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Neuroscience of Consciousness: What Lucid Dreaming Can —and Cannot—Tell Us

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Abstract. Lucid dreaming—when you know you are dreaming while still asleep—gives a very special way to compare non-lucid and lucid REM sleep inside the same person. In this review paper, I look at what eye-signaling, EEG, fMRI, structural brain imaging, and interactive dreaming studies can tell us about metacognition, agency, and conscious access. Eye movements decided in advance can prove lucidity during sleep verified by polysomnography, but they only give a point in time when the subject reports, not the full duration or strength of the lucid state. Early studies claimed that frontal 40-Hz gamma waves increased during lucid dreams, but later research showed this was mostly caused by muscle artifacts from eye movements. A recent 2025 pooled EEG analysis of 43 sleep recordings from 26 people found almost no strong differences at the sensor level, but source-level analysis showed lower beta power in right central-parietal areas, higher alpha connectivity, and temporary gamma1 changes around the eye signal. These results fit more with a distributed network changing its setup rather than one single brain region or frequency signature. Because the strongest brain imaging proof is still based on correlation, mathematical models, or very few subjects, lucid dreaming cannot solve big theoretical debates like why subjective experience exists in the first place. Its real power is more practical: it provides us a controlled method to study self-reflection, reality monitoring, and two-way communication directly inside REM sleep.

Keywords: consciousness, lucid dreaming, metacognition, REM sleep, neural correlates of consciousness

1. Introduction

Consciousness is one of the hardest questions in science because while we can easily observe brain activity and physical behavior, the subjective experience itself belongs only to the person experiencing it. David Chalmers called this gap between physical brain mechanisms and inner feeling the "hard problem" of consciousness [1]. Because of this difficulty, neuroscientists usually study the neural correlates of consciousness (NCC)—the specific neural events that go together with a specific conscious experience. Doing this allows us to see how self-monitoring, voluntary control, and the ability to report change when our mental state changes. Dreaming is a great situation for testing these ideas because our mind creates vivid scenes and strong emotions almost without external sensory inputs. But in normal dreams, we lack insight: we just accept the dream without

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knowing it is created by our own brain. In a lucid dream, this insight suddenly appears while we stay asleep. I should point out that being lucid is not the same as controlling the dream, someone can know they are in a dream but still cannot change what happens.

Lucid dreaming is scientifically useful because participants can send a signal to researchers using a pre-agreed eye-movement pattern. When recorded on an electro-oculogram (EOG) while polysomnography confirms REM sleep, this eye movement gives a precise timestamp inside the dream [2]. Recent experiments have even managed to ask simple math or yes/no questions and receive answers during REM sleep [3]. In this review, I first compare lucid and non-lucid REM sleep, then look at metacognition and agency, and finally discuss possible applications and the limits of current research. This also raises another important question: what are the potential therapeutic and ethical implications of lucid dreaming? Studying this state matters because it lets researchers examine reflective awareness without waking the subject or relying only on reports made the next morning.

2. Consciousness and the sleeping brain

2.1. Consciousness as a multidimensional construct

People often talk about consciousness like a single line going from "low" (coma or deep sleep) to "high" (fully awake). But I think this single scale hides important details. A state can have rich sensory experiences while having almost no self-reflection or memory access. Non-lucid REM sleep is a clear example: you might see vivid colors and feel panic or joy, but you don't realize you are lying in bed. Lucidity mostly alters what we call meta-awareness—knowing what your mind is currently doing—rather than creating awareness from zero. Also, some lucid dreams let you remember waking plans or perform intentional actions, but these capacities don't always happen together. So, treating arousal, perceptual richness, meta-awareness, memory, and control as separate dimensions gives a much more accurate framework than trying to give every state a single "consciousness score."

Looking at consciousness this way also helps us see what a lucid vs. non-lucid comparison actually controls for. Both states share dream imagery, emotions, stories, and REM physiology. Comparing them cancels out many confounding factors that make sleep-vs-wake comparisons so hard. Still, lucid dreams can sometimes be more vivid or cause more physiological arousal. If researchers don't measure and match these factors, a brain difference might be wrongly attributed to meta-awareness alone. That is why good studies should combine objective sleep scoring with subjective ratings of insight, control, vividness, and arousal.

2.2. Large-scale theories and their limits

Until now, neuroscience hasn't found any single "consciousness center" in the brain. Instead, theories debate which large-scale network features matter most.

Global Neuronal Workspace Theory (GNWT) says that an information piece becomes conscious when it gets amplified and broadcasted widely across brain networks responsible for reporting, memory, evaluation, and action [4].

Integrated Information Theory (IIT), on the other hand, measures consciousness by the amount and structure of irreducible causal information (Φ) generated by the brain as a whole system [5, 6].

We can describe lucid dream findings using words from both theories, but current data cannot prove one theory over the other. EEG and fMRI show changes in brain regions or functional

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connectivity, but they don't directly measure the global broadcasting dynamics predicted by GNWT or the mathematical integrated information of IIT. So the real question isn't which theory lucid dreaming "wins" for but which specific cognitive sub-processes—like metacognitive access—we can isolate in the lab.

Another point to keep in mind is that reporting an experience is not the exact same thing as having the experience. The eye movement signal is great because it shows the dreamer understands an instruction and can act voluntarily. But the brain activity around that eye movement also includes decision-making, motor execution, and counting. These processes are about conscious access and communication, but they might not be part of the core dream experience itself. To fix this, future experiments should try separating the moment of insight from the moment of signaling.

3. Evidence from lucid dreaming

3.1. Objective verification in the laboratory

Lucid dreaming became a real topic in scientific laboratories when Stephen LaBerge and his team verified eye signals from five selected subjects during clear REM sleep [2]. Because moving your eyes in a dream moves your physical eyes in the same direction, this technique provides a precise timestamp without waking the sleeper. It proves the person intended to signal lucidity at that exact second while standard PSG criteria confirmed REM sleep.

However, this method doesn't measure lucidity continuously. An eye signal doesn't tell us how long the insight lasts, how confident the dreamer is, or if they have full control. Two-way communication experiments bring out this limitation clearly. In the 2021 multi-center study by Konkoly et al., out of 158 questions asked to subjects during signal-verified lucid REM, only 18.4% got a correct answer, while 60.1% got no response at all [3]. The successful trials prove that real-time communication is possible, but the high failure rate shows that lucid REM sleep is not consistently interactive or responsive.

Retrospective reports after waking up add another layer of verification. Researchers ask subjects to describe the dream, when they became lucid, and what signals they sent. While agreement between eye records and morning reports builds trust, dream memory degrades quickly or gets reconstructed. A solid research design must keep both sources of proof: timestamped physical signals during sleep and structured, immediate reports right after waking.

3.2. Frontal-parietal evidence and the gamma debate

In 2009, Voss and colleagues reported that lucid REM sleep showed increased frontolateral gamma band activity around 40 Hz, calling lucidity a "hybrid state" between sleep and wakefulness [7]. But later studies changed this view. Baird et al. compared 14 verified lucid dreams from 6 participants against matched non-lucid REM periods [8]. They found that once saccadic spike potentials—electric signals caused by eye muscle movements—were carefully removed, the 40-Hz frontal difference vanished. Lucid REM is indeed a state with higher physiological activation, but its values stay inside the normal REM sleep range. So calling it an "activated REM" is much more accurate than calling it a half-awake hybrid state.

Brain localization data is interesting but still limited. Dresler et al. ran a combined EEG/fMRI experiment with four experienced lucid dreamers, but only one participant produced two verified lucid episodes long enough for fMRI scanning [9]. Compared to non-lucid REM, those two episodes showed higher activity in bilateral precuneus, cuneus, parietal lobules, prefrontal cortex, and

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occipito-temporal areas. This pattern matches regions involved in self-reflection and agency, but results from a single person cannot establish a general neural signature for everyone.

Filevich et al. asked a different question using structural MRI [10]. Among 63 participants, people who scored higher on self-reported lucid dreaming ability had larger gray matter volume in the frontopolar cortex (BA9/10) and stronger frontopolar activation during a waking metacognition task. This links lucid dreaming ability as a personality trait to waking self-monitoring, but it doesn't measure what happens in the brain during an actual lucid dream. Also, we cannot know if a bigger frontopolar volume causes lucid dreaming or if practicing lucid dreaming alters brain structure.

3.3. The 2025 multi-laboratory EEG study

To get clearer answers, Demirel et al. gathered EEG data from several labs and used advanced signal processing to clean out eye-muscle and movement artifacts [11]. Their final dataset had 43 usable sleep recordings from 26 participants. While 26 people is still a modest sample size in general neuroscience, it is one of the largest datasets ever assembled for lucid dream EEG.

At the scalp-sensor level, they found surprisingly few solid differences between lucid and non-lucid REM sleep. But when they performed source reconstruction, they found lower beta power (12–30 Hz) in right central and parietal regions, (including the temporoparietal junction, TPJ), as well as increased alpha-band (8–12 Hz) functional connectivity during lucid REM. Around the exact time of the initial eye signal, gamma1 power (30–36 Hz) increased in right temporo-occipital regions including the right precuneus, along with broader gamma1 connectivity across brain hemispheres.

This 2025 study is very important because it moves the focus away from a simple "40-Hz scalp marker" toward dynamic, distributed network changes. It doesn't mean lower beta power directly creates agency or that precuneus gamma generates insight—source estimation depends on mathematical assumptions, and signals tied to intentional eye movements must be separated from the neural trigger of becoming lucid. Still, it gives a much more realistic, network-based view of what happens during lucid REM.

3.4. What the current evidence supports

Summarizing what we know so far, the evidence supports three main points:

Signal-verified lucid dreams occur during real, polysomnographically confirmed REM sleep, lucidity is not just waking up briefly.

Frontopolar, parietal, and temporo-occipital networks likely contribute to reflective awareness during sleep, but precise localization remains preliminary.

There is no single scalp frequency or localized "lucidity spot" in the brain. Frontal 40-Hz power, in particular, is not a valid biomarker once eye-muscle artifacts are removed.

4. Metacognition, agency, and reality monitoring

Metacognition means thinking about your own thinking. In a normal dream, you might plan, feel scared, or solve a problem without realizing that the whole environment is generated by your mind. Becoming lucid adds that higher-order awareness. Therefore, lucid dreaming represents a change in insight within an already conscious state, rather than a jump from unconsciousness to consciousness.

It is crucial not to confuse metacognition (knowing you dream) with agency or control (changing the dream). A dreamer might know 100% that they are dreaming, yet remain completely unable to

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fly or change the scenery. Conversely, in a non-lucid dream, you might make choices without realizing it's a dream. Combining all these features into one single label called "lucidity" creates confusion. Future studies should measure insight, control, confidence, memory, vividness, and emotional arousal as separate variables.

Lucid dreaming also gives us a neat paradigm for reality monitoring. The dreamer updates their judgment ("this is a dream, not physical reality") while sensory details like touch, sound, and vision stay extremely realistic. This shows that perceptual richness and reality testing can split apart in the brain. Asking questions during REM sleep offers a direct way to test this: experimenters can test memory, logic, and self-judgment live during the dream instead of relying only on morning recollections.

5. Applications, ethics, and experimental constraints

5.1. Nightmare distress and PTSD symptoms

In a 2025 study, Yount and colleagues tested a 6-day online lucid dreaming workshop on 99 adults suffering from chronic PTSD symptoms (49 in the workshop group and 50 on a wait-list) [12]. The workshop group showed significantly greater reductions in nightmare distress and PTSD symptoms, which remained stable at a 1-month follow-up.

These results are encouraging for clinical work, but we shouldn't conclude that lucid dreaming itself was the sole reason for recovery. The workshop involved 22 hours of activities, including group discussions, intention setting, nightmare exposure exercises, and trauma processing. Only about half of the participants in both groups actually had a lucid dream during the study, and the wait-list control group didn't get equal attention or therapist support. So, while the overall program helped, we cannot say lucid dreaming alone acts as a standalone PTSD cure without testing it against an active control group receiving equal therapy time.

5.2. Induction, safety, and ethical constraints

In a systematic review of 14 induction techniques across 19 studies, Tan & Fan found that the Mnemonic Induction of Lucid Dreams (MILD) technique had the strongest empirical backing, while galantamine and senses-initiated methods showed promise but needed more replication [13]. Overall, study quality across the field was rated as moderate.

For neuroscience, low induction reliability is a major bottleneck. When only a few people can lucid dream on command, studies end up testing small, highly specialized samples or testing the same expert dreamers repeatedly. Also, protocols that wake subjects up at night interrupt sleep architecture, adding sleep deprivation as a confounding factor.

Researchers face a clear trade-off: using expert dreamers guarantees higher signal success during expensive fMRI/EEG scans, but their brains may not represent the general population. Training novices improves generalizability but introduces learning effects, sleep disruption, and variable signal quality. Future studies should report sleep fragmentation, dropouts, and induction failures transparently alongside their brain data.

Lucid-dreaming research also has an ethical side. People with PTSD should not be told that lucid dreaming is a proven treatment, because the evidence still comes from limited studies [12]. Techniques that wake people during the night can also interrupt sleep, so participants should be warned about possible fatigue and allowed to stop the training. Researchers need clear informed consent, careful screening, and an honest explanation of what the method can and cannot do. For

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now, lucid dreaming should be tested as a possible complementary tool, not as a replacement for established treatment.

6. Conclusion

Lucid dreaming provides something rare in neuroscience: a controlled change in reflective awareness while the brain remains in REM sleep. Prearranged eye signals prove that dreamers can recognize their state and voluntarily communicate with experimenters, and two-way interaction studies show that sleepers can process external questions and reply in real time.

However, current data does not support a simple "neural signature" or single brain marker for lucidity. Early reports of frontal 40-Hz gamma activity were largely eye-muscle artifacts. The classic fMRI study comes from just two episodes in one participant, and frontopolar structural differences reflect waking traits rather than dream states. The 2025 pooled EEG analysis provides a much better multi-center dataset, but its findings (lower parietal beta, alpha connectivity, and transient precuneus gamma1) point to a reconfigured distributed network rather than a single "lucidity region."

Because sample sizes remain modest, induction methods vary, and eye artifacts are tricky to clean, lucid dreaming cannot settle big philosophical debates like Chalmers' hard problem or decide between GNWT and IIT. Its true value is more specific and practical: it serves as a unique experimental tool to dissect how metacognition, reality monitoring, and agency separate and rejoin during sleep. Any therapeutic use should also be handled carefully, with informed consent and clear evidence that the benefit comes from lucid dreaming itself rather than from attention, group support, or other parts of the workshop.

To move forward, the field must tackle recurring limits: small sample sizes, eye-muscle EEG contamination, variable induction methods, and reliance on single time-point eye signals. Priority should be given to preregistered multi-site trials, standardized artifact cleaning pipelines, simultaneous high-density EEG/fMRI, and direct real-time testing of memory and agency inside the dream.

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