并且**尚未**观察到实验对小鼠的健康有损伤。



Song K*(宋昆，南科大), et al. The TRPM2 channel is a hypothalamic heat sensor that limits fever and can drive hypothermia. Science (2016)

人工诱导冬眠

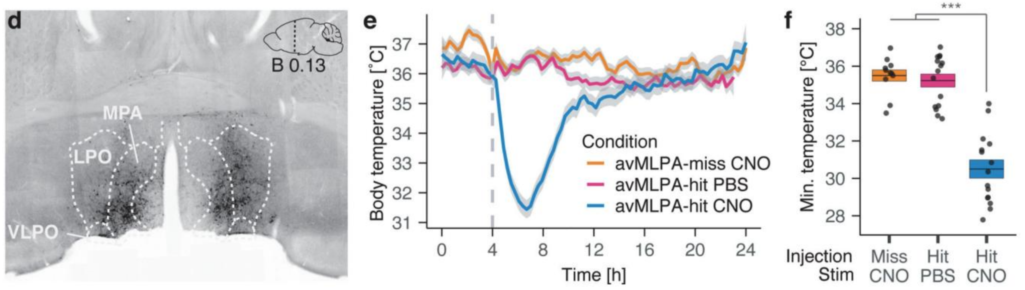
如何通过刺激hypothalamus的preoptic area区域来诱导冬眠?

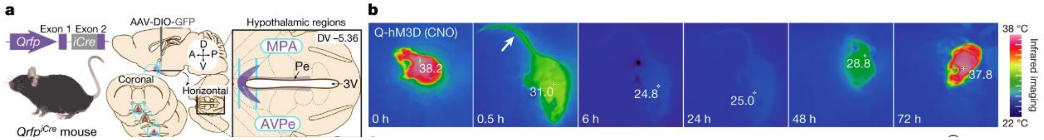
诱导冬眠或类似低代谢状态的关键在于激活下丘脑中的前视区（preoptic area, POA），该区域与体温调节和代谢控制密切相关。在动物实验中，研究人员通过特定的神经刺激技术，如光遗传学和化学遗传学，成功地在非冬眠动物（如小鼠）中诱导了类似冬眠的状态。

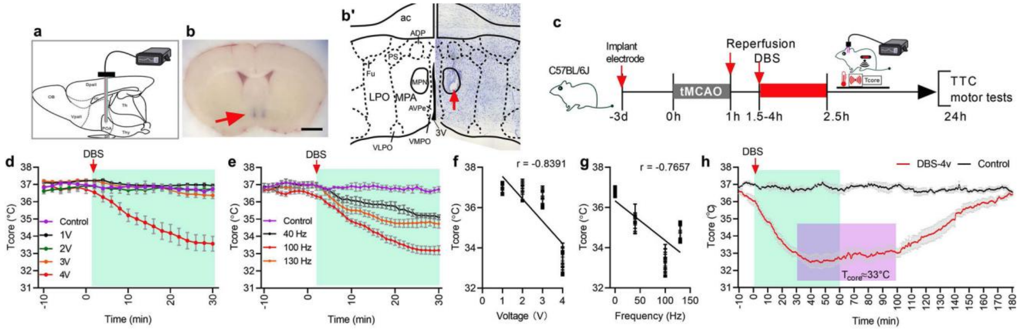
以下是主要的诱导方法：

1. **光遗传学（Optogenetics）**：通过向特定的POA神经元导入光敏蛋白（如ChR2），可以利用光刺激来精确控制这些神经元的活动。当这些神经元被激活时，POA会触发体温和代谢率的下降，导致进入低代谢状态。这种方法的优点是具有时间和空间上的高度精准性，可以快速观察到体温和心率的变化 HARVARD GAZETTE 。
2. **化学遗传学（Chemogenetics）**：使用FosTRAP等技术，研究人员可以将POA区域在低温下活跃的神经元标记出来，并通过注射特定化学物质（如CNO）来激活这些神经元群。这种激活能引发小鼠的体温降低至接近冬眠的水平，同时降低其代谢率。实验中观察到的成功标志包括显著的体温下降、呼吸减慢和行为减少 NIIGATA UNIVERSITY 。
3. **药物和神经调控**：一些实验还尝试通过药物直接作用于POA神经元或其相关通路，从而调节其活动。通过直接在POA区域施用GABA等神经递质的激动剂，可以抑制神经元活动，从而导致体温和代谢的下降。此类研究利用代谢测量和脑电活动监测来验证进入的低代谢状态是否符合冬眠特征。

这些研究揭示了POA在冬眠和体温调控中的核心作用，通过神经调控来激活或抑制该区域的特定神经元，可以为非冬眠动物诱导类似冬眠的状态提供参考。







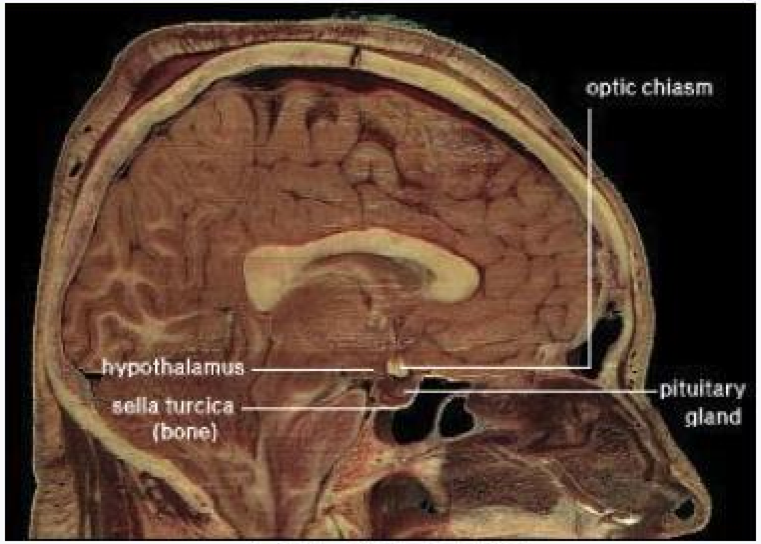
Hrvatin, Sinisa, et al. "Neurons that regulate mouse torpor." Nature (2020)
Takahashi, Tohru M., et al. "A discrete neuronal circuit induces a hibernation-like state in rodents." Nature (2020)
Zhang, Shuai, et al (侯圣陶 南科大). "Hypothermia evoked by stimulation of medial preoptic nucleus protects the brain in a mouse model of ischaemia." Nature Comm (2022)

下丘脑（英语：hypothalamus）又称**下视丘**、**丘脑下部**，是位于丘脑腹侧属于间脑的脑组织。下丘脑有合成和分泌各种神经激素的神经核团，参与调节机体代谢、应激反应及其他自主神经系统活动；也是调节内脏活动、内分泌功能和情绪行为等的中枢。英语 hypothalamus 源自古希腊语 ὑπό（*hupó*）下（under）之义，加上 θάλαμος（*thálamos*）腔室（chamber）之义，此因丘脑中央有第三脑室。

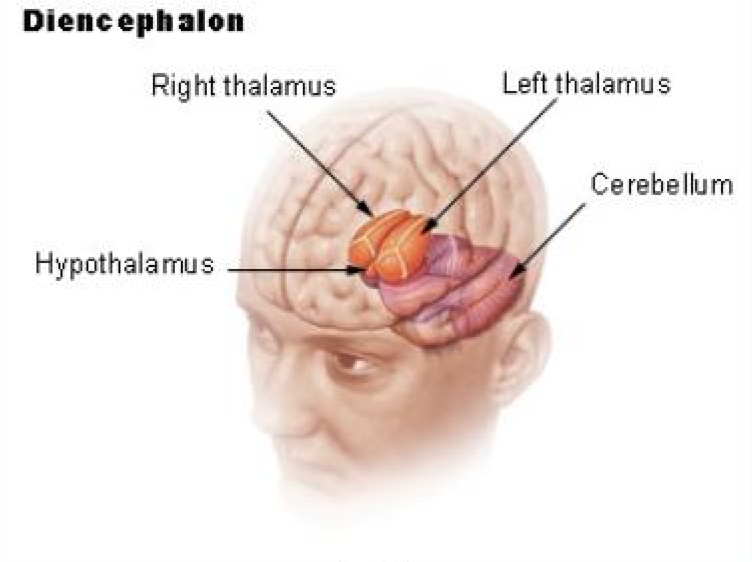
下丘脑被第三脑室分成左、右两半，其区域包括间脑腹侧的大部分区域，通过脑下垂体连接神经系统和内分泌系统；在人体中，它和杏核的大小相当。通常将下丘脑从前向后分为四个区：视前区、视上区、结节区和乳头体区[1][2]。视前区在视交叉前缘和前连合之间，内含视前核；视上区在视交叉上方，内含视交叉上核、视上核、室旁核及下丘脑前核；结节区则含下丘脑弓状核、腹内侧核、背内侧核；乳头体区含下丘脑后核、乳头体核。

下视丘位于脑的底部，具调节体温、血糖、水平衡、脂肪代谢、摄食习惯、睡眠、性行为、情绪、荷尔蒙（例如：肾上腺素及皮质醇）以及自律神经系统的作用。它接收从自律神经系统而来的讯号，并决定相应的行动。当人类遇到恐惧或兴奋的事情，身体的自律神经系统会向视丘下部腺体发出讯号，从而使身体加速心跳和呼吸、瞳孔扩张，并增加血液流量，以使身体能够及时作出相应的行动。虽然它在身体占有极为重要的地位，但它的体积只有整个脑部不足1%的空间。

下视丘



人体下视丘位置



间脑

睡眠障碍

Sleep disorders

More than half of the population experiences significant difficulties with sleep at least on occasion, and as many as one in five persons suffers from chronic sleep problems.

Disruption of sleep and waking is the most prevalent health disorder in the United States.

Sleep Disorders Have Behavioral, Psychological, and Neurological Causes.

- Most sleep problems have mundane causes and may simply require a change in **habit**.
- Others involve **complicating factors** such as shift work, depression, or substance abuse.
- Some sleep disorders now provide new insights into **brain function**.

As sleep is organized into several cyclical, roughly 90-minute periods of REM and non-REM sleep, **each component can be disrupted.** The most common disorders are related to a breakdown in the transition between sleep and waking, such as difficulty falling asleep or early morning wakening. Other sleep disorders may represent a breakdown in specific neural circuits.

Sleep disorders – Insomnia（失眠症）

Insomnia is a sleep disorder associated with inadequate sleep

- Insomnia can manifest as difficulty falling asleep, difficulty staying asleep through the night, or early morning awakening before sufficient sleep is obtained.
- Insomnia may result from **physical** or **emotional** complications or simply from poor sleep **habits** (eg, consumption of excessive caffeine, alcohol, or food, or exercising vigorously before sleep).
- It can also be the result of **disorders** such as epilepsy, Parkinson’s disease, depression, anxiety or other conditions.

Sleep disorders - Sleep Apnea （睡眠呼吸暂停症）

Sleep apnea is a sleep disorder characterized by the inability to breathe while sleeping for a prolonged period of time

Consequences: sleepiness during the day, impaired attention, depression, and sometimes heart problems

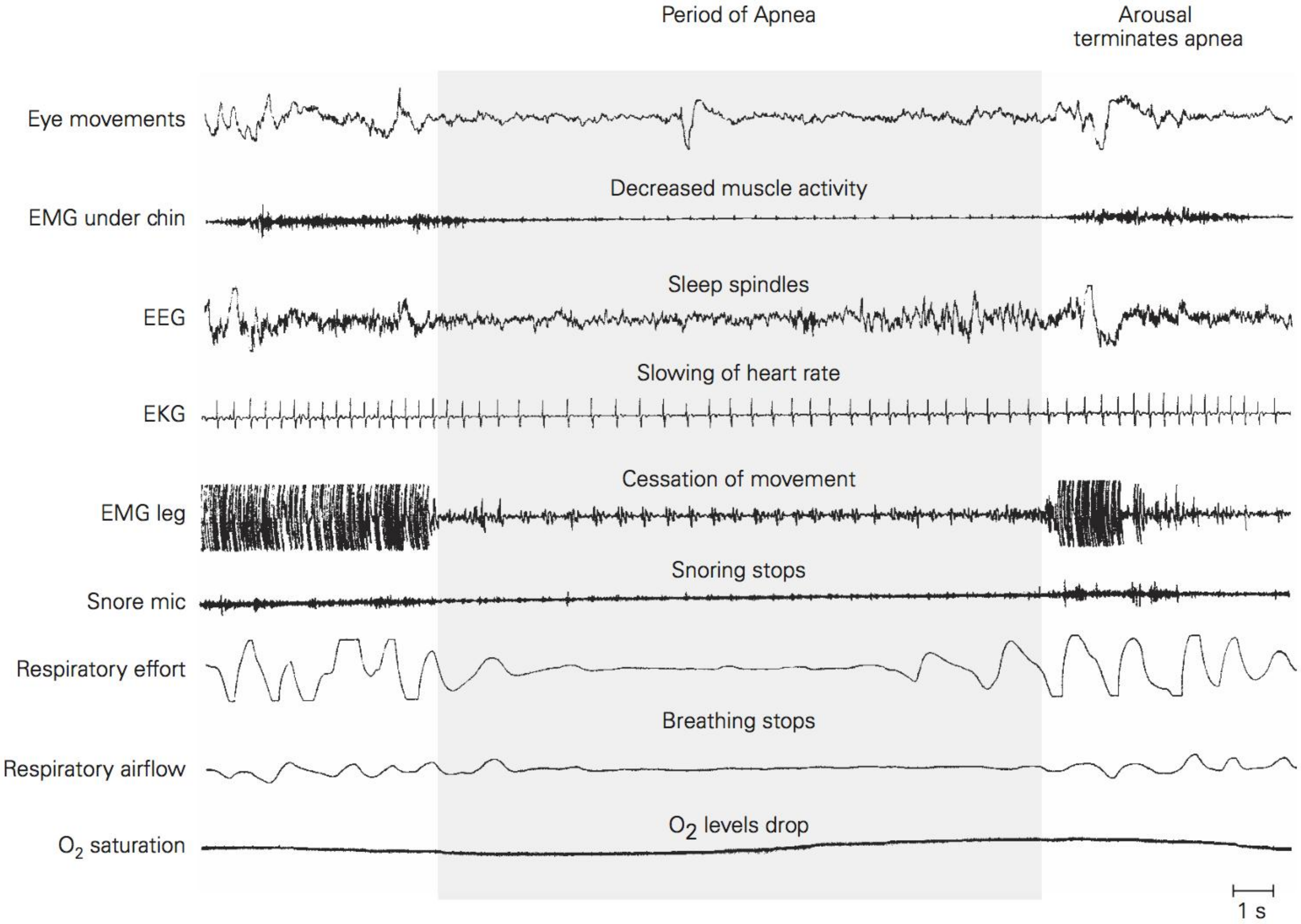
Causes: genetics, hormones, old age, and deterioration of the brain mechanisms that control breathing and obesity

Cognitive impairment may result

Sleep disorders - Sleep Apnea （睡眠呼吸暂停症）

Reduction of muscle tone can result in either an annoying disturbance of sleep, as in snoring, or in greatly disturbed sleep, as in **sleep apnea** (cessation of breathing).

Approximately 4% of middle-aged men (2% of middle- aged women) have sleep apnea. At **older** than age 65 years these percentages increase to more than 28% of men and 24% of women.



Sleep disorders – Narcolepsy （嗜睡症）

Narcolepsy is a sleep disorder characterized by frequent periods of sleepiness.

- Gradual or sudden attack of sleepiness
- Occasional cataplexy: muscle weakness triggered by strong emotions
- Sleep paralysis: inability to move while falling asleep or waking up
- Hypnagogic hallucinations: dreamlike experiences
- Narcolepsy seems to run in families although **no gene has been identified**
- Caused by lack of **hypothalamic cells** that produce and release **orexin**
- Primary treatment is with **stimulant drugs** (i.e., Ritalin), which increase wakefulness by enhancing dopamine and norepinephrine activity

Sleep disorders – Narcolepsy （嗜睡症）

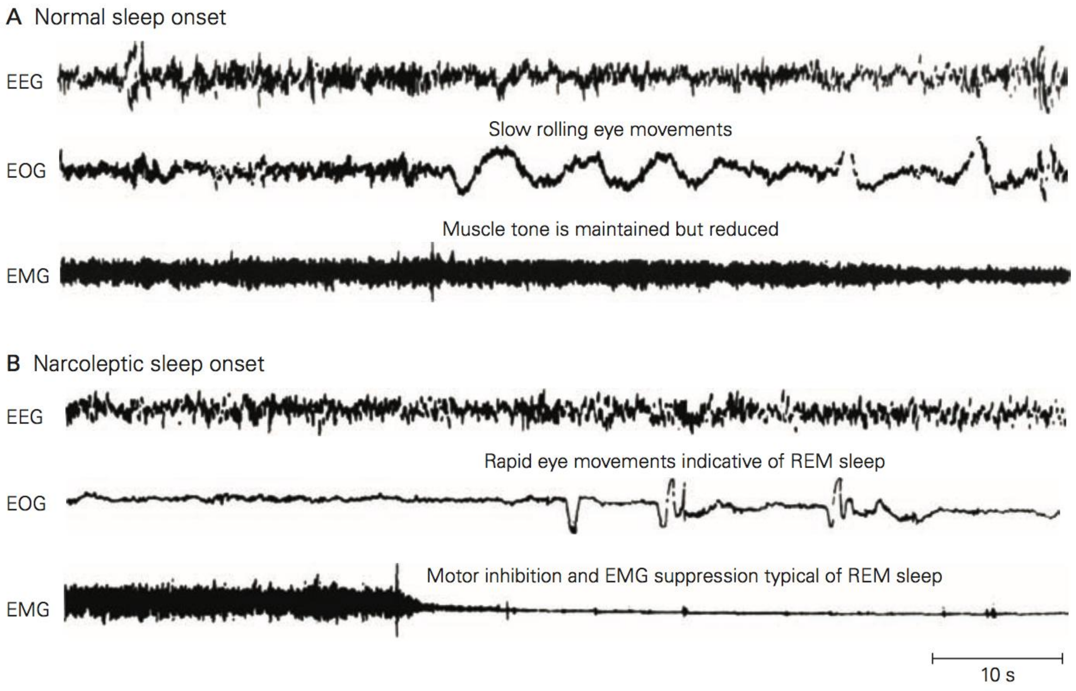
In narcoleptic patients sleep can initiate with REM sleep.

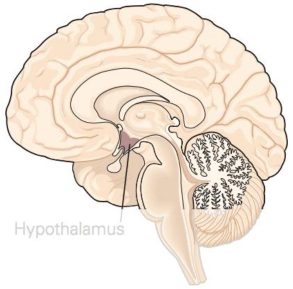
A. Sleep onset in a normal person is associated with slow rolling eye movements and a slow decrease in muscle tone.

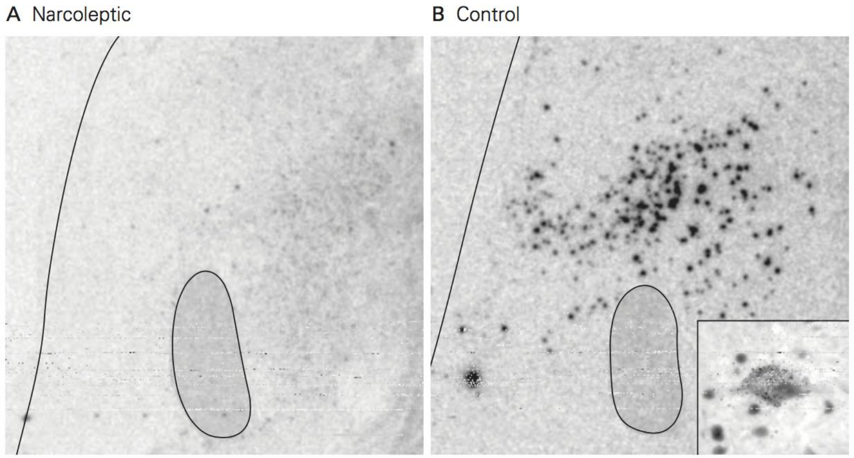
B. Sleep onset in a narcoleptic is associated with a sudden decrease in muscle tone and the appearance of rapid eye movements typical of REM sleep.

Narcolepsy is associated with a loss of hypothalamic neurons that produce the peptide hypocretin.

A dramatic loss of neurons is evident in the brain of a narcoleptic compared to a normal brain.







Sleep disorders – Parasomnias （异样睡眠障碍）

Parasomnias include sleep walking, sleep talking, confusional arousals, bed wetting, night terrors, and REM behavior disorder. Sleep walking, sleep talking, and confusional arousals are relatively common in children and typically occur during **stages 3 and 4** sleep.

- For short events the EEG is a **continued pattern** of slow waves; for longer events the pattern changes to **an “activated” pattern**—low-voltage, desynchronized high-frequency activity—characteristic of waking.
- Usually sleepwalkers or talkers are **unaware** of an event and have no memory of it.
- Speech is largely **incoherent** during an event. Remarkably, **sleep walkers are often able to avoid colliding with objects**.

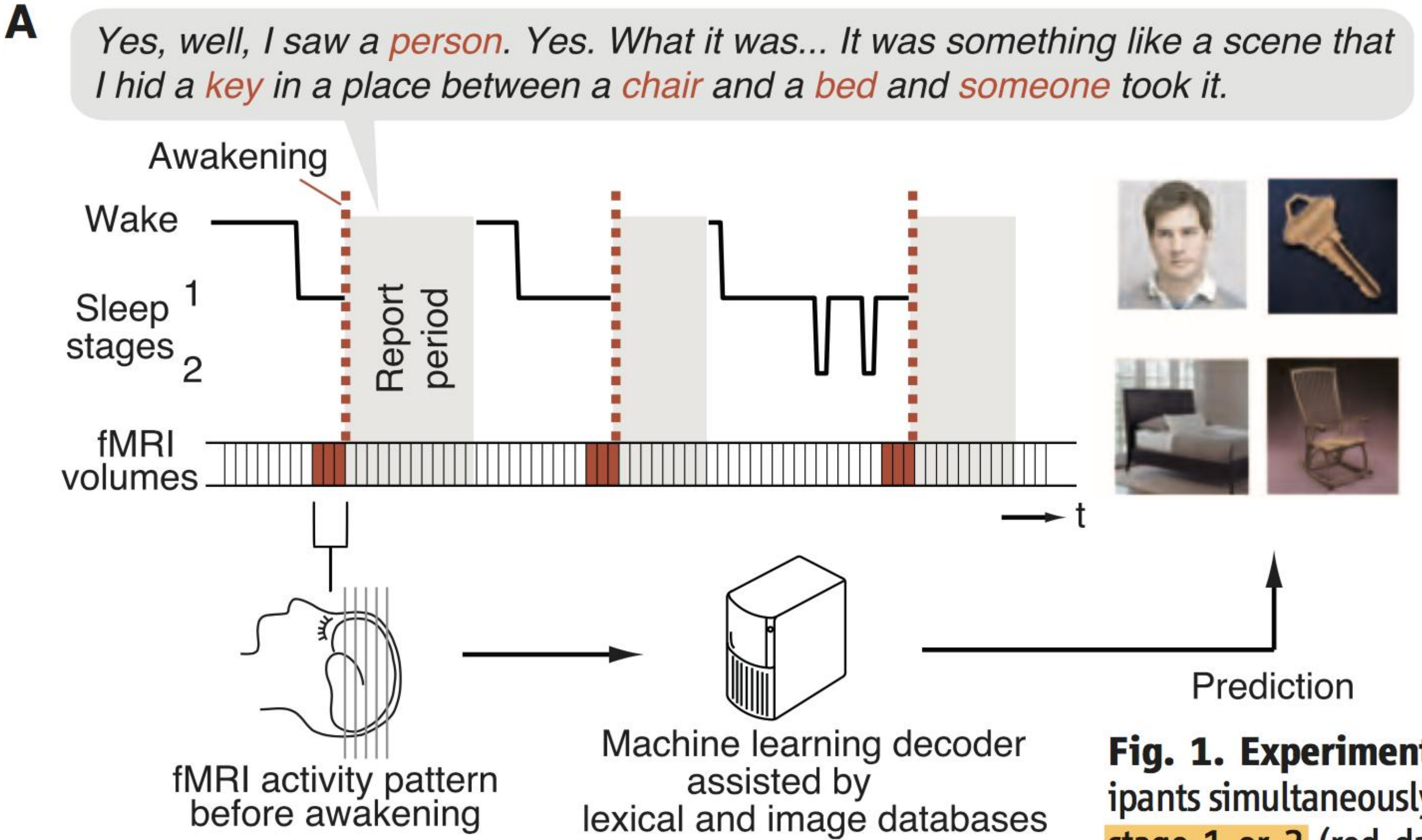
During REM sleep descending **inhibition of motor neurons** in the spinal cord normally prevents people from acting out their vivid dreams. This descending pathway may be **damaged** in people suffering from **REM behavior disorder** (usually men and elderly people).

The mechanisms underlying REM behavior disorder are **not yet known**.

AI for decoding dreams

- datasets
- AI models
- validation

Decoding dreams



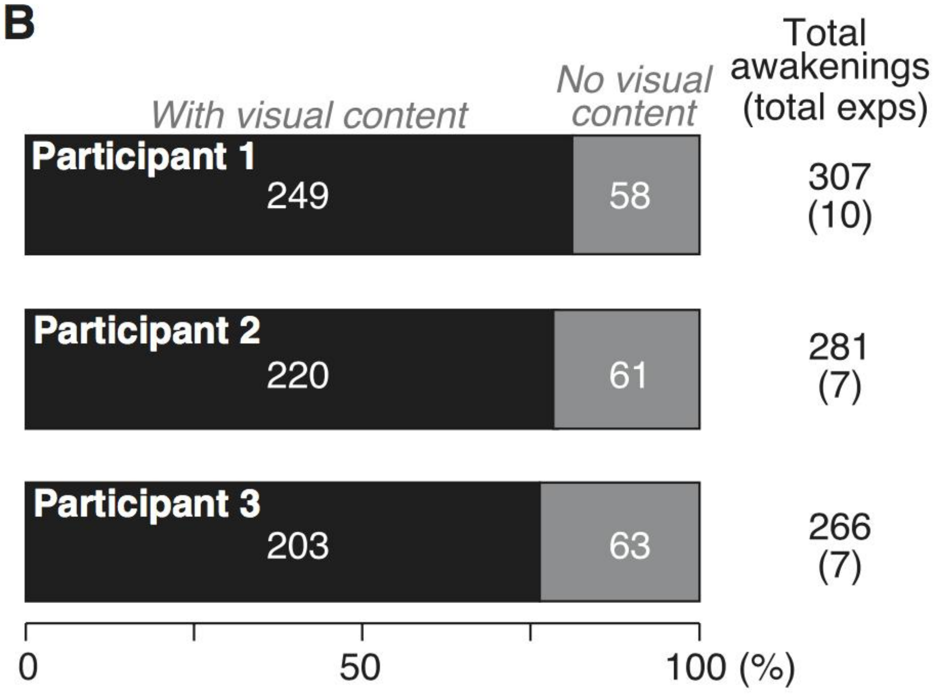


Fig. 1. Experimental overview. (**A**) fMRI data were acquired from sleeping participants simultaneously with polysomnography. Participants were awakened during sleep stage 1 or 2 (red dashed line) and verbally reported their visual experience during sleep. fMRI data immediately before awakening [an average of three volumes (= 9 s)] were used as the input for main decoding analyses (sliding time windows were used for time course analyses). Words describing visual objects or scenes (red letters) were extracted. The visual contents were predicted using machine-learning decoders trained on fMRI responses to natural images. (**B**) The numbers of awakenings with and without visual contents are shown for each participant (with numbers of experiments in parentheses).

T Horikawa, et al (2013) Neural Decoding of Visual Imagery During Sleep, **Science., 2013**

Decoding dreams

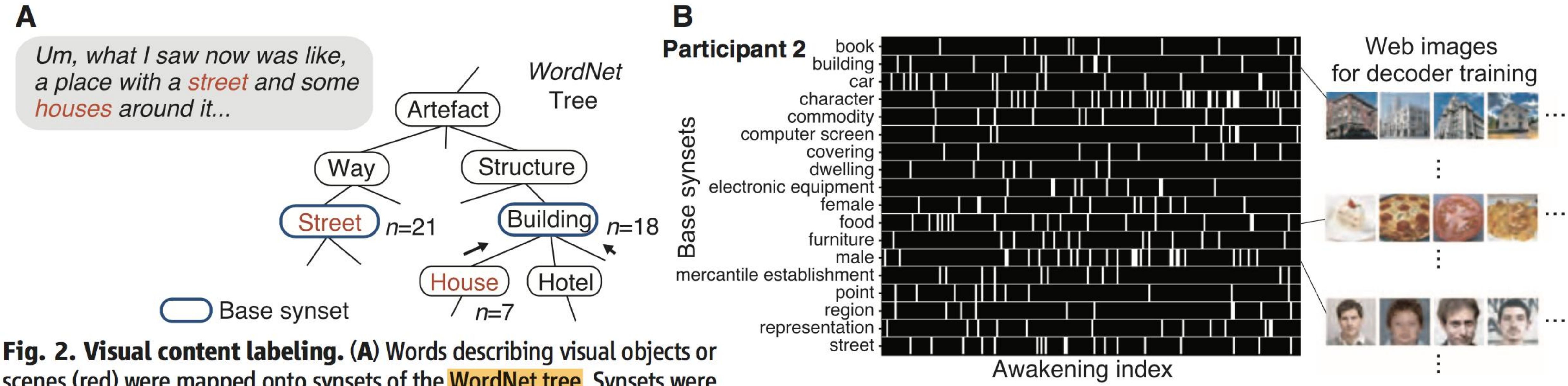


Fig. 2. Visual content labeling. (**A**) Words describing visual objects or scenes (red) were mapped onto synsets of the WordNet tree. Synsets were grouped into base synsets (blue frames) located higher in the tree. (**B**) Visual reports (participant 2) are represented by visual content vectors, in which the presence or absence of the base synsets in the report at each awakening is indicated by white or black, respectively. Examples of images used for decoder training are shown for some of the base synsets.

T Horikawa, et al (2013) Neural Decoding of Visual Imagery During Sleep, **Science., 2013**

Decoding dreams with SVM on fMRI data

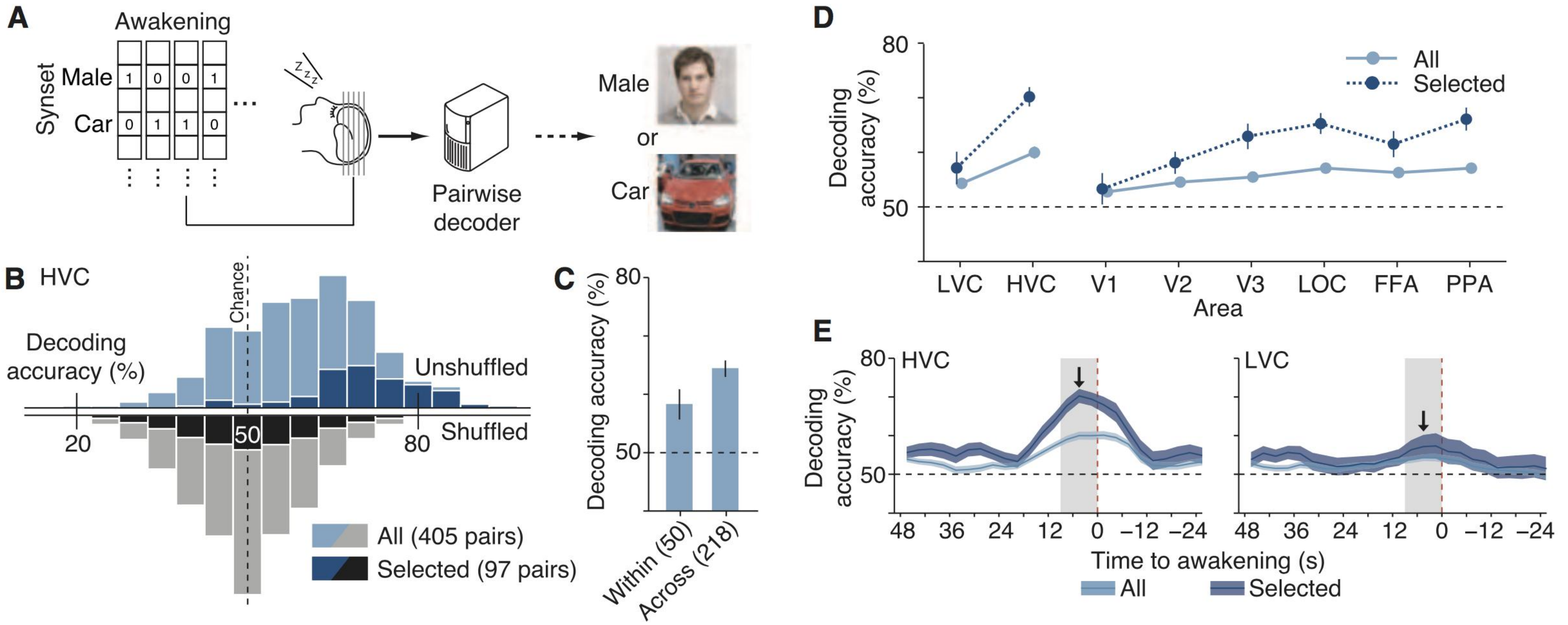


Fig. 3. Pairwise decoding. (**A**) Schematic overview. (**B**) Distributions of decoding accuracies with original and label-shuffled data for all pairs (light blue and gray) and selected pairs (dark blue and black) (three participants pooled). (**C**) Mean accuracies for the pairs within and across meta-categories (synsets in others were excluded; numbers of pairs are in parentheses). (**D**) Accuracies across visual areas (numbers of selected pairs for V1, V2, V3, LOC, FFA, PPA, LVC, and HVC: 45, 50, 55, 70, 48, 78, 55, and 97). (**E**) Time course (HVC and LVC; averaged across pairs and participants). The plot shows the performance with the 9-s (three-volume) time window centered at each point (gray window and arrow for main analyses). For all results, error bars or shadings indicate 95% CI, and dashed lines denote chance level.

T Horikawa, et al (2013) Neural Decoding of Visual Imagery During Sleep, **Science., 2013**

Decoding dreams with deep learning

In this study, we used a deep neural network (DNN) model for object recognition as a proxy for hierarchical visual feature representation, and DNN features for dreamed objects were analyzed with brain decoding of fMRI data collected during dreaming.

The decoders were first trained with stimulus-induced brain activity labeled with the feature values of the stimulus image from multiple DNN layers. The decoders were then used to decode DNN features from the dream fMRI data, and the decoded features were compared with the averaged features of each object category calculated from a large-scale image database.

We found that the feature values decoded from the dream fMRI data positively correlated with those associated with dreamed object categories at mid- to high-level DNN layers. Using the decoded features, the dreamed object category could be identified at above-chance levels by matching them to the averaged features for candidate categories. The results suggest that dreaming recruits hierarchical visual feature representations associated with objects, which may support phenomenal aspects of dream experience.

Hierarchical Neural Representation of Dreamed Objects Revealed by Brain Decoding with Deep Neural Network Features, **Front. Comput. Neurosci., 2017**

Decoding dreams with deep learning

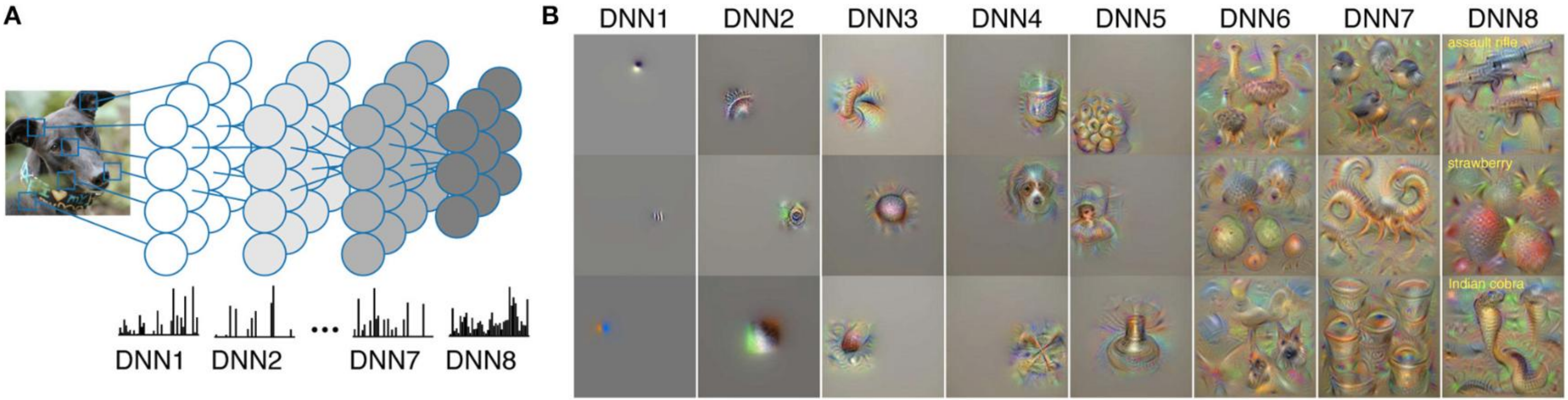
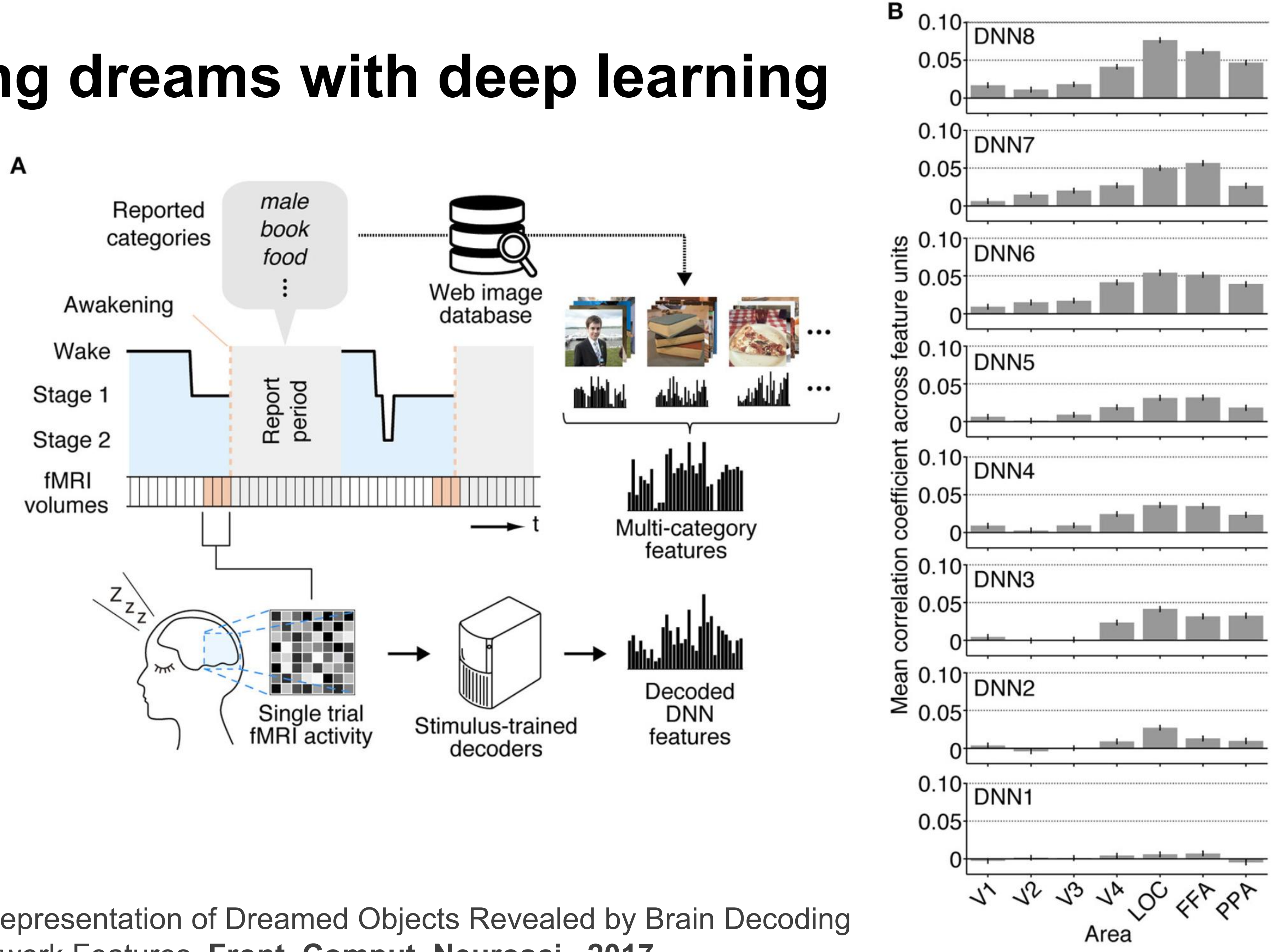


FIGURE 1 | Deep neural network features. (A) Representing an input image by visual feature patterns derived by DNN. The DNN was used to extract feature values of individual units in each layer. **(B)** Preferred images for each DNN layer. The images that highly activate each DNN unit were generated using activation maximization methods (see Materials and Methods: "Synthesis of Preferred Images Using Activation Maximization" for details).

Hierarchical Neural Representation of Dreamed Objects Revealed by Brain Decoding with Deep Neural Network Features, **Front. Comput. Neurosci., 2017**

Decoding dreams with deep learning



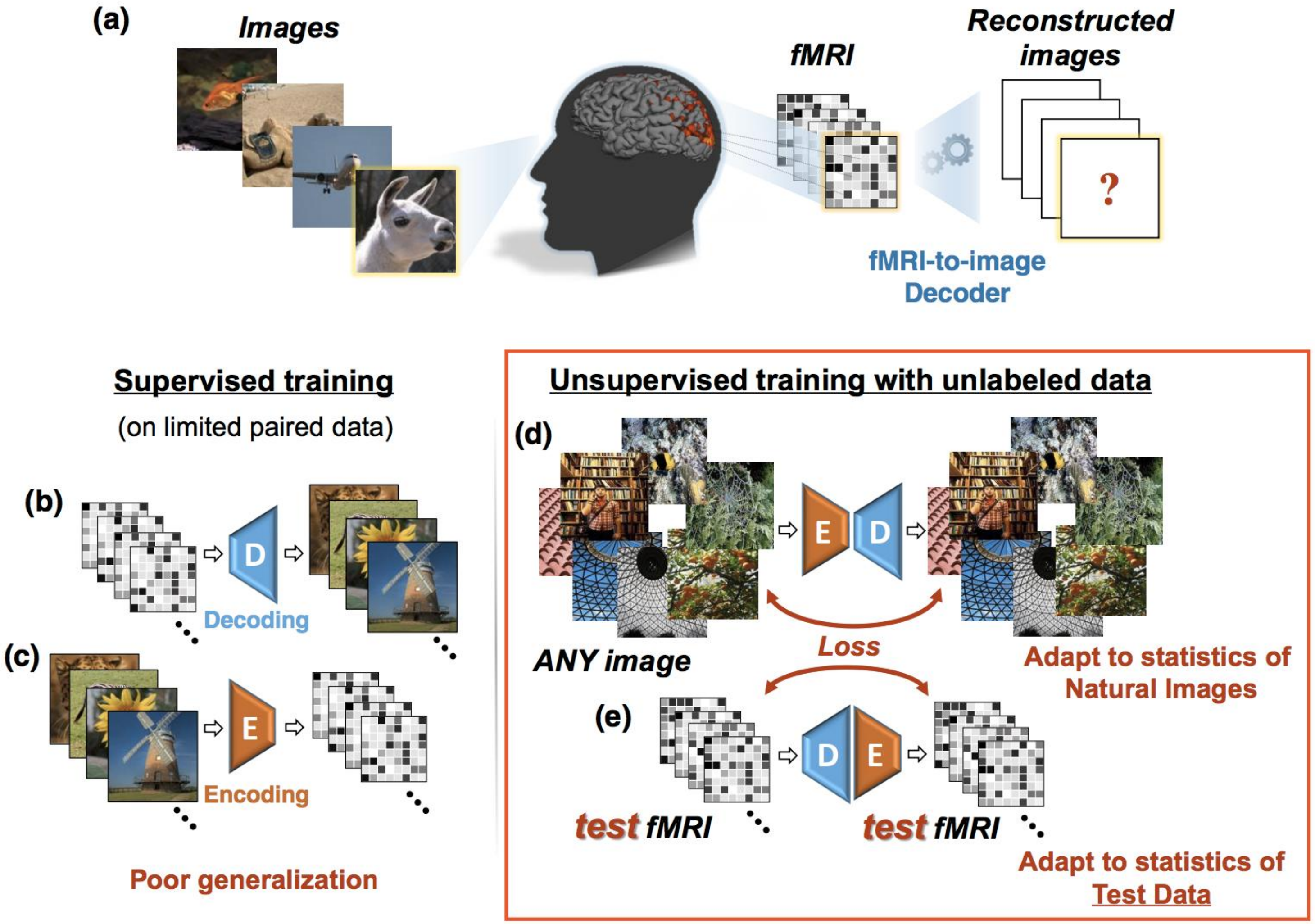
Hierarchical Neural Representation of Dreamed Objects Revealed by Brain Decoding with Deep Neural Network Features, **Front. Comput. Neurosci., 2017**

Self-supervision in natural-image reconstruction from fMRI

We present a novel approach which, in addition to the scarce labeled data (training pairs), allows to train fMRI-to-image reconstruction networks also **on “unlabeled” data** (i.e., images without fMRI recording, and fMRI recording without images).

The proposed model utilizes both an Encoder network (image-to-fMRI) and a Decoder network (fMRI-to-image). Concatenating these two networks back-to-back (Encoder-Decoder & Decoder-Encoder) allows augmenting the training with both types of unlabeled data. Importantly, it allows training on the unlabeled test-fMRI data.

This self-supervision adapts the reconstruction network to the new input test-data, despite its deviation from the statistics of the scarce training data.



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Self-supervision in natural-image reconstruction from fMRI

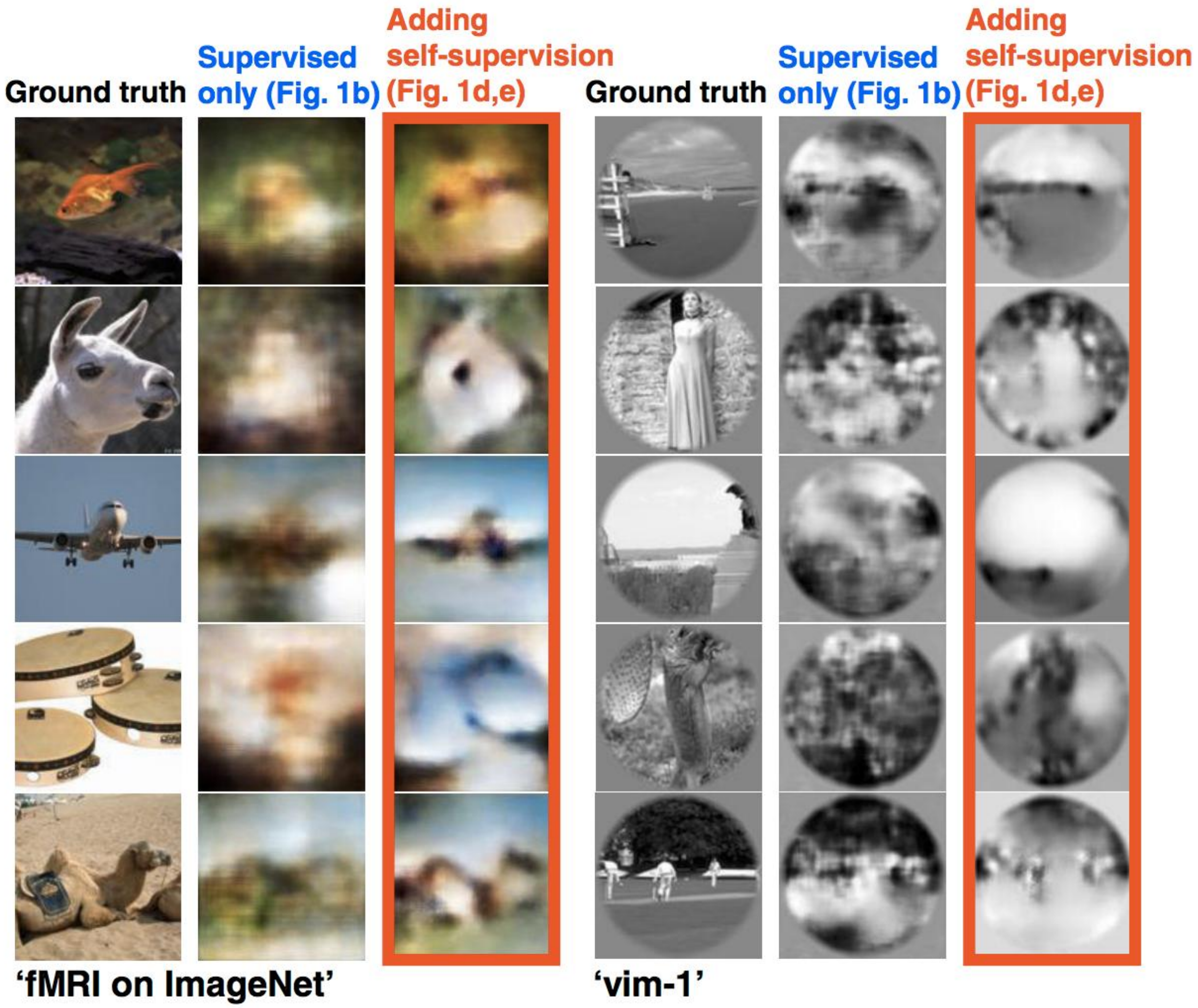


Figure 2: **Adding unsupervised training on unlabeled data improves reconstruction.** ***(Left column):*** *the images presented to the human.* ***(Middle column):*** *Reconstruction using the training pairs only (Fig 1b).* ***(Right column):*** *Reconstruction when adding unsupervised training on unlabeled data (Fig 1d,e). Example results are shown for two fMRI datasets: 'fMRI on ImageNet' [16] and 'vim-1' [1].*

https://papers.nips.cc/paper/2019/file/7d2be41b1bde6ff8fe45150c37488ebb-Paper.pdf

[1] K. N. Kay, et al (2008), "Identifying natural images from human brain activity," *Nature*

[16] T. Horikawa and Y. Kamitani (2015), "Generic decoding of seen and imagined objects using hierarchical visual features," *Nature Communications*

图片-fMRI 数据集

Natural Scenes Dataset (NSD)

High-resolution image reconstruction with latent diffusion models from human brain activity

Yu Takagi[1,2*]   Shinji Nishimoto[1,2]

[1]Graduate School of Frontier Biosciences, Osaka University, Japan

[2]CiNet, NICT, Japan

{takagi.yuu.fbs,nishimoto.shinji.fbs}@osaka-u.ac.jp

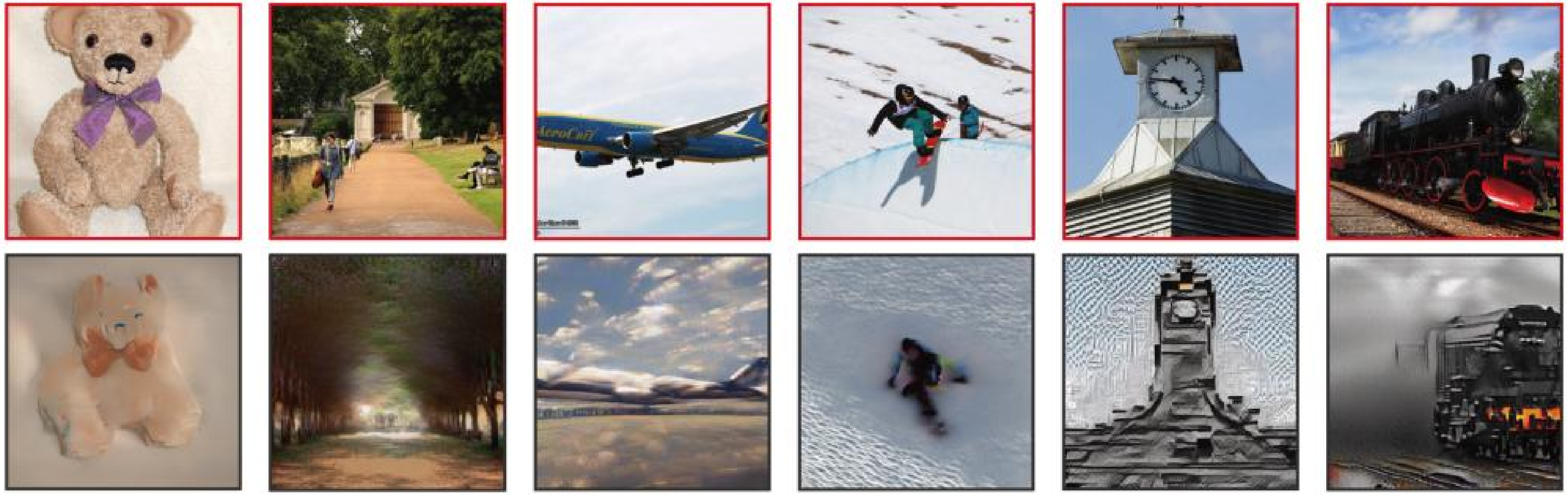
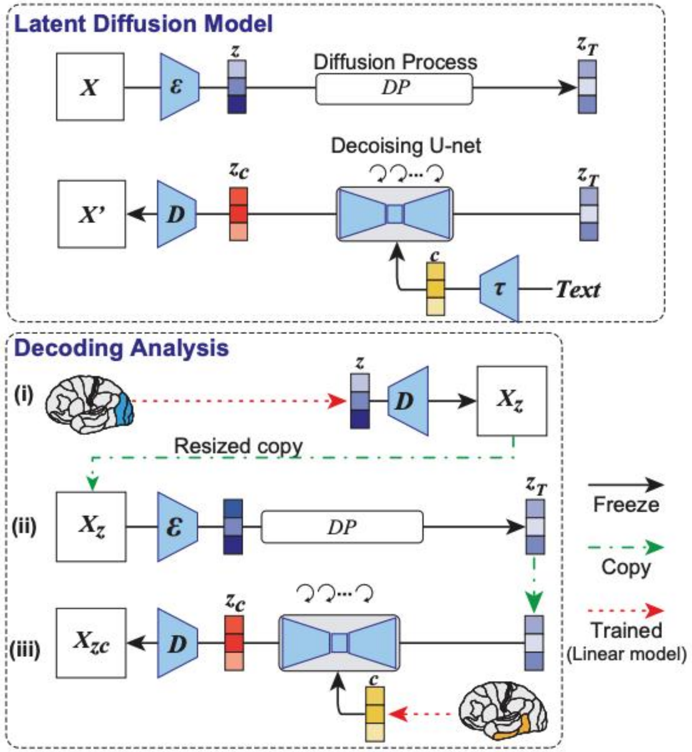


Figure 1. Presented images (red box, top row) and images reconstructed from fMRI signals (gray box, bottom row) for one subject (subj01).



Takagi, Yu, and Shinji Nishimoto. "High-resolution image reconstruction with latent diffusion models from human brain activity." CVPR (2023)

Reconstructing the Mind's Eye: fMRI-to-Image with Contrastive Learning and Diffusion Priors

Paul S. Scotti[*,1,2], Atmadeep Banerjee[*,2], Jimmie Goode[†,2], Stepan Shabalin[2], Alex Nguyen[1], Ethan Cohen[3], Aidan J. Dempster[4], Nathalie Verlinde[1], Elad Yundler[5], David Weisberg[1,2], Kenneth A. Norman[‡,1], and Tanishq Mathew Abraham[‡,2,6,7]

[1]Princeton Neuroscience Institute
[2]Medical AI Research Center (MedARC)
[3]Ecole Normale Supérieure, PSL University
[4]University of Toronto
[5]Hebrew University of Jerusalem
[6]EleutherAI
[7]Stability AI

Project Page: `https://medarc.ai/mindeye/`

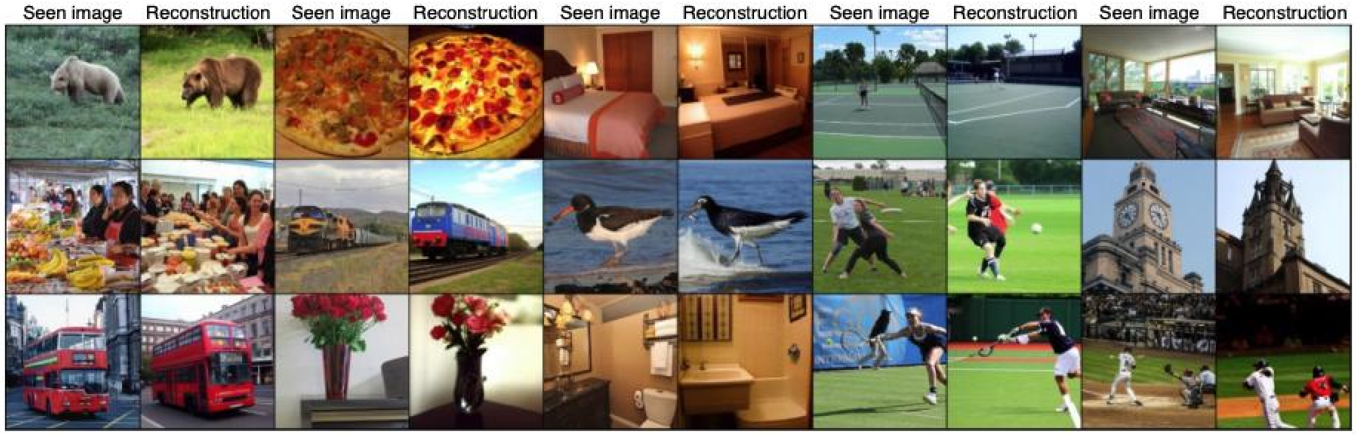
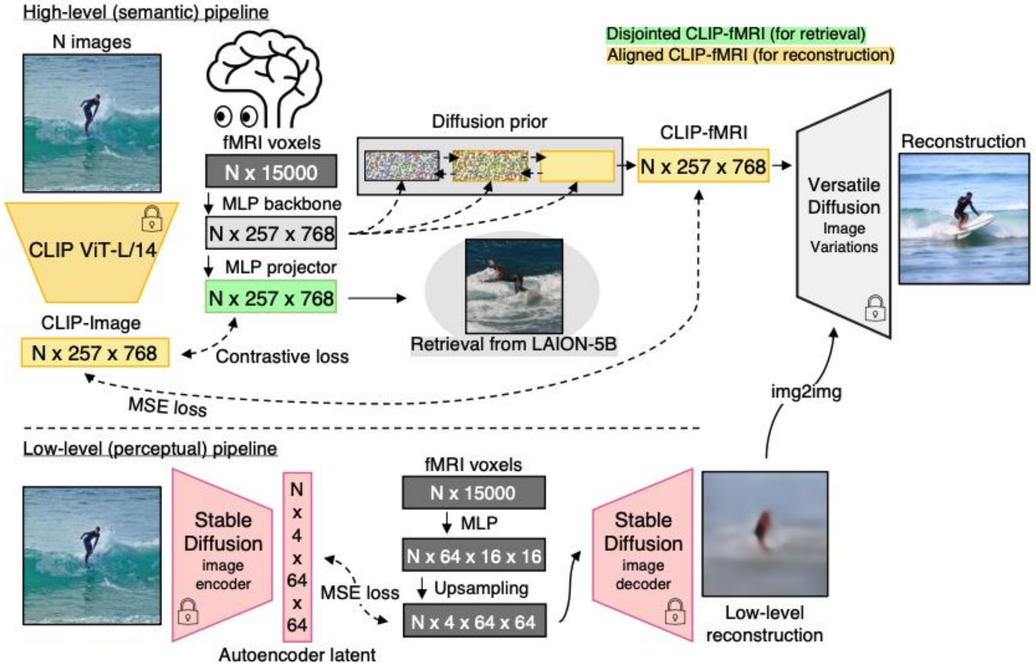


Figure 1: Example images reconstructed from human brain activity corresponding to passive viewing of natural scenes. Reconstructions depict outputs from Versatile Diffusion [6] given CLIP fMRI embeddings generated by MindEye for Subject 1. See Figure 4 and Appendix A.4 for more samples.

图片-fMRI 数据集

Natural Scenes Dataset (NSD)



Scotti, Paul, et al. "Reconstructing the mind's eye: fMRI-to-image with contrastive learning and diffusion priors." NeurIPS (2024).

DREAM: Visual Decoding from REversing HumAn Visual SysteM

Weihao Xia[1] ✉ Raoul de Charette[2] Cengiz Oztireli[3] Jing-Hao Xue[1]
[1]University College London [2]Inria [3]University of Cambridge
{weihao.xia.21,jinghao.xue}@ucl.ac.uk, raoul.de-charette@inria.fr, aco41@cam.ac.uk

图片-fMRI 数据集

Natural Scenes Dataset (NSD)

Abstract

In this work we present DREAM, an fMRI-to-image method for reconstructing viewed images from brain activities, grounded on fundamental knowledge of the human visual system. We craft reverse pathways that emulate the hierarchical and parallel nature of how humans perceive the visual world. These tailored pathways are specialized to decipher semantics, color, and depth cues from fMRI data, mirroring the forward pathways from visual stimuli to fMRI recordings. To do so, two components mimic the inverse processes within the human visual system: the Reverse Visual Association Cortex (R-VAC) which reverses pathways of this brain region, extracting semantics from fMRI data; the Reverse Parallel PKM (R-PKM) component simultaneously predicting color and depth from fMRI signals. The experiments indicate that our method outperforms the current state-of-the-art models in terms of the consistency of appearance, structure, and semantics. Code will be available at https://github.com/weihaox/DREAM.

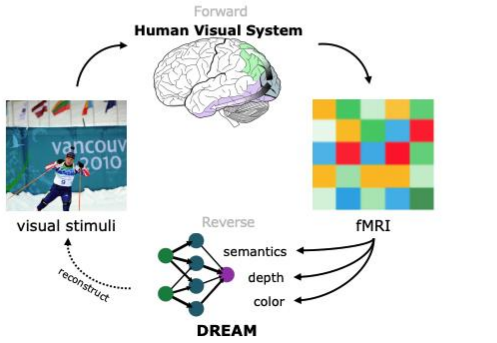
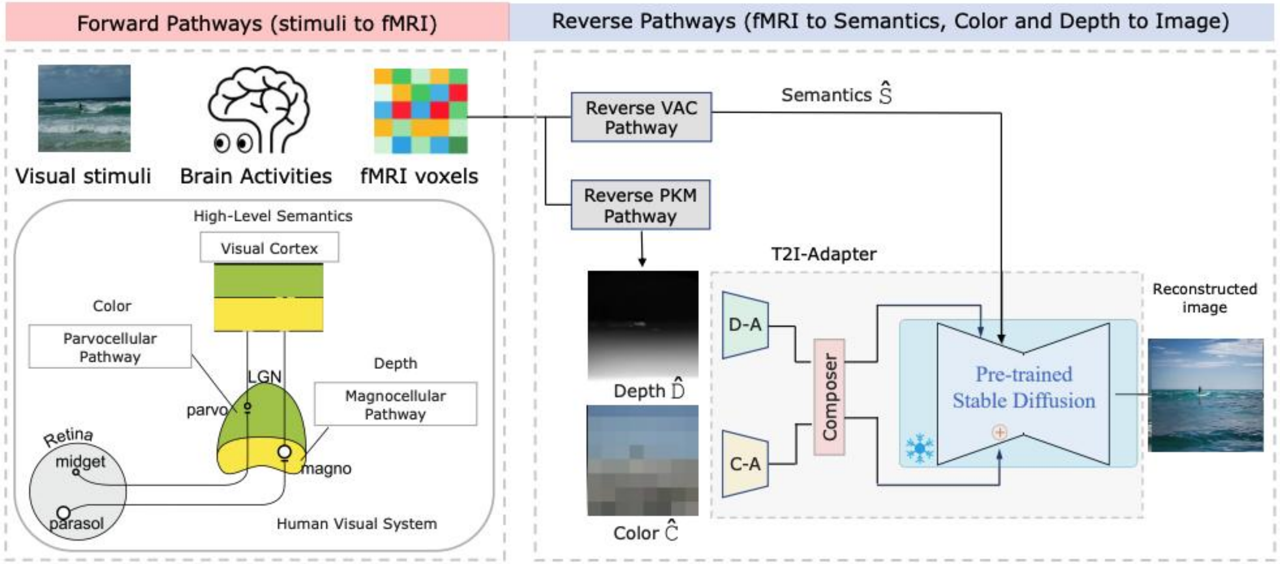
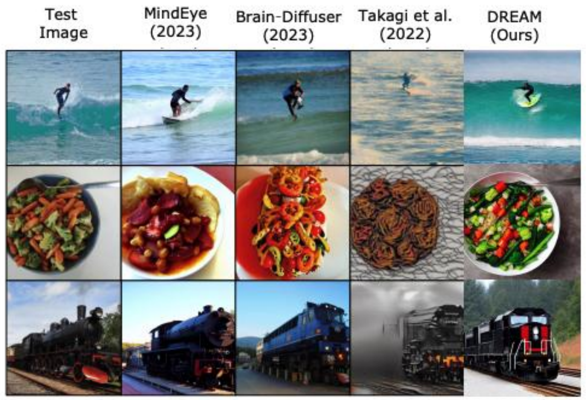
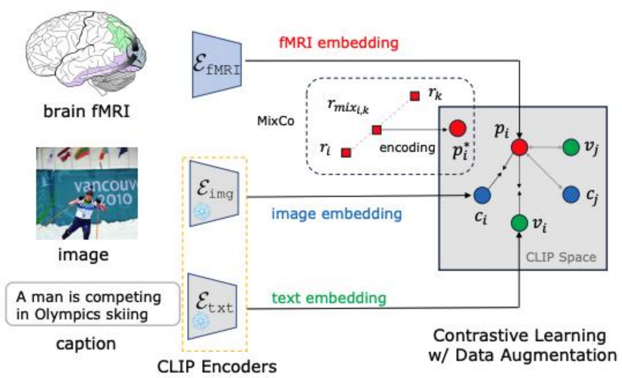


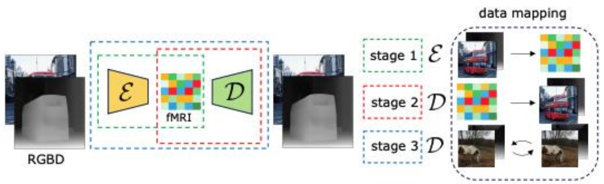
Figure 1. **Forward and Reverse Cycle**. Forward (HVS): visual stimuli ↦ color, depth, semantics ↦ fMRI; Reverse (DREAM): fMRI ↦ color, depth, semantics ↦ reconstructed images.

sual decoding. Hence, current methods have endeavored to incorporate structural and positional details, either through depth maps [7, 35] or by utilizing the decoded representa-









Xia, Weihao, Raoul de Charette, Cengiz Oztireli, and Jing-Hao Xue. "Dream: Visual decoding from reversing human visual system." CVPR (2024)

Cinematic Mindscapes: High-quality Video Reconstruction from Brain Activity

Zijiao Chen*
National University of Singapore
zijiao.chen@u.nus.edu

Jiaxin Qing*
The Chinese University of Hong Kong
jqing@ie.cuhk.edu.hk

Juan Helen Zhou†
National University of Singapore
helen.zhou@nus.edu.sg

https://mind-video.com

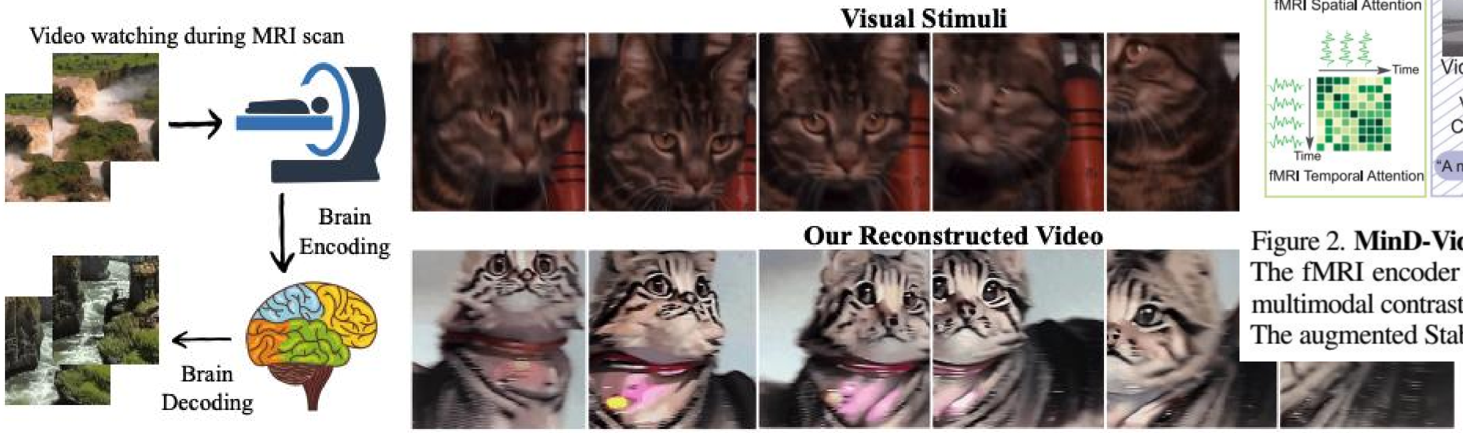


Figure 1. **Brain decoding & video reconstruction**. We propose a progressive learning approach to recover continuous visual experience from fMRI. High-quality videos with accurate semantics and motions are reconstructed.

4.1 Datasets

Pre-training dataset Human Connectome Project (HCP) 1200 Subject Release [28]: For our upstream pre-training dataset, we employed resting-state and task-evoked fMRI data from the HCP. Building upon [7], we obtained 600,000 fMRI segments from a substantial amount of fMRI scan data.

Paired fMRI-Video dataset A publicly available benchmark fMRI-video dataset [11] was used, comprising fMRI and video clips. The fMRI were collected using a 3T MRI scanner at a TR of 2 seconds with three subjects. The training data included 18 segments of 8-minute video clips, totaling 2.4 video hours and yielding 4,320 paired training examples. The test data comprised 5 segments of 8-minute video clips, resulting in 40 minutes of test video and 1,200 test fMRIs. The video stimuli were diverse, covering animals, humans, and natural scenery, and featured varying lengths at a temporal resolution of 30 FPS.

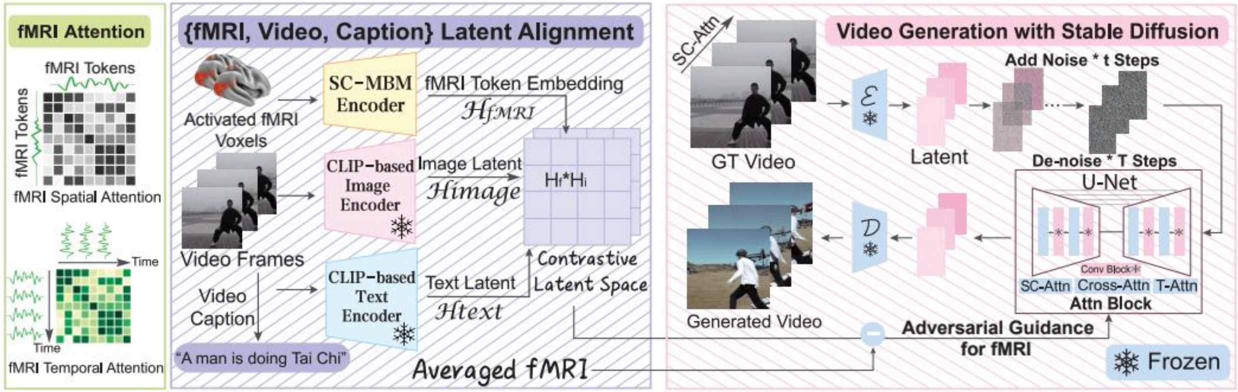


Figure 2. **MinD-Video Overview**. Our method has two modules that are trained separately and then finetuned together. The fMRI encoder progressively learns fMRI features through multiple stages, including MBM pre-training and multimodal contrastive learning. A spatiotemporal attention is designed to process multiple fMRI in a sliding window. The augmented Stable Diffusion is trained with videos and then tuned with the fMRI encoder using annotated data.

Chen, Zijiao, Jiaxin Qing, and Juan Helen Zhou (周涓, NUS). "Cinematic mindscapes: High-quality video reconstruction from brain activity." NeurIPS (2024).

Summary Lecture 11 – Sleep & Dreaming

- **Five sleep stages**
  - Non-REM sleep: stage 1 – stage 4
  - REM sleep
- **Functions of sleep**
- **Circadian and Ultradian rhythms**
  - SCN in hypothalamus for Circadian rhythms
  - Brain stem for Ultradian rhythms
- **Hypnosis**
- **Hibernation**
- **Sleep disorders**
  - Insomnia (失眠); Sleep Apnea (呼吸暂停症); Narcolepsy (嗜睡症); Parasomnia (sleep walking, sleep talking)
- **Decoding dreams with AI**

Reading materials

- *Neuroscience: Exploring the brain* (3rd ed), **Chapter 19 – Brain Rhythms and Sleep**, pp645-682
- *Principles of Neural Science* (5th ed), **Chapter 51 – Sleep and Dreaming**, pp1140-1158

- Science 2013, Neural Decoding of Visual Imagery During Sleep, https://www.cse.iitk.ac.in/users/se367/14/Readings/papers/horikawa-tamaki-kamitani-13_neural-decoding-of-dreams.pdf
- NeurIPS 2019, From voxels to pixels and back: Self-supervision in natural-image reconstruction from fMRI, https://papers.nips.cc/paper/2019/file/7d2be41b1bde6ff8fe45150c37488ebb-Paper.pdf