NEUROSCIENCE of Consciousness

Neuroscience of Consciousness, 2026, **2026(1)**, niaf067

DOI: https://doi.org/10.1093/nc/niaf067

Research Article

Creative problem-solving after experimentally provoking dreams of unsolved puzzles during REM sleep

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Abstract

Dreams have arguably been a source of creative insight for millennia. The specific assertion that dreams during rapid eye movement (REM) sleep promote creative problem-solving, however, has only anecdotal support, lacking strong empirical support from rigorous studies. Experimental manipulations of dream content have been confounded by waking components, such that any boost in creative problem-solving could be attributable to waking cognition rather than sleep cognition. Likewise, correlational evidence cannot unequivocally establish that dreams cause insights. Evidence that memory reactivation during sleep promotes creative problem-solving is also insufficient for implicating dreaming *per se*. Better methods for directly manipulating REM-sleep dreaming are needed. Here, we studied individuals who frequently have lucid dreams—realizing they are dreaming while still asleep. Participants slept after failing to solve several puzzles that had unique soundtracks, and they were instructed to continue working on a puzzle if they heard its soundtrack in a dream. Half of the soundtracks were played during REM sleep to reactivate memories of corresponding puzzles, with the goal of biasing dreams to connect with those specific puzzles *versus* the remaining puzzles. Those sound cues reliably increased dreaming about the associated puzzles. Furthermore, a post-hoc analysis showed that, for participants with an increase in cue-related dreaming, cues boosted later puzzle-solving. We thus expanded on a well-known phenomenon, that sounds can be incorporated into dreams and can change dream content, by substantiating experimental procedures to align dreams with the search for creative answers to specific challenges. Results highlight that REM dreams can contribute to next-day problem solving.

Keywords: consciousness; sleep and dreaming; states of consciousness; unconscious processing; metacognition

Introduction

When facing a problem with no apparent solution, taking a break from deliberate effort can help. Upon returning to the problem, the solution can more easily come to mind. Outside the limelight of conscious deliberation, representations of incorrect solution paths can fade (Smith and Beda 2020) while spreading activation can allow for novel and potentially insightful associations between problems and existing knowledge (Yaniv and Meyer 1987).

Creative problem solving can be studied experimentally by presenting participants with problems that have a hidden rule or that can only be solved if approached from a novel angle. Participants may initially pursue an incorrect path and reach an impasse, feeling they can no longer progress toward a solution (Ross and Arfini 2024). Following a period of incubation, the solution sometimes appears in a surge of creative insight (Kounios and Beeman 2014). In one traditional paradigm for studying creativity, the number-reduction task, participants complete laborious mathematical calculations and may at some point discover a hidden rule that allows them to rapidly complete the task (Verleger et al. 2013).

Sleep may be advantageous for exploring new paths to solutions (Cartwright and Lamberg 2000). Several studies have found that participants are more likely to solve a problem after sleeping as opposed to after an equivalent period of wakefulness (Wagner et al. 2004; Verleger et al. 2013; Beijamini et al. 2014, 2021). However, other studies challenged participants with ten or more problems and found no sleep benefit (Brodt et al. 2018; Schönauer et al. 2018). With so many problems to contemplate at once, and potential interference between problems, perhaps participants were unable to incubate effectively, awake or asleep.

Rapid eye movement (REM) sleep may be particularly conducive to creative restructuring (Lewis et al. 2018; Horne 2020). Distant semantic associations may be more readily available during REM sleep. In one study, for example, individuals awoken from REM sleep exhibited greater priming from weak associations than from strong associations, a pattern not found after a period of wake or after awakening from non-rapid eye movement (NREM) sleep (Stickgold et al. 1999). Another study evaluated associative breadth by asking participants to memorize several target words before sleep, and then awakening them from either REM or NREM sleep to list associations to old and new target words. The investigators found that participants made more atypical associations to emotional target words learned before sleep when awoken from REM sleep compared NREM sleep (Carr and Nielsen 2015). A nap

Received 1 September 2025; **revised** 24 November 2025; **accepted** 22 December 2025

containing REM sleep also increased the use of hints in the Remote Associates Task, which requires inferring connections among a set of three seemingly unrelated words (Cai et al. 2009).

Other studies have used the method of targeted memory reactivation (TMR), whereby specific memories can be selectively strengthened by presenting associated sensory cues during sleep (Hu et al. 2020; Paller et al. 2021). Studies applying TMR in REM sleep have found reactivation to promote generalization (Sterpenich et al. 2014) and rule abstraction (Pereira et al. 2023). Speculatively, the neurobiology of REM sleep promotes neural plasticity and memory reorganization, allowing new information to be integrated into existing knowledge stores (Almeida-Filho et al. 2018; Pereira and Lewis 2020; Aime et al. 2022). Whereas non-REM sleep also plays a role in creative cognition (e.g. Drago et al. 2011; Sanders et al. 2019; Lacaux et al. 2021; Horowitz et al. 2023), here we chose to focus on the contribution of REM sleep, given the long-standing association between creativity and dreams.

REM sleep has long been linked with bizarre and hyper-associative dreams. Anecdotes throughout history as well as survey studies suggest that dreams can be a source of creative insight (Schredl and Erlacher 2007; Klepel et al. 2019). For example, the organization of the periodic table of elements, Paul McCartney's ballad *Yesterday*, and the main scenes in the novel *Frankenstein* all originated from insights during dreams (Barrett 2017). Individuals who frequently recall dreams tend to have more creative interests (Schredl 1995; Schredl et al. 2003), score higher on tests of verbal creativity (Schredl 1995) and produce more creative alternate uses for everyday objects (Vallat et al. 2022). Focusing on a topic before sleep with the intention to dream about it has also been used to produce solutions to personal problems (Barrett 1993; White and Taytroe 2003). Individuals who frequently have lucid dreams—becoming aware that they are dreaming while remaining asleep—report using lucid dreams for solving waking-life problems and for creative inspiration (Schädlich and Erlacher 2012).

Although these anecdotes and studies support a link between REM-sleep dreaming and problem solving, causal evidence remains scant, in part due to the difficulty of systematically manipulating dreams. Without the ability to randomly assign dream content, putative functions of dreaming tend to be supported by correlations, such as that those who naturally dreamed of a learning task performed better the next day (Wamsley 2014; Wamsley and Stickgold 2019). Thus, the possibility remains that other variables drive the correlations between dreaming and positive outcomes (Bloxham and Horton 2024). For instance, a high level of motivation or unconscious memory replay in previous sleep stages could promote both dreaming about a problem and subsequent creative insight, precluding causal conclusions about a putative creativity-boosting function of dreaming (Picard-Deland et al. 2023; Mallett et al. 2024). Further, sleep onset is known as a creative sweet spot (Lacaux et al. 2021), so studies that employ a pre-sleep manipulation (e.g. Barrett 1993; Saredi et al. 1997; White and Taytroe 2003) cannot isolate the contribution of dreaming in subsequent sleep stages, given that participants may also be having beneficial dreams at sleep onset.

Recent advances in sleep and dream engineering—systematically manipulating sleep physiology or dream content *via* sensory stimulation or other approaches—show promise for overcoming these challenges to elucidate the role of dreaming in creative problem solving (Mallett et al. 2024; Salvesen et al. 2024). For instance, Horowitz et al. (2023) found that focusing on a particular topic before sleep (such as a tree) produced on-topic dreaming in sleep-onset dreams. Upon awakening, the participants assigned to dream of trees performed better on creativity tasks involving trees compared to the group that thought of trees while awake as well as the group that napped without incubating on trees. Another study found that using TMR during non-REM sleep to reactivate memories of specific unsolved problems increased later solving for those problems (Sanders et al. 2019), perhaps because memory reactivation in non-REM sleep selects memories for reorganizing in subsequent REM sleep (Lewis et al. 2018). TMR in REM sleep has increased dreams of associated themes both in the lab (Konkoly et al. 2025a; Schredl et al. 2014) and in the days following stimulation (Konkoly et al. 2025a; Picard-Deland and Nielsen 2022), and has also been used to manipulate emotions in dreams (Schwartz et al. 2022). However, the precision with which TMR can induce specific dream content remains unclear, as is whether dreaming mediates the memory processing triggered by TMR (Picard-Deland et al. 2023). It is thus unknown whether TMR cues applied in REM sleep can promote dreams of associated problems and subsequent creative problem-solving.

Whereas TMR studies have shed light on the mneumonic functions of REM sleep, such as promoting abstraction and generalization, even more could conceivably be learned by applying this technique to individuals during lucid dreams. In the technique of *interactive dreaming* (Konkoly et al. 2021), cues such as spoken questions are presented during REM sleep and lucid dreamers respond in real-time using pre-arranged signals, such as specific patterns of eye movements (Baird et al. 2019) or sniffing (Konkoly et al. 2025b). Here, we used interactive dreaming to directly test the role of REM-sleep dreaming in problem solving. Each participant went to sleep after failing to solve several puzzles that were designed to benefit from creative restructuring and each associated with a unique sound. We employed a within-subjects manipulation by presenting a random half of the sounds during REM sleep as cues to remind individuals to continue working on just that subset of unsolved problems in their dreams. We sought to maximize our influence over dream content by recruiting frequent lucid dreamers to intentionally dream of cued puzzles, as well as by presenting sensory cues, previously linked with lucidity, during REM sleep (Carr et al. 2023). We tested two predictions. One was that TMR would produce both lucid and non-lucid dreams about cued puzzles. The second was that dreaming of specific puzzles—particularly during lucid dreams—would increase the likelihood of later solving, based on the hypothesis that dreaming is useful for creatively solving problems.

Methods

Participants

We recruited 20 participants (14 female, 5 male, 1 non-binary; *ages* 18–46 years, *mean* = 24.3, *SD* = 7.4). Because our primary goal was to study creative problem solving during lucid dreams, we first recruited individuals with a demonstrated ability to lucid dream in the laboratory ($n = 5$). Other participants were then recruited from online forums and word of mouth. Potential participants filled out a pre-screening form, and individuals who reported having a lucid dream at least once a month were invited to participate. Due to scheduling constraints, we also included a non-lucid dreamer with high dream-recall frequency and interest in lucid dreaming. We collected data over a total of 39 nights (two nights from each participant except for one who completed only the first session). Data from 4 of the 39 nights were excluded (two nights had insufficient REM sleep for cueing, one lacked dream reports due to technical failure, and one contained puzzle cues presented in a hybrid state (Fig. S1)), yielding a total of 35

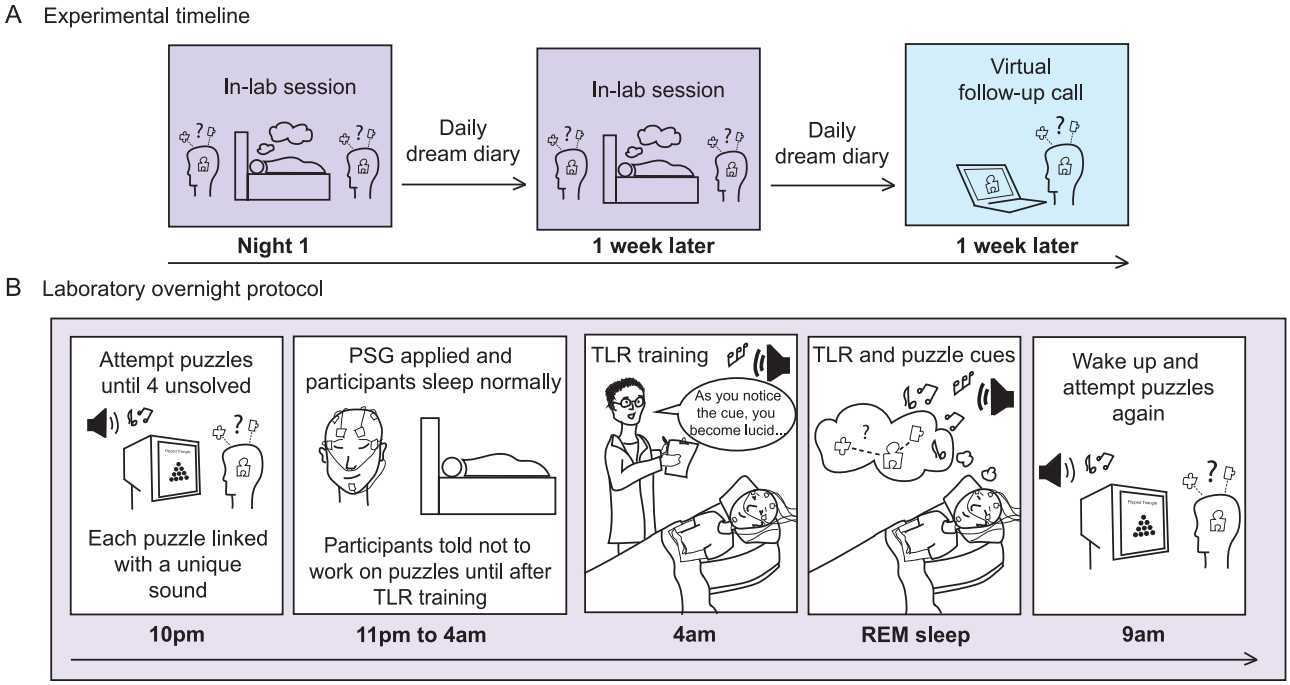

Figure 1. Experimental timeline. (A) Overview of experimental timeline for most participants. (B) Each in-lab session had an identical procedure, except with different puzzles. Lucid dreams were induced with targeted lucidity reactivation (TLR).

overnight laboratory sessions from 20 participants. All procedures were approved by the Institutional Review Board at Northwestern University and informed consent was obtained. Participants were compensated $80 per overnight session, $10 per week of dream journaling, and $10 per follow-up session.

Procedure

Each participant was scheduled to come to the lab for two overnight sleep sessions with identical procedures approximately a week apart. Figure 1A provides a schematic illustration of the study timeline. Starting after their first session, participants were instructed to fill out a dream diary at home each morning until they completed a follow-up video call, usually a week after their second session (*mean* = 7.41 days, *SD* = 1.4 days, *range* = 5–10 days). Three participants whose laboratory sessions occurred more than a week apart due to scheduling constraints (28, 54, and 56 days apart) completed follow-up calls both after their first and second sessions.

For each overnight laboratory session (Fig. 1B), participants arrived in the lab ~2 h before their usual bedtime, or at 10 pm, whichever was earlier. Participants first completed a psychomotor vigilance task in which they were asked to press a button whenever a specific letter appeared on the screen. Performance on this task pertains to alertness during relatively monotonous conditions, which are very different from those of the problem-solving task, so vigilance results are not reported here. Participants were then told that they would be given puzzles to solve while listening to a unique soundtrack for each puzzle. Two example puzzles were first given, along with solutions. Puzzles were designed to require creative cognitive restructuring rather than step-by-step analytical approaches, and were drawn from a bank of 25 matchstick, rebus, verbal, and spatial puzzles from prior studies (Sanders et al. 2019; Sanders and Beeman 2021). Each puzzle was paired with a 15-s soundtrack randomly selected from a bank of 27 musical and environmental clips used in a prior study (Sanders et al. 2019), and soundtrack-puzzle pairings were randomly selected for each participant. Each soundtrack included 8–12 s of sound and 3–7 s of silence to reduce habituation. Before starting each puzzle, participants were familiarized with the associated soundtrack by listening to it once. Next, participants were given as much time as needed to read the puzzle instructions and confirm that they had not solved it previously. Then, participants were given 3 min to work on each puzzle while listening on repeat to a verbal recording of the puzzle's title and then its soundtrack.

Experimenters gave participants real-time feedback on proposed solutions. If correct, participants were asked whether their solving approach resembled insight (i.e. they would not be able to articulate how they arrived at the answer, which arrived suddenly like an 'a-ha' moment) or analysis (i.e. the answer arrived through a logical progression, trial and error, or step-by-step approach amenable to being described). If incorrect, the remaining time was available for continued efforts. If the puzzle was not solved within the timeframe, they were asked to stop working and indicate how close they felt they were to solving the puzzle, and whether they were still working or felt stuck. They then listened to the puzzle's soundtrack one more time and were asked to memorize the sound-puzzle pairing. Participants continued with additional puzzles until they had 4 unsolved puzzles each night, on average attempting 5.4 puzzles per evening (*SD* = 2.25, *range* = 0 to 12).

Finally, we ensured that participants had a strong association between the soundtrack and the puzzle by presenting soundtracks from all unsolved puzzles in a randomized order, four times each, and asking participants to name the corresponding puzzle before showing them the correct answer. As in prior studies, our design included two sessions with similar procedures so that we could collect data on more unsolved puzzles per participant without asking participants to incubate on too many puzzles on any given night (Sanders et al. 2019; Sanders and Beeman 2021).

Following this puzzle-solving period, participants were asked not to intentionally work on any puzzles until the dreaming portion of the study began at 4 am. Although we acknowledge that not all participants may have followed this instruction, we opted

to include this instruction and then later exclude any puzzles solved in this intermittent period. We then applied polysomnography (F3, F4, C3, C4, O1, O2, 2 electromyography (EMG) channels, 3 electrooculography (EOG) channels, left mastoid reference, electrocardiogram, and nasal cannula) for ~45 min while participants watched a movie about lucid dreaming, either *Inception* ($N = 16$) or *Waking Life* ($N = 5$). Participants were told that they could sleep normally for the first half of the night, and that we would wake them up at 4 am to begin the experimental portion. We told them that upon returning to sleep, they might hear sounds to help them have a lucid dream, and that if they became lucid, they should let us know by performing at least two rapid left–right eye movements (LRLR signal). We also told them that they might hear sounds associated with puzzles, and if they did, that they should work on the puzzle in their dream. They were told to indicate to us that they had heard a puzzle sound and were working on the puzzle by performing at least two rapid in-out sniffs (Konkoly et al. 2025b; Morris et al. 2025). Participants were also given suggestions for how to continue working on puzzles in dreams, such as, (1) asking the dream out loud for help solving the puzzle, (2) asking a puzzle-savvy dream character to work with them on the puzzle, or (3) seeking out the puzzle scenario in their dream, for instance by entering a room and expecting to find it there. They were told to continue working and checking any proposed solutions for so long as they were dreaming and hearing the puzzle sound. The last step before sleep was that we calibrated the minimum intensity at which participants could hear cues, and a greater intensity that they felt would be comfortable for sleep. We calibrated the intensity by presenting the cue from an example puzzle and the lucidity cue (described below) at increasing intensities, noting the intensity at which when the participant could first detect that any sound had been presented and the intensity at which they could identify the sound. We then increased the intensity until participants reported it was comfortable for sleep, although this intensity was noted as a reference point rather than used in volume titration during sleep.

At 4 am, we awoke participants and administered Targeted Lucidity Reactivation (TLR) training to promote lucid dreaming (Carr et al. 2023; Konkoly et al. 2024). This procedure entailed ~20 min of associating a sound cue (a sequence of 3 pure-tone beeps ascending in pitch lasting ~650 ms) with a lucid state of mind as participants allowed themselves to fall asleep. If participants reported incidentally solving any puzzles before 4 am (as occurred for 4 total puzzles from 3 participants), those puzzles were excluded from cueing and all analyses. Half of the remaining unsolved puzzles were randomly selected for cueing in REM sleep.

When participants entered REM sleep, we first presented ~10 TLR cues to attempt to trigger lucidity. We then presented cues pertaining to a randomly selected two of the four unsolved puzzles. As such, we presented cues from each puzzle in blocks of up to 30 cues, interspersing music and title cues (music cues per REM period: *mean* = 9.52, *SD* = 8.16, *range* = 0–33; title cues per REM period: *mean* = 2.04, *SD* = 2.5, *range* = 0–14), and we typically presented ten lucid cues again before switching from one puzzle cue to the other (*mean* = 13.3 lucid cues per REM period, *SD* = 9.8, *range* = 0–52). We tailored the cueing procedure to individuals depending on their REM propensity and responsiveness to cues because our goal was to maximize incorporation into dreams. Cues were presented approximately every 15–30 s, starting at the lowest detectable volume and gradually increasing so long as participants remained soundly asleep. Cues were paused and intensity was lowered if any signs of arousal appeared such as increased EMG or alpha oscillations, cessation of rapid eye movements, or cessation of theta oscillations. For participants with fractured REM sleep or those who did not enter REM sleep until late in the night, we presented fewer of each type of cue before switching to the next to facilitate presenting cues for both puzzles. We succeeded in presenting cues for both puzzles in 62% of the REM periods (in 38%, only one puzzle was cued).

After we finished presenting cues or when the REM period ended according to AASM criteria (AASM Manual for the Scoring of Sleep and Associated Events: Rules, Terminology and Technical Specifications Version 3 2023), we awoke participants for dream reports. We asked them to tell us everything they could remember from before the awakening, including whether they heard any cues or if anything in their dream pertained to the puzzles or the task. If they reported any task incorporation, we asked them to try to recount in sequence and in as much detail as possible any sounds they heard, signals they completed, and everything they remembered about problems worked on during sleep including any new thoughts, hints, or potential answers that occurred to them. If the participant wished to return to sleep, we resumed presenting cues in their next REM period.

In the morning, we removed participants' electrodes and offered them snacks and tea. Then, participants completed another psychomotor vigilance task as well as a puzzle-sound association test where they were asked to identify which puzzle was paired with each sound, as well as a memory test where they reported the instructions for each unsolved puzzle from the night before (results not reported here). Subsequently, participants were given a 4-min opportunity to work on each puzzle again. To reduce the possibility of experimenters inadvertently influencing solving of cued puzzles, only standardized feedback was provided (either 'yes, that is the answer we were looking for,' or 'no, that is not the answer we were looking for'). Afterwards, participants were again told not to intentionally work on puzzles or look up the answers, and that they would be told the correct solutions during their virtual follow-up call.

After each in-lab session, participants completed 7 days of dream journaling at home (or a different number of days if the next in-lab session or follow-up call could not be scheduled exactly 7 days later). Each morning, they were sent an online form asking them to report their dreams from the night prior, whether and how their dreams incorporated any puzzles, whether they were lucid, and whether they thought of any potential answers to unsolved puzzles.

At the end of this dream-journaling period, we conducted a follow-up call with participants over zoom where they were given 3-min opportunities to attempt each puzzle one more time according to the procedure described previously, except without sound cues. Follow-up calls were scheduled based on availability and occurred an average of 10.1 days after the in-lab session (*SD* = 3.75, *range* = 5–19). Participants were then told the correct answers to any remaining unsolved puzzles, and they were asked to rate the fairness of the answers given.

Analysis

Sleep recordings were scored by an expert sleep scorer according to standard guidelines (AASM Manual for the Scoring of Sleep and Associated Events: Rules, Terminology and Technical Specifications Version 3 2023). LRLR signals indicating lucidity were identified as two horizontal eye-movement signals of large amplitude and even pace, which are easily distinguished from typical rapid eye movements. Real-time sniffing signals were identified as a series of two or more rapid in-out breaths distinctive from normal breathing rhythms. Sniffing signals within 15 s after a puzzle

cue were considered to indicate real-time incorporation of the most recently cued puzzle. Although some participants reported dreams during the 4 am awakening, or at the end of the sleep session after a period of non-REM sleep, only dreams reported following a period of REM sleep containing cues were included in analyses. We excluded reports in which participants could not recall any dreams ($n = 3$ dreams), and puzzles for which participants failed the puzzle-sound association test following sleep, indicating they forgot the sound that corresponded to a puzzle ($n = 12$ puzzles). See Fig. S2 for a flowchart of the data structure.

Dream report coding

Dream reports were qualitatively coded by two independent raters blind to which puzzles were cued. After coding all dreams independently, the raters met and agreed on a consensus for any disagreements. For each dream, raters evaluated whether the participants reported hearing the TLR cue, whether their dream pertained to puzzles generally (e.g. dreams involving problem solving or working on a puzzle without mention of a specific puzzle from the study), and whether they incorporated the sleep laboratory environment. Dream reports were then rated to assess incorporation of each of the unsolved puzzles from the night before. Incorporations from dream reports were considered retrospective, as distinguished from real-time incorporation indicated by sniffing signals.

Raters denoted sound-cue incorporation if the participant mentioned hearing a specific puzzle cue in their dream (Salvesen et al. 2024). Raters denoted conceptual incorporation if the puzzle itself was incorporated into the dream in some way. In the case of conceptual incorporation, raters indicated whether incorporation was direct (the puzzle itself was incorporated into the dream) or indirect (content related to the puzzle was incorporated into the dream, but not the puzzle itself). They also denoted whether the participant reported being lucid during the incorporation of each specific puzzle. Raters also indicated what type of attempt, if any, was made to solve the puzzle in the dream. A third rater also evaluated whether each dream collected in the laboratory was lucid or not. Dreams reported at home were coded by two separate raters using the same procedure, except that sound-cue incorporation was not evaluated in these dreams because cues were not presented at home. A full description of the dream rating system is provided in Appendix S1 of the Supplementary Material. For our analyses, we considered puzzle incorporation as either (a) a retrospective dream report conceptually incorporating the puzzle (20 puzzles), (b) when the dreamer produced real-time signals in response to a puzzle cue (7 puzzles) or (c) both (2 puzzles).

Statistical analysis

Statistical analyses were conducted in *R* using generalized linear mixed models (*GLMM* package, *glmer* function (Bates et al. 2015)) with subject ID as a random intercept and puzzle ID nested within subject when possible (see Table S1). When tests included an interaction term, we reported the results from the *ANOVA* function (*car* package (Fox et al. 2007)). For tests without an interaction term, 95% Confidence Intervals (CIs) and p-values were computed using a Wald z-distribution. Post-hoc tests were calculated with the *emmeans* and *pairs* functions (*emmeans* package (Lenth et al. 2024)), using the Tukey method to correct for multiple comparisons. For analyses of how cues impacted dreaming, there was one observation for each puzzle for each dream report, and dream report number was included as a random effect. For analyses of how cues and dreams impacted solving, variables related to cueing and dreaming were aggregated across dream reports so that each participant had one observation per puzzle for the whole night. A summary of mixed models and the number of observations in each can be found in Table S1.

Results

Puzzles were incorporated into some dreams

Participants reported on average 2.02 dreams per night ($SD = 1.04$, *range* = 1–4) for a total of 71 dream reports collected during the study. Fifteen out of 20 participants had at least one dream that pertained to an unsolved puzzle according to their real-time and/or retrospective dream reports. This included 9 dreamers that reported puzzle incorporation in their dream report upon awakening, 3 dreamers that responded to puzzle cues in real-time, and 3 dreamers that did both (see Fig. 2). On average, participants dreamed of 26% of their unsolved puzzles ($SD = 25\%$, *range* = 0–75%). Table 1 and Fig. 2 provide examples of puzzle incorporation in dreams.

Some cues produced dreams with puzzle incorporation

Figure 3 shows the rate of incorporation of puzzle features into reported dreams. We fitted a model to test whether cueing (cued versus uncued puzzles) produced puzzle incorporation (*Puzzle incorporation ~ puzzle cued*). As predicted, we found that cued puzzles were incorporated more than uncued puzzles ($\beta = 1.84$, 95% *CI* (.76, 2.93), $p < .001$). According to blind raters' assessments of lucidity, 7.8% of puzzles cued in non-lucid dreams were incorporated (16 puzzles) and 24.6% of puzzles cued in lucid dreams were incorporated (15 puzzles). In addition to this incorporation of puzzle features into dreams, sensory incorporation of sound cues was also reported for 15 cued puzzles and 6 uncued puzzles. Note that we collected a total of 13 lucid dream reports verified by real-time signaling from 6 participants.

Increased solving for puzzles incorporated into dreams

As shown in Fig. 4, puzzle incorporation predicted solving the next morning (*Solved ~ conceptual incorporation;* $\beta = 1.241$, 95% CI (.07, 2.40), $p = .037$). Sensory incorporation of sound cues, on the other hand, did not predict solving the next morning (*Solved ~ sensory incorporation;* $\beta = -.86$, 95% CI (−2.52, .8), $p = .31$).

As shown in Table 1, solving rates were lower following incorporation in lucid dreams compared to nonlucid dreams. Interestingly, puzzles that dreamers did not remember incorporating but whose cues they responded to in real-time were solved at the highest rate the next morning. See Table S2 for a summary of how different strategies in dreams related to solving outcomes.

Did cueing promote solving?

To test whether the interaction between cueing and incorporation promoted solving, we aggregated incorporation for each puzzle across all dreams for each participant and entered incorporation and cueing into a logistic mixed model (*Solved ~ puzzle incorporation * puzzle cued*). There was a nonsignificant trend for a greater solving rate for puzzles that were incorporated into dreams than for puzzles that were not ($X^2(1) = 3.61$, $p = .057$), potentially because including the interaction with cueing reduced power for detecting effects of dreaming. There was no significant main effect of cueing or interactions (*ps* > .6). On average, 30% of cued puzzles and 22% of uncued puzzles were solved the next morning ($SE_{within} = 7\%$ for cued and 6.4% for uncued puzzles). Given that there was no main effect of cueing on solving, we could not execute our plan

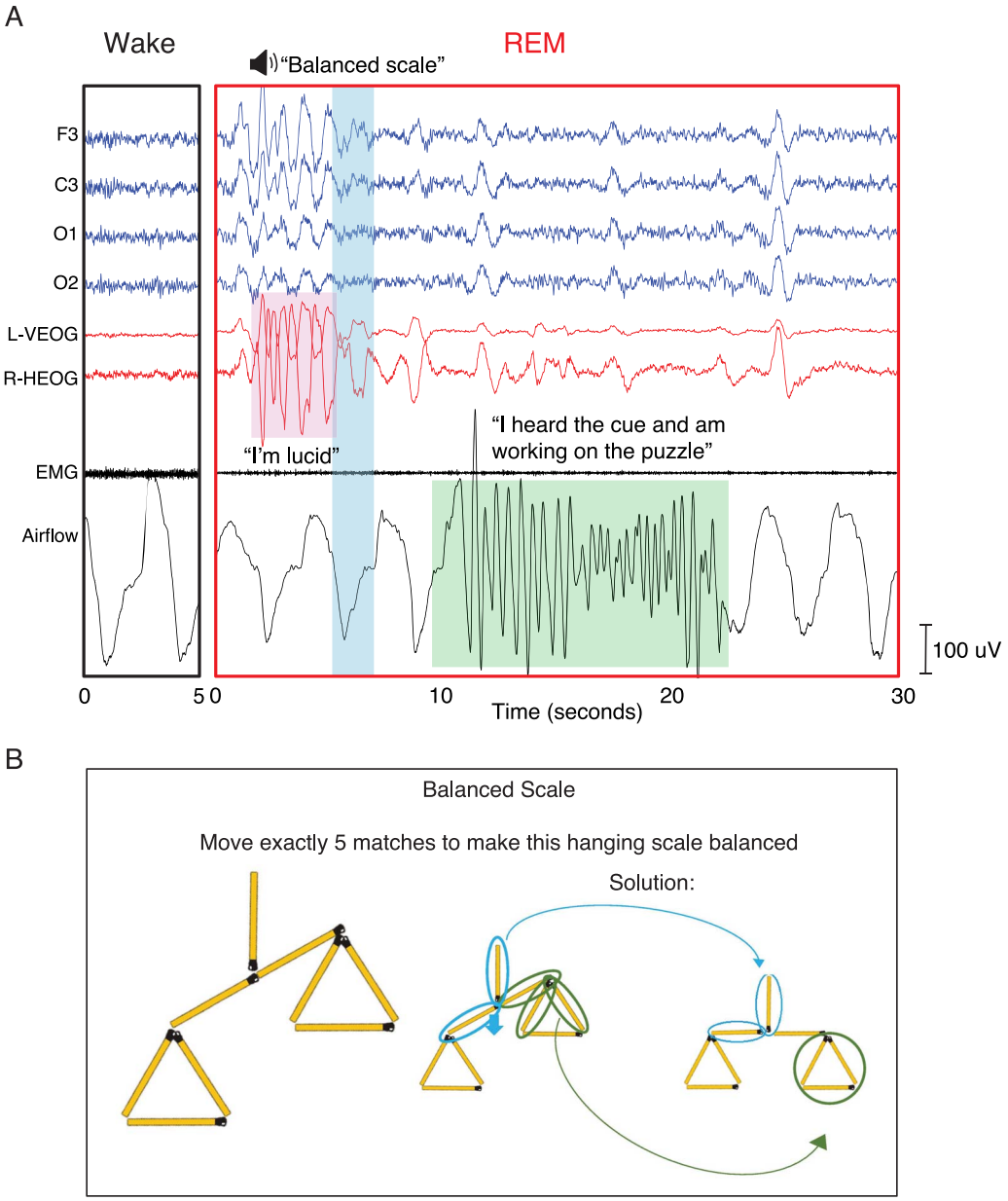

Figure 2. Example of real-time puzzle incorporation. (A) After the participant indicated that she was lucid dreaming with a series of left–right eye movements (highlighted in pink), we presented the title of one of her previously unsolved puzzles (duration of sound presentation highlighted in blue). She produced rapid in-out sniffing signals (highlighted in green) to indicate that she had heard the puzzle cue and was working on the puzzle. Upon awakening, she reported, "I was like 'I need to find this puzzle. I need y'all to help me!' I tried to dream about a puzzle. My friend and his wife and his daughter—his daughter has autism—I was trying to have her to help me… she don't talk… She got on a seesaw. That's how I realized the scales weren't flat. Like one of them was up and the other one was down… the ground was slanted or something." (B) Illustration of the puzzle she was working on and its solution, which requires realizing that the bottom rung of the rightmost triangle can remain in place to become part of the lever. It is unclear whether the dream provided any helpful information, and the participant never solved this puzzle.

of performing a mediation analysis to test whether dreaming mediated the effect of TMR on solving.

Did experimentally induced dreaming promote solving?

Nevertheless, we took advantage of the variable effectiveness of cues' influence on dreaming to perform a post-hoc analysis of whether experimentally induced dream content promoted solving. We divided participants based on the extent to which dreams of cued puzzles were reported after REM-sleep periods with cues. As shown in Fig. 3B, 12 participants were categorized as targeted dreamers—those who had more incorporation of cued puzzles than uncued puzzles. Targeted dreamers dreamed on average 43% more of cued puzzles than uncued puzzles. The other 8 participants were categorized as nonresponders, dreaming on average 5% less of cued puzzles than uncued puzzles (including five participants who dreamed the same amount about cued and uncued puzzles). We then tested whether participants' status as a targeted dreamer *versus* nonresponder interacted with cueing to predict solving the next morning (*Solved* ~ *puzzle cued* ∗ *responder status*).

As shown in Fig. 5, we found a significant interaction indicating that cueing influenced solving differently in targeted dreamers and nonresponders ($X^2(1) = 4.18$, $p = .04$). In targeted dreamers,

Table 1. The relationship between lucidity during puzzle incorporation and solving.

Lucidity During Incorporation	Next-Morning Solving Rate	Dream Report Excerpt
Lucid Incorporation (9 puzzles)	1 solved (11%)	"I was riding in a car … I turn to my friend next to me and try to envision that she's (the experimenter] … I say, '[Experimenter], how do you do the four-shape puzzle?' She's like, 'Well I actually don't know. It's kind of hard.' And I'm like 'Oh well what wasn't helpful.'" (uncued; never solved)
Nonlucid Incorporation (13 puzzles)	6 solved (46%)	"I was at a river and I was catching fish with a net … I was working on something … like a puzzle. So it could've been the jungle one" (cued; solved next morning)
Real-time Incorporation Only (6 puzzles)	4 solved (67%)	"I was looking through a dresser and there were papers … The puzzles were on the papers that I was looking through … I solved one of them and I got like a little celebration … I don't remember which one I solved though … I remember doing them [the signals] when I heard the stuff [cues]." (both cued puzzles solved next morning)

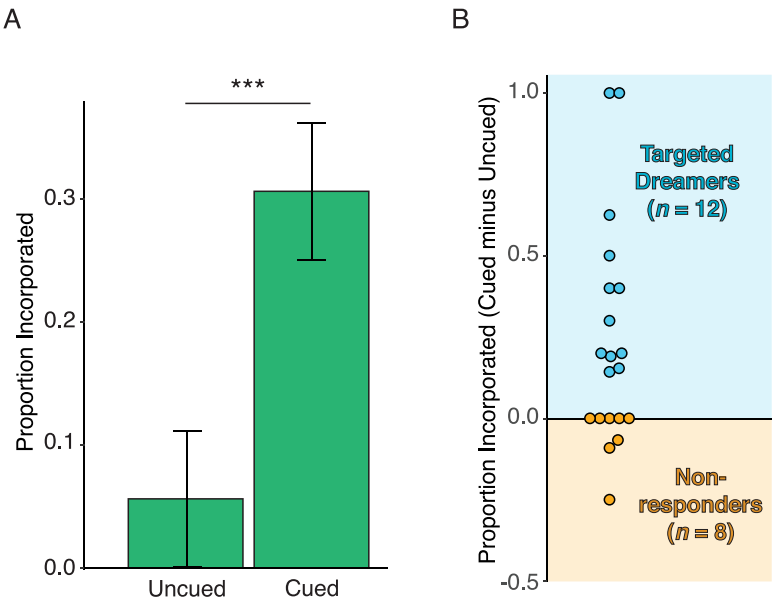

Figure 3. Cues produced puzzle incorporation into dreams. (A) Cued puzzles were incorporated into dreams more often than uncued puzzles. Error bars represent the within-subjects standard error of the mean. (B) Illustrates the benefit of cueing for dream incorporation per participant (proportion of cued minus uncued puzzles incorporated). Here incorporation includes puzzles incorporated either as indicated in their retrospective report or by a real-time response to a puzzle cue. Participants who dreamed more of cued than uncued puzzles were categorized as targeted dreamers (data points above 0), and those who did not were categorized as nonresponders (data points equal to or below 0). *** indicates significance at $p < .001$.

cued puzzles were solved significantly more often than uncued puzzles (*Odds Ratio* = .32, *SE* = .18, $z = -2.0$, $p = .046$), whereas whether a puzzle was cued did not predict solving for nonresponders (*Odds ratio* = 2.66, *SE* = 2.27, $z = 1.14$, $p = .25$). There was no main effect of cueing or responder status on solving (*p*s > .3).

Dream diaries at home

Participants filled out their dream diary on an average of 11.1 mornings following laboratory sessions (*SD* = 3.8, *range* = 1–18), in 7.4 of which they reported recalling a dream (*SD* = 2.83, *range* = 2–13 entries). On average, 3.68 puzzles were left unsolved after their in-lab sessions that could be potentially incorporated into dreams at home (*SD* = 1.92, *range* = 1–8).

Based on raters' assessments of dream content reported in at-home dream diaries, participants incorporated an average of 14.3% of the puzzles left unsolved following laboratory sessions (*SD* = 12%, *range* = 0–33%). Of the 134 dreams reported at home, 16 dreams (12%) from 12 participants (60%) referenced an unsolved puzzle. Although there were too few instances of at-home incorporation to statistically test whether these dreams resulted from previous laboratory cueing or increased later solving, results trended in the same direction as those from the laboratory portion of the experiment (Appendix S2).

Discussion

Whereas dream content is notoriously difficult to control experimentally, here we induced dreams about specific puzzles by presenting associated sounds during REM sleep. We preferentially recruited experienced lucid dreamers, intending for them to receive our real-time instructions in their dreams about which puzzles to volitionally attempt to solve. Although many participants did not experience lucid dreams, we nevertheless found that cues successfully influenced dream content, biasing dreaming toward specific puzzles.

We found that dreaming of puzzles was linked with increased solving upon awakening, but future studies are needed to disentangle the complex relationships among dreaming, TMR, and creative problem solving. Although there was a pattern for cued puzzles to be solved more often than uncued puzzles, this effect

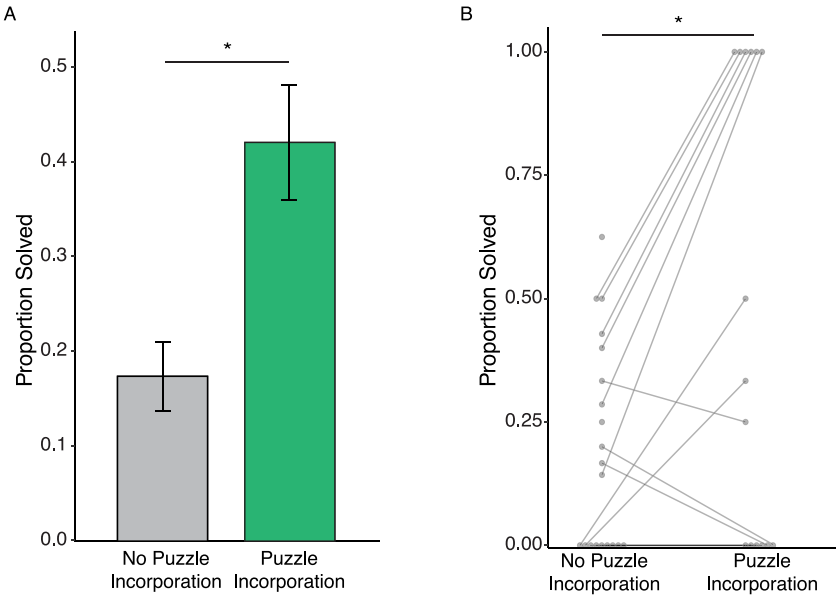

Figure 4. Puzzles incorporated into dreams were solved more often (sensory incorporation not shown). The y-axes show the proportion of puzzles solved the next morning relative to the total number of puzzles in each category. (A) Compares the proportion of not incorporated *versus* incorporated puzzles solved. Error bars represent the within-subjects standard error of the mean. (B) Shows values for individual participants. Lines connect the proportion of solved puzzles for each participant, and solo dots occur when participants did not have any puzzles in the other category. Note that there are four participants with lines across the x-axis, indicating that they had some puzzles incorporated and others not, but they did not solve any. ∗ indicates significance at $p < .05$.

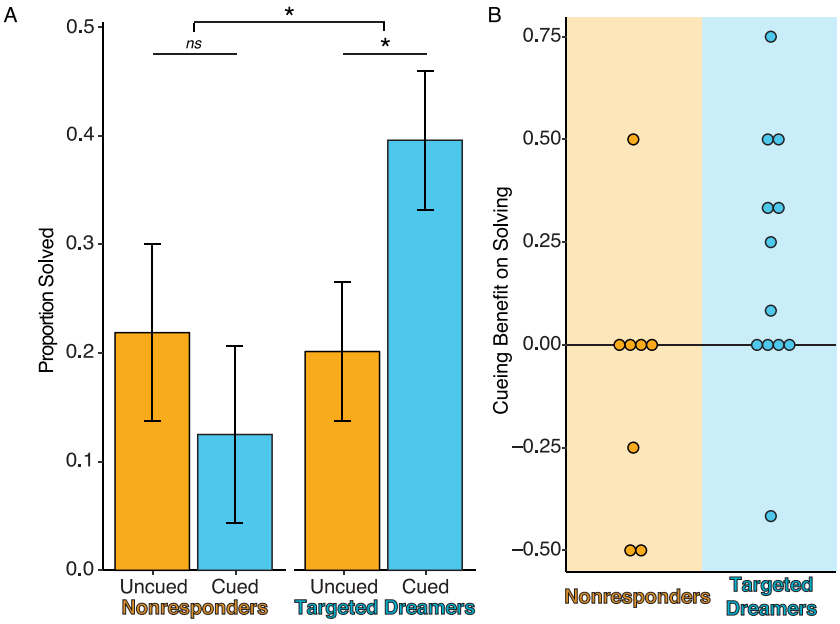

Figure 5. Cues promoted solving in participants for whom cues influenced dreaming. (A) Solving rates from the next morning are shown separately for targeted dreamers (those who dreamed more of cued puzzles than uncued puzzles) and nonresponders (those who did not). Bar height represents solving rates averaged across participants, and error bars represent the within-subjects standard error of the mean. (B) The cueing benefit for solving (proportion of cued—uncued puzzles solved) in each participant, segregated by nonresponders and targeted dreamers. ∗ indicates significance at $p < .05$.

was not reliable in the full sample. Therefore, we could not directly test whether the effectiveness of TMR in this study was mediated by dreaming. However, we did find that TMR increased puzzle solving in the subset of participants for whom we successfully influenced dream content. Accordingly, in this group of targeted dreamers (12 of the 20 participants in the study), the combination of cueing and dreaming benefitted problem solving. There has been much speculation about whether dreaming promotes creative insight. By using TMR to elicit dreams of specific memories, we demonstrate a new method for addressing the controversy about whether dreaming itself promotes creativity versus the idea that creativity arises due to unconscious processing during sleep.

A prior study from which we adapted our puzzle stimuli found that cues presented in slow-wave sleep reliably boosted next-day solving from 21% to 32% for puzzles unsolved prior to sleep (Sanders et al. 2019). That study implemented wearable sleep technology to present nonverbal cues for three puzzles each night after identifying six unsolved puzzles prior to sleep. Given the

at-home TMR methodology, puzzle testing was done many hours prior to sleep. Here, we found no overall benefit of cues presented in REM sleep, in line with the mixed findings on the efficacy of TMR in REM sleep (Hu et al. 2020), and perhaps also reflecting other protocol differences such as less elapsed time between puzzle exposure and sleep onset. However, we did find that dreaming of puzzles increased solving at a similar rate (from 17% to 42%), as did REM-sleep cueing for the subset of participants who dreamed more of cued puzzles (from 20% to 40%). The efficacy of cues presented in non-REM in the study by Sanders et al. (2019) may have partially relied on participants' ability to produce puzzle-related dreams in subsequent REM sleep. Indeed, a previous study found that the efficacy of TMR in non-REM sleep sometimes depends on a period of subsequent REM sleep (Batterink et al. 2017). Another study found that task-related dreaming improved performance on a virtual-reality flying task, but only for dreams occurring during REM sleep (Picard-Deland et al. 2021).

Because our study did not involve TMR during waking or non-REM sleep, we cannot address whether REM-sleep dreaming is superior for creative problem solving compared to other states of consciousness. Future studies could compare the effect of cues across sleep stages to test whether they differently affect mentation and later solving. For instance, dreams at sleep onset are a particularly promising candidate for boosting creativity (Lacaux et al. 2021; Horowitz et al. 2023). A control condition with cues presented subliminally during wake (Tal et al. 2024) would also be useful to rule out priming effects, although the present results are unlikely to be explained by priming given the lack of an overall cueing effect. Aside from the impact of cueing, we also cannot conclude that REM-sleep dreaming is more helpful for creative problem solving than an equivalent period spent working while awake. Despite these shortcomings, our findings nevertheless support the conclusion that dreaming in REM sleep can contribute to creative problem solving.

Why only some participants reported dreams related to the cues they received during REM sleep is an intriguing topic for speculation. A simple explanation is that some cued incorporations were forgotten. Or, perhaps some sounds were not very amenable to incorporation or happened to be delivered at a suboptimal time. Or, some puzzle content was not easily incorporated. Another explanation is that differences in external processing account for inter-individual variations in cueing efficacy. Indeed, the mechanisms of sensory disconnection in REM sleep are hotly debated (Andrillon and Kouider 2020; Salvesen et al. 2024; Tononi et al. 2024). Perhaps traits, such as a higher auditory arousal threshold (Salvesen et al. 2024), or states, such as cues being serendipitously presented during times of enhanced processing of the external environment (Türker et al. 2023), made some participants' dreams more malleable to the influence of cues. We speculate that the frequent lucid dreamers we recruited incorporated cued puzzles more often than a less-selective sample would have incorporated them. Firstly, by design, much incorporation occurred because individuals in lucid dreams followed instructions, intentionally dreaming of cued puzzles. Moreover, lucid dreamers exhibit altered functional neuroconnectivity even while awake (Baird et al. 2018), and as a population they may have enhanced sensory processing during sleep (Simor et al. 2022; Türker et al. 2023). Future studies could test whether lucid dreamers experience more sensory incorporation even during non-lucid dreams.

It is important to note that our participants were instructed to continue working on puzzles in their dreams and to seek out solving-related information. This directive before sleep highlights an interesting issue in dream engineering—to what extent does pre-sleep intention facilitate the effect of cueing on later dreaming? We recently showed that this combination of dream incubation and TMR can increase dream incorporation of real-world memories experienced before sleep (Konkoly et al. 2025a). In another study in which participants wore an olfactometry device during sleep and thus may have suspected that smells would be presented to them, olfactory cues previously associated with rural scenes increased rural themes in dreams (Schredl et al. 2014). In a study in which participants were unaware of cueing, on the other hand, cues did not increase task-related dreaming in the lab (Picard-Deland et al. 2021), although task dreams increased for cued participants in the following days (Picard-Deland and Nielsen 2022). Indeed, instructing participants to focus on specific topics before sleep with the intention of dreaming about them can produce on-topic dreaming (Barber et al. 1973; Barrett 1993; Horowitz et al. 2023) and has been shown to reduce nightmares and increase positive dream emotions when paired with TMR (Schwartz et al. 2022).

The within-subjects design in the present experiment was powerful because participants could potentially solve any of the problems they were incubating on overnight, allowing us to test whether dreaming about a problem contributed to solving it. At the same time, this study design did not allow us to disentangle whether creativity is an inherent function of dreaming *versus* whether this benefit emerges when combined with pre-sleep intention. Indeed, one prior study found that participants rated personal problems as more solvable after incubating on them before sleep compared to just relaxing before sleep (White and Taytroe 2003). How different types of dream incorporation relate to later solving may speak to this point. Of the 17 dreamed attempts to solve puzzles (such as by asking for help, visualizing the problem, etc.), 6 were solved the next morning (35%). Five puzzles were incorporated into dreams without a specific solving attempt, one of which (20%) was solved the next morning. This rate is perhaps reflective of the degree of potential benefit from naturally occurring problem-related dreams.

There are multiple types of creativity. Our findings are most relevant for understanding convergent creativity, the process of identifying one correct response out of many alternatives (Cortes et al. 2019). Previous studies (e.g. Cai et al. 2009) as well as anecdotes (e.g. ring structure of the Benzene molecule and format of the periodic table of elements; Barrett 2017) support the role of REM sleep and dreaming in producing correct solutions to problems with only one possible answer. Nevertheless, REM sleep and dreaming might be particularly well-suited for amplifying divergent creativity, the generation of useful and novel ideas (Cortes et al. 2019). Indeed, the hyper-associative nature of REM-sleep dreams and the distant semantic associations REM sleep facilitates may be more valuable for expanding cognition into new terrain as opposed to effectively evaluating ideas for usefulness. Future studies could test if REM sleep and dreams are particularly beneficial for divergent creativity tasks such as coming up with creative stories, apt metaphors (Stumbrys and Daniels 2010), or alternative uses for everyday objects (Guilford 1967; Horowitz et al. 2023; Konkoly et al. 2025a). It would also be interesting to assign lucid dreamers to focus on a particular subset of their own personal problems, to test the degree to which this technique would extrapolate to benefit real-world problem solving (Griffin and Foulkes 1977).

This study also highlights other limitations of studying dream function via experimentally induced dream content. First, the benefits of dreaming still cannot be disentangled from processing occurring in the interim between dreaming and subsequent

testing. It may be that after experiencing a dream pertaining to a specific puzzle, participants thought about that puzzle more or engaged in unconscious processing following their dreams, increasing solving. Future studies could minimize this issue by ensuring testing occurs immediately after provoked dreams or by studying creative ideation occurring exclusively within dreams. Second, our design does not allow us to disentangle the effects of dreaming from cognitive activity at the time of dream reporting. Further, given that participants could not be fully blinded from the purpose of the study, we cannot rule out the influence of demand characteristics, although participants were blind to which TMR cues were received, unless they heard them in a dream. However, perhaps real-time dream communication can shed light on this topic in cases where the dreamer forgets relevant details upon awakening. For example, here one participant responded to two puzzle cues in real-time while asleep, but upon awakening she only remembered, 'I was looking through a dresser … the puzzles were on the papers I was looking through… I solved one of them, and I got a little celebration, but I don't remember which one I solved.' The following morning, this participant solved one uncued and both cued puzzles. Future studies could explore whether this technique can shed light on functional differences between remembered and forgotten dreams, as some theorists argue that dreams' functions differ depending on whether or not they are remembered upon awakening (e.g. Crick and Mitchison 1983; Blagrove et al. 2019).

Another strength of our study was that we compared the dreaming and solving trajectories of multiple unsolved puzzles in each participant. While this design allowed us to control for variability in creative performance across participants, it also introduced noise due to individual differences in the degree of challenge of each puzzle. Outcomes for each puzzle were binary (solved/unsolved), lessening our power to detect meaningful effects, particularly in models with interactions. This issue was exacerbated because our data lacked variability to add the specific puzzle as a random effect in most models, which would have allowed us to statistically control for variable solving rates across puzzles. Further, cues may have provoked reactivation of the episodic puzzle context, thereby spreading reactivation to other puzzles besides the ones we intended to cue. If the effect of cueing spread to non-cued puzzles, the observed effects of cueing on dreaming and solving are diluted, such that the true effect of cueing may be stronger than observed. A useful control for future studies could thus be to add an additional night without any cues to provide baseline rates of cueing and solving. If enough frequent lucid dreamers could be recruited, future studies with larger sample sizes or continuous measures of creativity would be beneficial for confirming our findings, as our sample size of 20 participants with 8 unsolved puzzles each was likely underpowered for detecting all effects of interest.

While we predicted that lucid dreaming would be particularly beneficial for solving, we instead found numerically higher solving rates for puzzles incorporated into nonlucid dreams (Table 1). We did not achieve high enough rates of lucid dreaming to conduct robust tests about how different types of dreaming impacted solving. However, this pattern of results suggests that lucidity may not be necessary, or even helpful, for solving these types of puzzles. Perhaps nonlucid dreams enhance the beneficial effects of unconscious incubation, such as forgetting of incorrect solution paths and increasing access to distant semantic associations (Sanders and Beeman 2021). Deliberate effort in lucid dreams, on the other hand, may at times produce a return to incorrect solution paths and narrow one's access to distant associations. One's approach to interacting with their dream also likely plays a role in the dreams' helpfulness. If one views dreams as a rich source of information from the subconscious mind or even transcending the mind (e.g. LaBerge and Rheingold 1990; Waggoner 2008; Morris et al. 2025; Stumbrys 2018), this expectation might play out in the dream, allowing the dreamer to access helpful solutions. Indeed, many anecdotes support the idea that posing questions within lucid dreams can provide insight into personal problems (e.g. LaBerge and Rheingold 1990; Waggoner 2008). For dreamers without this prior framework, as seemed to be the case for many natural lucid dreamers in our study, dreamers may have been skeptical of our suggestions, such as to ask the dream itself for help on the problem. This skepticism may have played out in their dreams, reducing the likelihood that deliberate attempts in lucid dreams helped solving. Interestingly, we did observe high solving rates for puzzles that participants indicated working on in real-time but did not subsequently remember incorporating. One interpretation of this finding is that the content of forgotten dreams benefits solving, perhaps by promoting forgetting of incorrect solution paths.

Sometimes participants reported hearing puzzle sound cues but did not incorporate other puzzle elements into dreams, and in those cases, beneficial solution processing did not seem to occur. This finding argues against the interpretation that cues promoted solving due to participants' expectation that they should solve more cued puzzles. In typical TMR studies (Paller et al. 2021), participants are not aware of cueing and remain blinded throughout the experiment. Here, participants were told before sleep that cues may be presented to them but were blind to the design that half the puzzles were cued. Participants who heard cues while asleep were no longer blinded to the fact that those puzzles were cued, so long as their incorporation reflected sensory perception rather than endogenous dream content, as happened occasionally. It may be that incorporation of only sound cues was accompanied by increased arousal from cues, which reverses the memory benefits of TMR (Whitmore and Paller 2023). In addition, low motivation or poor memory for particular puzzles could have led both to sound-cue incorporation and reduced solving.

In sum, it is well-known that the chances of being struck by a creative insight can be increased by sleeping on a problem. Whereas dreams have long been thought to facilitate creativity, scientific methods previously used to influence or otherwise study dreaming have faced many limitations that reduce confidence in conclusions about dream functions per se. Here, we demonstrated that applying TMR in REM sleep can bias dream content toward unsolved puzzles; moreover, when puzzles were incorporated into dreams, they were more likely to be solved the next morning. This experimental strategy may likewise be helpful for future research aimed at the problem of directly demonstrating the usefulness of dreams.

Acknowledgments

K.R.K. was supported by the US National Institutes of Health (T32-HL007909). This study was supported by the National Science Foundation grant BCS-1921678, the US National Institutes of Health grant DP1-HL179370, and the Mind Science Foundation, 2022 BrainStorm Award to K.R.K.

Author contributions

Karen R. Konkoly (Conceptualization [equal], Data curation [lead], Formal analysis [lead], Investigation [lead], Methodology

[equal], Project administration [equal], Visualization [lead], Writing—original draft [lead], Writing—review & editing [equal]), Daniel Morris (Data curation [supporting], investigation [supporting], writing—review & editing [equal]), Kaitlyn Hurka (Data curation [equal], Writing—review & editing [supporting]), Alysiana Martinez (Data curation [supporting]), Kristin Sanders (Conceptualization [supporting], Methodology [equal], Writing—review & editing [equal]), and Ken A. Paller (Conceptualization [equal], Funding acquisition [lead], Methodology [equal], Project administration [equal], Resources [lead], Supervision [lead], Writing—review & editing [lead])

Supplementary data

Supplementary data is available at *Neuroscience of Consciousness* online.

Conflict of interest: None declared.

Data availability

Data will be shared upon reasonable request to the corresponding author.

Disclosure statement

Financial Disclosure: None.
Non-financial Disclosure: None.

References

AASM. *Manual for the Scoring of Sleep and Associated Events: Rules, Terminology and Technical Specifications Version 3*. Darien, IL: American Academy of Sleep Medicine, 2023.

Aime M, Calcini N, Borsa M *et al.* Paradoxical somatodendritic decoupling supports cortical plasticity during REM sleep. *Science* 2022;**376**:724–30. https://doi.org/10.1126/science.abk2734

Almeida-Filho DG, Queiroz CM, Ribeiro S. Memory corticalization triggered by REM sleep: Mechanisms of cellular and systems consolidation. *Cell Mol Life Sci* 2018;**75**:3715–40. https://doi.org/10.1007/s00018-018-2886-9

Andrillon T, Kouider S. The vigilant sleeper: Neural mechanisms of sensory (de)coupling during sleep. *Curr Opinion Physiol* 2020;**15**:47–59. https://doi.org/10.1016/j.cophys.2019.12.002

Baird B, Castelnovo A, Gosseries O *et al.* Frequent lucid dreaming associated with increased functional connectivity between frontopolar cortex and temporoparietal association areas. *Sci Rep* 2018;**8**:17798. https://doi.org/10.1038/s41598-018-36190-w

Baird B, Mota-Rolim SA, Dresler M. The cognitive neuroscience of lucid dreaming. *Neurosci Biobehav Rev* 2019;**100**:305–23. https://doi.org/10.1016/j.neubiorev.2019.03.008

Barber TX, Walker PC, Hahn KW. Effects of hypnotic induction and suggestions on nocturnal dreaming and thinking. *J Abnorm Psychol* 1973;**82**:414–27. https://doi.org/10.1037/h0035267

Barrett D. The "committee of sleep": A study of dream incubation for problem solving. *Dreaming* 1993;**3**:115–22. https://doi.org/10.1037/h0094375

Barrett D. Dreams and creative problem-solving. *Ann N Y Acad Sci* 2017;**1406**:64–7. https://doi.org/10.1111/nyas.13412

Bates D, Mächler M, Bolker B *et al.* Fitting linear mixed-effects models using lme4. *J Stat Softw* 2015;**67**:1–48. https://doi.org/10.18637/jss.v067.i01

Batterink LJ, Westerberg CE, Paller KA. Vocabulary learning benefits from REM after slow-wave sleep. *Neurobiol Learn Mem* 2017;**144**:102–13. https://doi.org/10.1016/j.nlm.2017.07.001

Beijamini F, Pereira SIR, Cini FA *et al.* After being challenged by a video game problem, sleep increases the chance to solve it. *PLoS One* 2014;**9**:e84342. https://doi.org/10.1371/journal.pone.0084342

Beijamini F, Valentin A, Jäger R *et al.* Sleep facilitates problem solving with no additional gain through targeted memory reactivation. *Front Behav Neurosci* 2021;**15**:645110. https://doi.org/10.3389/fnbeh.2021.645110

Blagrove M, Hale S, Lockheart J *et al.* Testing the empathy theory of dreaming: The relationships between dream sharing and trait and state empathy. *Front Psychol* 2019;**10**:1351. https://doi.org/10.3389/fpsyg.2019.01351

Bloxham A, Horton CL. Enhancing and advancing the understanding and study of dreaming and memory consolidation: Reflections, challenges, theoretical clarity, and methodological considerations. *Conscious Cogn* 2024;**123**:103719. https://doi.org/10.1016/j.concog.2024.103719

Brodt S, Pöhlchen D, Täumer E *et al.* Incubation, not sleep, aids problem-solving. *Sleep* 2018;**41**:zsy155. https://doi.org/10.1093/sleep/zsy155

Cai DJ, Mednick SA, Harrison EM *et al.* REM, not incubation, improves creativity by priming associative networks. *Proc Natl Acad Sci* 2009;**106**:10130–4. https://doi.org/10.1073/pnas.0900271106

Carr M, Nielsen T. Morning REM sleep naps facilitate broad access to emotional semantic networks. *Sleep* 2015;**38**:433–43. https://doi.org/10.5665/sleep.4504

Carr M, Konkoly K, Mallett R *et al.* Combining presleep cognitive training and REM-sleep stimulation in a laboratory morning nap for lucid dream induction. *Psychol Conscious Theory Res Pract* 2023;**10**:413–30. https://doi.org/10.1037/cns0000227

Cartwright R, Lamberg L. Crisis dreaming: Using your dreams to solve your problems. *iUniverse* 2000.

Cortes RA, Weinberger AB, Daker RJ *et al.* Re-examining prominent measures of divergent and convergent creativity. *Curr Opin Behav Sci* 2019;**27**:90–3. https://doi.org/10.1016/j.cobeha.2018.09.017

Crick F, Mitchison G. The function of dream sleep. *Nature* 1983;**304**:111–4. https://doi.org/10.1038/304111a0

Drago V, Foster PS, Heilman KM *et al.* Cyclic alternating pattern in sleep and its relationship to creativity. *Sleep Med* 2011;**12**:361–6. https://doi.org/10.1016/j.sleep.2010.11.009

Fox, J., Graves, G. G., Heiberger, R., Monette, G., Nilsson, H., Ripley, B., & Weisberg, S. (2007). The car Package. *R Foundation for Statistical Computing*, **1109**, 1431.

Griffin ML, Foulkes D. Deliberate presleep control of dream content: An experimental study—M. L. Griffin, D. Foulkes, 1977. *Percept Mot Skills* 1977;**45**:660–2. https://doi.org/10.2466/pms.1977.45.2.660

Guilford JP. Creativity: Yesterday, today and tomorrow. *J Creat Behav* 1967;**1**:3–14. https://doi.org/10.1002/j.2162-6057.1967.tb00002.x

Horne J. REM sleep vs exploratory wakefulness: Alternatives within adult 'sleep debt'? *Sleep Med Rev* 2020;**50**:101252. https://doi.org/10.1016/j.smrv.2019.101252

Horowitz AH, Esfahany K, Gálvez TV *et al.* Targeted dream incubation at sleep onset increases post-sleep creative performance. *Sci Rep* 2023;**13**:7319. https://doi.org/10.1038/s41598-023-31361-w

Hu X, Cheng LY, Chiu MH *et al.* Promoting memory consolidation during sleep: A meta-analysis of targeted memory reactivation. *Psychol Bull* 2020;**146**:218–44. https://doi.org/10.1037/bul0000223

Klepel F, Schredl M, Göritz AS. Dreams stimulate waking-life creativity and problem solving: Effects of personality traits. *Int J Dream Res* 2019;**12**:95–102. https://doi.org/10.11588/ijodr.2019.1.58950

Konkoly KR, Appel K, Chabani E *et al.* Real-time dialogue between experimenters and dreamers during REM sleep. *Curr Biol* 2021;**31**:1417–1427.e6. https://doi.org/10.1016/j.cub.2021.01.026

Konkoly, K., Whitmore, N., Mallett, R., Mazurek, C., & Paller, K. A. (2024). Provoking lucid dreams at home with sensory cues paired with pre-sleep cognitive training. *Consciousness and Cognition* 2024;**125**:103759.

Konkoly KR, Al-Youssef S, Mazurek CY *et al.* Using real-time reporting to investigate visual experiences in dreams. *J Cogn Neurosci* 2025b; 1–16. https://doi.org/10.1162/JOCN.a.107

Konkoly KR, Morris DJ, Cho M *et al.* Investigating dreams by strategically presenting sounds during REM sleep to reactivate waking experiences. *Neuropsychologia* 2025a;**217**:109229. https://doi.org/10.1016/j.neuropsychologia.2025.109229

Kounios J, Beeman M. The cognitive neuroscience of insight. *Annu Rev Psychol* 2014;**65**:71–93. https://doi.org/10.1146/annurev-psych-010213-115154

LaBerge S, Rheingold H. *Exploring the World of Lucid Dreaming*. New York: Ballantine Books, 1990.

Lacaux C, Andrillon T, Bastoul C *et al.* Sleep onset is a creative sweet spot. *Science Advances* 2021;**7**:eabj5866. https://doi.org/10.1126/sciadv.abj5866

Lenth, R., Banfai, B., Bolker, B., Buerkner, P., Giné-Vázquez, I., Herve, M., Jung, M., Love, J., Miguez, F., Piaskowski, J., Riebl, H., & Singmann, H. (2024). emmeans: Estimated Marginal Means, aka Least-Squares Means. R package version 1.10.3.

Lewis PA, Knoblich G, Poe G. How memory replay in sleep boosts creative problem-solving. *Trends Cogn Sci* 2018;**22**:491–503. https://doi.org/10.1016/j.tics.2018.03.009

Mallett R, Konkoly KR, Nielsen T *et al.* New strategies for the cognitive science of dreaming. *Trends Cogn Sci* 2024;**28**:1105–17.

Morris DJ, Elliot DB, Torres-Platas SG *et al.* Lucid Dreaming of a Prior Virtual-Reality Experience with Ego-Transcendent Qualities: A Proof-of-Concept Study. *Neuroscience of Consciousness* 2025;**2025**:niaf017.

Paller KA, Creery JD, Schechtman E. Memory and sleep: How sleep cognition can change the waking mind for the better. *Annu Rev Psychol* 2021;**72**:null. https://doi.org/10.1146/annurev-psych-010419-050815

Pereira SIR, Lewis PA. The differing roles of NREM and REM sleep in the slow enhancement of skills and schemas. *Curr Opin Physiol* 2020;**15**:82–8. https://doi.org/10.1016/j.cophys.2019.12.005

Pereira SIR, Santamaria L, Andrews R *et al.* Rule abstraction is facilitated by auditory cuing in REM sleep. *J Neurosci* 2023;**43**:3838–48. https://doi.org/10.1523/JNEUROSCI.1966-21.2022

Picard-Deland C, Nielsen T. Targeted memory reactivation has a sleep stage-specific delayed effect on dream content. *J Sleep Res* 2022;**31**:e13391. https://doi.org/10.1111/jsr.13391

Picard-Deland C, Aumont T, Samson-Richer A *et al.* Whole-body procedural learning benefits from targeted memory reactivation in REM sleep and task-related dreaming. *Neurobiol Learn Mem* 2021;**183**:107460. https://doi.org/10.1016/j.nlm.2021.107460

Picard-Deland C, Bernardi G, Genzel L *et al.* Memory reactivations during sleep: A neural basis of dream experiences? *Trends Cogn Sci* 2023;**27**:568–82. https://doi.org/10.1016/j.tics.2023.02.006

Ross W, Arfini S. Impasse-driven problem solving: The multidimensional nature of feeling stuck. *Cognition* 2024;**246**:105746. https://doi.org/10.1016/j.cognition.2024.105746

Salvesen L, Capriglia E, Dresler M *et al.* Influencing dreams through sensory stimulation: A systematic review. *Sleep Med Rev* 2024;**74**:101908. https://doi.org/10.1016/j.smrv.2024.101908

Sanders KEG, Beeman M. Sleep and incubation: Using problem reactivation during sleep to study forgetting fixation and unconscious processing during sleep incubation. *J Cogn Psychol* 2021;**33**:738–56. https://doi.org/10.1080/20445911.2021.1912050

Sanders KEG, Osburn S, Paller KA *et al.* Targeted memory reactivation during sleep improves next-day problem solving. *Psychol Sci* 2019;**30**:1616–24. https://doi.org/10.1177/0956797619873344

Saredi R, Baylor GW, Meier B *et al.* Current concerns and REM-dreams: A laboratory study of dream incubation. *Dreaming* 1997;**7**:195–208. https://doi.org/10.1037/h0094474

Schädlich M, Erlacher D. Applications of lucid dreams: An online study. *Int J Dream Res* 2012;**5**:134–8. https://doi.org/10.11588/ijodr.2012.2.9505

Schönauer M, Brodt S, Pöhlchen D *et al.* Sleep does not promote solving classical insight problems and magic tricks. *Front Hum Neurosci* 2018;**12**:72. https://doi.org/10.3389/fnhum.2018.00072

Schredl M. Creativity and dream recall. *J Creat Behav* 1995;**29**:16–24. https://doi.org/10.1002/j.2162-6057.1995.tb01420.x

Schredl M, Erlacher D. Self-reported effects of dreams on waking-life creativity: An empirical study. *J Psychol* 2007;**141**:35–46. https://doi.org/10.3200/JRLP.141.1.35-46

Schredl M, Ciric P, Götz S *et al.* Dream recall frequency, attitude towards dreams and openness to experience. *Dreaming* 2003;**13**: 145–53. https://doi.org/10.1023/A:1025369311813

Schredl M, Hoffmann L, Sommer JU *et al.* Olfactory stimulation during sleep can reactivate odor-associated images. *Chemosens Percept* 2014;**7**:140–6. https://doi.org/10.1007/s12078-014-9173-4

Schwartz S, Clerget A, Perogamvros L. Enhancing imagery rehearsal therapy for nightmares with targeted memory reactivation. *Curr Biol* 2022;**32**:4808–4816.e4. https://doi.org/10.1016/j.cub.2022.09.032

Simor P, Bogdány T, Peigneux P. Predictive coding, multisensory integration, and attentional control: A multicomponent framework for lucid dreaming. *Proc Natl Acad Sci* 2022;**119**:e2123418119. https://doi.org/10.1073/pnas.2123418119

Smith SM, Beda Z. Old problems in new contexts: The context-dependent fixation hypothesis. *J Experimental Psychol General* 2020;**149**:192–7. https://doi.org/10.1037/xge0000615

Sterpenich V, Schmidt C, Albouy G *et al.* Memory reactivation during rapid eye movement sleep promotes its generalization and integration in cortical stores. *Sleep* 2014;**37**:1061–75. https://doi.org/10.5665/sleep.3762

Stickgold R, Scott L, Rittenhouse C *et al.* Sleep-induced changes in associative memory. *J Cogn Neurosci* 1999;**11**:182–93. https://doi.org/10.1162/089892999563319

Stumbrys T, Daniels M. An exploratory study of creative problem solving in lucid dreams: Preliminary findings and methodological considerations. *Int J Dream Res* 2010;**3**:121–9. https://doi.org/10.11588/ijodr.2010.2.6167

Stumbrys T. Bridging lucid dream research and transpersonal psychology: Toward transpersonal studies of lucid dreams. *J Transpersonal Psych* 2018;**50**:176–93.

Tal A, Schechtman E, Caughran B *et al.* The reach of reactivation: Effects of consciously triggered versus unconsciously triggered reactivation of associative memory. *Proc Natl Acad Sci* 2024;**121**:e2313604121. https://doi.org/10.1073/pnas.2313604121

Tononi G, Boly M, Cirelli C. Consciousness and sleep. *Neuron* 2024;**112**:1568–94. https://doi.org/10.1016/j.neuron.2024.04.011

Türker B, Musat EM, Chabani E *et al.* Behavioral and brain responses to verbal stimuli reveal transient periods of cognitive integration of the external world during sleep. *Nat Neurosci* 2023;**26**: Article 11. https://doi.org/10.1038/s41593-023-01449-7

Vallat R, Türker B, Nicolas A *et al*. High dream recall frequency is associated with increased creativity and default mode network connectivity. *Nat Sci Sleep* 2022;**14**:265–75. https://doi.org/10.2147/NSS.S342137

Verleger R, Rose M, Wagner U *et al*. Insights into sleep's role for insight: Studies with the number reduction task. *Adv Cogn Psychol* 2013;**9**:160–72. https://doi.org/10.2478/v10053-008-0143-8

Waggoner R. *Lucid Dreaming: Gateway to the Inner Self*. Needham, MA: Red Wheel/Weiser, 2008.

Wagner U, Gais S, Haider H *et al*. Sleep inspires insight. *Nature* 2004;**427**:352–5. https://doi.org/10.1038/nature02223

Wamsley EJ. Dreaming and offline memory consolidation. *Curr Neurol Neurosci Rep* 2014;**14**:433. https://doi.org/10.1007/s11910-013-0433-5

Wamsley EJ, Stickgold R. Dreaming of a learning task is associated with enhanced memory consolidation: Replication in an overnight sleep study. *J Sleep Res* 2019;**28**:e12749. https://doi.org/10.1111/jsr.12749

White GL, Taytroe L. Personal problem-solving using dream incubation: Dreaming, relaxation, or waking cognition? *Dreaming* 2003;**13**:193–209. https://doi.org/10.1023/B:DREM.0000003143.00133.1c

Whitmore NW, Paller KA. Sleep disruption by memory cues selectively weakens reactivated memories. *Learn Mem* 2023;**30**:63–9. https://doi.org/10.1101/lm.053615.122

Yaniv I, Meyer DE. Activation and metacognition of inaccessible stored information: Potential bases for incubation effects in problem solving. *J Exp Psychol Learn Mem Cogn* 1987;**13**:187–205. https://doi.org/10.1037/0278-7393.13.2.187

Neuroscience of Consciousness, 2026, **2026(1)**, **2026**, niaf067
https://doi.org/10.1093/nc/niaf067
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