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Title

The Neurocognition of Dreaming: Key Questions and Foci

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Abstract

Until recently, understanding the neurobiology of dreaming has relied upon correlating a subjective dream report with a measure of brain activity or function sampled from a different occasion. As such, most assumptions about dreaming come from the neuroscience of REM sleep from which many, but not all, dream reports are recalled. Core features of REM sleep (intense emotional activation, a reduction in activity in most frontal regions, particularly the dorsolateral prefrontal cortex, along with increased dopamine, acetylcholine, cholinergic activation) align with typical dream characteristics (characterised by fear, reduced reality monitoring, increased bizarreness and hyperassociativity, respectively). The default mode network offers a way of understanding the nature of dreaming more independently from a REM sleep context, and EEG methods paired with serial awakenings to elicit dream reports demonstrate how high-frequency activity in posterior regions may be associated with dreaming. Nevertheless, all measures of dreaming rely fundamentally on recall processes, so our understanding of dreaming must embrace and address memory's crucial involvement in dream report production.

Summary points:

Dreaming can occur during, as well as independently from, REM sleep.

The neurobiology of REM sleep provides a starting point for understanding sleep mentation, but it is not sufficient.

Whilst many common dream features can be accounted for by the neurobiology of REM sleep, dreaming cognition is complex, multi-faceted and relatively misunderstood.

Understanding dreaming needs to rely heavily upon understanding neurocognitive features of sleep across the night: specifically, memory processes both during, and emerging from, sleep.

1 How can we make sense of the neurobiology underpinning dreaming?

Dreaming occurs during sleep and is often, somewhat erroneously, reported as a feature of REM sleep, as dreams are most spontaneously recalled from this stage (1). Dreaming likely occurs during all sleep phases, every night, although dream reports are only recalled occasionally, approximately eight per month (2). Dreaming can only be verified via subjective report, as such, it can be defined as memory for mental content or experiences from sleep (3). Dreaming can occur either with or in the absence of specific sensory experiences, including emotions and visions, and may range from fleeting to being lengthy and highly detailed.

Understanding the neurobiology of dreaming relies on correlating a subjective dream report with a measure of brain activity or function. Unfortunately, due to the practical challenges of measuring sleep in a neuroimaging scanner, there are relatively few empirical accounts that have been able to validate a dream experience at the same time as measuring neuro-cognitive function in some way.

Our understanding of the neurological profile of dreaming relies on imaging of REM sleep along with cognitive aspects of sleep mentation and general, rather than specific, dream characteristics, which were not sampled during the imaging process. Evidence demonstrates that the entire cortex is implicated during REM (4-7). There are notable features of REM sleep: heightened activity in the limbic and paralimbic areas, particularly the amygdala, and decreased activity in the frontal lobes. In addition, there is increased activity in occipito-temporal-visuo, and motor, cortices (as described in 5). Most dream reports reflect mentation in line with this, namely with heightened emotional content (8), lacking in some higher-order cognition such as reality monitoring (9), and comprising personal memories and experiences, albeit in a fragmented and non-episodic way (10-11). Perhaps unsurprisingly, REM sleep has also been associated with activity in the motor and visual cortices (12; see also 5, for a thorough review).

NREM sleep generally shows a decrease in cerebral energy compared to REM stages (6). The result is that, given the inability to perceive stimuli from the external environment whilst asleep, some memories, thought or concerns, or parts of these, are activated. This may be a by-product of consolidation processes (13). Visual images arise, often accompanied by emotional content or other sensory perceptions, although these are not controlled, planned or manipulated due to the deactivation of the frontal lobes. The extent to which dreams reflect material that is deeply motivated, perhaps arising from the “unconscious”, is subject to scrutiny and is well debated between Solms (14-15) and Hobson (16-17), with the latter arguing that the lack of frontal control produces meaningless images as opposed to deeply meaningful and personally salient dreams.

Imaging studies of sleep (4, 6, 18) have demonstrated a distinctive reduction in activity in the dorsolateral prefrontal cortex during REM sleep relative to non-REM and wakefulness, which has been regularly explained as accounting for a lack of volition, or control over one's actions, during dreaming. In other words, involuntary activity occurs whilst accepting events unfold around the dreamer, in the absence of lucidity or accurate reality monitoring (9). However, this should not be confused with cognition or metacognition being severely impaired during sleep, as a number of studies have demonstrated comparable cognitive functioning within dreams as compared to focusing waking thought (19). It is important to remember then not to over-interpret findings from imaging studies of sleep to account for more complex, changeable, and nuanced dream experiences.

Rather than exploring specific cognitions then, general dream features and characteristics can be appraised for more readily. The strange and discontinuous nature of sleep mentation, "dream bizarreness", has been proposed to emerge more prominently from the ponto-geniculo-occipital, or PGO, waves originating from the brainstem, that signal and characteristically define REM sleep (20). Furthermore, the sometimes vivid and powerful images and feelings experienced in dreams has been proposed to emerge from increased dopamine released during REM sleep. Dopamine is associated with some aspects of psychosis, such as hallucinations, and the drug levodopa, which converts into dopamine and increases dream recall (21). Indeed, some scholars have noted the similarities between dreaming and psychosis, not only in characteristic terms but also due to the unclear distinctions between sleep and wakefulness, with confused reality monitoring (22). Likewise, the cholinergic activation of the brain during REM sleep has been proposed to account for the bizarre features of dreams (17). Unfortunately, some medications commonly prescribed for insomnia such as antihistamine sedatives, which have anticholinergic properties, have been shown to lead to an increased risk of dementia (23), illustrating the counterintuitive idea that dreaming is both akin to cognitive disorganisation, but also important to experience in order to prevent such disorganisation from occurring during waking cognition.

The emotional tone of dreams further reinforces this idea that dreaming may provide a safe context in which the dreamer can experience and simulate otherwise extreme and unusual experiences as an emotion regulation function of sleep and dreaming (24). In the absence of sufficient sleep (25), and perhaps dreaming, also (26) unregulated fear responses may prevail, leading to uncontrolled anxiety during waking.

Activity in the precuneus is decreased in REM relative to waking (6). This brain region is implicated in the holistic integration of recollected information, such as with episodic information featuring numerous sensory components, although this complex structure is also associated with a range of features of self- and visuo-spatial processes (27). Indeed, whilst dreams are comprised mainly of our personal autobiographical experiences (10),

veridical episodic information from waking-life is not activated (11) and furthermore, personal memories are fragmented and re-combined, known as hyperassociativity (28-29).

Taken together, neural activity during REM can help to account for common features of dreaming, but as yet there is no evidence from imaging studies to explore dreaming directly. As such, we can use models of cognition to understand and illustrate common features of dreaming.

2. What are the cognitive features associated with dreaming? Foundations of the neurocognition of dreams

It is almost impossible to disentangle the experience of dreaming from the experience of sleep. Dreaming may overlap with some wakeful cognitions (e.g. 30; for a summary see 18), such as visual hallucinations, but there exist several differences also. Additionally, dreaming likely accompanies sleep much more frequently than estimates suggest. Table 1 compares waking cognitions that share features with dreaming cognition.

Domhoff's Neurocognitive Theory of Dreaming (31) synthesises the neural substrates of sleep in comparison to wakefulness to consider the cognitive possibilities of the dreaming brain. A number of cognitive features of dreaming are outlined and interpreted in relation to evidence of the neurobiology of REM sleep, and therefore dreaming. For instance, waking experiences such as mind-wandering, daydreaming and experiencing involuntary autobiographical memories may be highly similar to dreams, occurring in the absence of distracting external stimulation. They constitute mental correlates of the default mode network (DMN), which emerged from baseline or control "activities" from a vast range of functional neuroimaging studies (32). Domhoff and Fox (33) noted the similarities between the DMN and dreaming, proposing that the brain's "default" state is the neurological basis of dreaming. Table 1 outlines the cognitive processes involved in a range of conscious states comparable to dreaming, to help illustrate this.

The ventromesial prefrontal cortex (vmPFC) in part accounts for reality monitoring, namely the ability to determine whether an experience is real (externally-generated) or imagined (internally-generated). During dreaming, reality monitoring is suspended, and the vmPFC is relatively attenuated during REM sleep (18), which may account for this. In contrast, during moments of lucidity during dreaming, there is greater frontal activity (34).

Table 1:
Waking experiences comparable to dreaming

Experience	Similarities to dreaming	Differences to dreaming
Hallucinations	Decreased reality monitoring (awareness of the experience being real or imagined); highly sensory (visual/auditory); Seemingly personal whilst also bizarre	As a pathological symptom of psychosis, hallucinations occur infrequently in psychologically healthy individuals. Conversely, almost all healthy adults dream.
Involuntary autobiographical memories	Occur in the absence of controlled thought; Draws on personal memories; May be cued by current sensory experiences.	Short-lived, more episodic in nature. Focused thought can resume quickly in waking when the memory passes; in dreaming, autobiographical memories remain the dominant mental content until dreaming ends.
Mindfulness / meditation	Must occur in the absence of other stimulation and/or distractions. Requires suspension of current concerns, thoughts and perception of environmental stimuli, to allow a focus on internal mentation and processes.	Requires extensive training and focus. Can only occur with effortful focus.
Night terrors	Intensely emotional; Occurs during sleep; Often occurs in the absence of awareness or memory of the experience.	Typically only occur in at least one of the following: young children, individuals who are sleep-deprived, individuals struggling to process highly stressful life events. Night terrors occur predominantly early in the sleep cycle (deep stages of sleep), from which it is difficult to wake.

Experience	Similarities to dreaming	Differences to dreaming
Hypnagogic imagery	Highly sensory (visual) experience, occurring without conscious control. Occurs during sleep [onset].	Occurs during the transition from wakefulness to sleep. The mentation typically occurs briefly and features simple patterns, rather than more complex characters, narratives and/or emotions.
Daydreaming	Akin to fantasising, occurs during restful [waking] periods; Can be multi-sensory	More focused and controlled activity, greater cognitive effort and involvement than dreaming. Occurs when awake.
Confabulation	Includes a report of an experience that either happened in part and has been expanded upon, or did not happen at all.	Accompanied by high confidence in the recall and with detail of the experience.
Mind-wandering	Occurs when external stimulation is non-engaging or non-distracting; Can be involuntary; May be a precursor to dreaming (if sleep was able to occur). Memory for the mind-wandering experience can be difficult to access.	Typically positively emotional, or at least rarely intense and negative. Can be difficult to determine how long the mind-wandering occurred for. Can be reversed easily, for instance if needing to focus after losing focus during driving.

3. Is dreaming independent from REM sleep?

Aserinsky and Kleitman (35) and then from the same laboratory, Dement and Kleitman (36) characterised REM sleep, noting its features (wake-like EEG, denoting high-frequency, low-amplitude cortical activity, along with observable eye movements, increased heart rate and respiratory activity, including that waking from REM sleep often yielded dream reports (even though the findings from (36) were only taken from five participants, in detail). REM sleep was considered to be “paradoxical” in showcasing wake-like features during sleep. Furthermore, the mental activity was – and has since been evidenced to be – detailed yet distinct from focused waking thought, featuring bizarre sequences and events that would be

impossible in real-life. These REM periods were also found to be associated with muscle atonia (37), which was interpreted as serving the function of preventing dream content from being acted out.

REM dreams may be easier to recall than non-REM dreams for at least two main reasons: 1 with the brain activity being more similar to the waking brain's than different, the carry-over of a dream memory from REM to waking is relatively easy, from one similar active context to another; and 2 REM dreams are typically longer, more vivid, bizarre and more emotional than non-REM dreams (1, 35), comprising features that aid memory.

This has led some to propose that REM dreams are quantitatively rather than qualitatively distinct from non-REM dreams (e.g. 38), nevertheless, there remains a strong historical account that dreaming is a purely REM-sleep phenomenon, in spite of evidence against this. Most notably, Mark Solms (14, 15) has demonstrated the double dissociation between REM sleep and dreaming and argued for models of dreaming that rely on REM sleep physiology to be updated. In (39), diurnal rhythms were found to influence report length, bizarreness and clarity of the imagery, arguably mediated by increased cortical activation. This influence was more profound than that of REM cortical activation patterns. Several studies have demonstrated a time-of-night effect on dream characteristics (e.g. 29), with dream bizarreness, continuity and hyperassociativity increasing as a function of time spent asleep. This may still reflect some differences between non-REM (early night) and REM (late night) dreams, however, longer sleep time could reflect an increased number of prior sleep stage transitions (e.g. 40) or other physiological changes, also.

Acetylcholine keeps the brain in a relatively active state during REM sleep (41). Frontal brain regions in stage 2 non-REM sleep reflect higher levels of activation than in REM sleep (42). Deactivation of such regions will likely lead to memory impairment for events or images experienced whilst asleep, however, the memory benefit for Stage 2 dreams is compounded by the rare awakenings that occur from this stage.

As our understanding of cortical activation associated with dreaming has come from imaging studies of REM sleep, in contrast to non-REM sleep, some (e.g. 43) have emphasised the relative attenuation of the frontal lobes during sleep, particularly during non-REM, as the cause of dreaming either occurring infrequently, or occurring but being rapidly forgotten. In contrast, the heightened activation of frontal and frontolateral regions that accompany lucid dreaming are associated with rich, conscious experiences and detailed memories of those (34, 44). Such experiences occur during hypnopompia, and as such further complicate our understanding of the neural conditions of dreaming.

More recently, electroencephalography (EEG) has been used across the night of sleep along with serial awakenings to elicit dream reports. (45) observed brain activity in this way, from

sleep onset through to REM, and compared EEG activity preceding awakenings that yielded dream reports, with awakenings that yielded no such reports. Their observations suggested an inverted-U-shaped relationship between dreaming and the prevalence of low-frequency EEG rhythms, with dreaming emerging along with EEG slowing during the sleep-wake transition. Dreaming subsequently disappears as high-amplitude slow oscillations were more prevalent during later N2 sleep. Siclari and colleagues (46) adopted a similar approach, monitoring activity in real-time across both non-REM and REM, and comparing periods either accompanied or not by a dream report. Like (45), decreases in low-frequency activity in posterior regions accompanied dream reports. Dream characteristics, such as inclusion of speech, movement, or face-processing, were correlated with high-frequency activity in these areas, which led the authors to propose that the posterior so-called “hot zone” predicted whether an individual reported dreaming or not during non-REM. A follow-up study (47) identified hallmarks of dreaming in non-REM, namely shallower slow waves, faster spindles, and occasional steep large waves in frontal areas, relative to periods that were not accompanied by a dream. However, in (48) a trained EEG classifier failed to differentiate between dreamful and dreamless non-REM sleep reports, demonstrating the multi-faceted markers of consciousness in sleep as well as in wake.

This focus on EEG determinants of dreams was extended to include markers of emotional features (49). Frontal alpha asymmetry in both REM and preceding evening periods of wakefulness predicted anger levels in dreams. The authors interpret this as a neural basis for [poor] emotion regulation processes across both sleep and wake. Whilst this indicates a more trait-like association between EEG and dream characteristics, than a specific feature of dream consciousness, the approach paves the way for future studies to explore general trend relationships between sleep physiology and dreaming.

These studies reflect an advance in both methodological approaches to understanding the neurobiology of dreaming, and a shift in recognising that dreaming exists somewhat independently from REM sleep. Nevertheless, the serial awakenings paradigms are highly disruptive to sleep patterns and occur within the sleep laboratory rather than natural sleep environments, so neurocognitive activity may be somewhat unrepresentative in these conditions.

4 Can the AIM model and associated neurotransmitters account for dream synthesis and recall?

A prominent model of brain activation and dreaming that has been refined since its original inception (50), is the AIM model of dreaming and REM sleep (1). Initially the model was devised in order to account for the changes in brain activation between sleep stages (the activation part of the model), whilst a more cognitive focus, resulting from this, explains how dream mentation is so bizarre, random and unpredictable (synthesis). That is, REM sleep is

initiated by the pons (51) as opposed to the cortex, resulting in uncontrolled thoughts requiring the brain to “make the best of a bad job” (50, p1347) by “synthesizing” the thoughts together upon waking into some narrative that is as meaningful as the individual can allow it to be. The main claim of this theory is that dreaming does not result from higher order processing. Rather, it is generated by reflex actions, and then edited into a narrative; thus the dream is intrinsically meaningless as it is beyond control. This somewhat controversial claim has been challenged, mainly by Solms (14, 15) who disagreed that uncontrolled thoughts are meaningless and that dreaming is a purely physiological process. In addition, the assumption that dreaming is equivocal to REM sleep has been increasingly refuted over time (15, 29, 38, 46, 47, 52).

Hobson, Pace-Schott & Stickgold (1) proposed in their AIM model a three-dimensional account of dreaming in neurocognitive terms. A (activation) referred to thresholds for the existence of dreaming, regardless of sleep-/consciousness-state; I (information flow and source) referred to the intensity of the dream experience, whereby attention is focused inwards to the detriment of interference from external sensory stimuli; and M (mode of information processing) accounted for the cognitive functioning of the dreaming brain, as neurologically underpinned by the position upon an aminergic-cholinergic neuromodulation spectrum. Increases in aminergic function during REM leads a dreamer to accepting the strange nature of sleep mentation. Meanwhile, noradrenalin underpins low arousal and reduced and uncontrolled cognitive function. Stickgold et al. (53) noted how associations between different activated memories and information, which are weakly related and so would not be preferentially activated during wake, are activated similarly to strongly associated information. Noradrenalin is proposed to account for this, which may itself explain hyperassociativity in dream content. Weakly semantically associated information is activated during non-REM, and very much so during REM (53), allowing these associations to present novel insights and opportunities. This forms the basis of the NEXTUP model of dreaming cognition (54), whereby these unconventional associates are processed and considered along with more conventional ones, allowing memory fragments to combine in novel ways, promoting problem solving, creativity and insight, all of which benefit preferentially from REM sleep. Thus, AIM model of dreaming is well supported by neuroscience, whilst accounting for the cognitive functioning (or, indeed, cognitive deficits) during dreaming, and has provided the basis for more recent models of sleep.

The “M” of Hobson’s model represents the likelihood that memory for dreams will be low, due to the cholinergic activation of the brain, and indeed most dreams are indeed forgotten. However, there is variability in that some people are consistently more likely to remember dreams than others, and certain dreams are more recallable than others. The cholinergic-aminergic activation from sleep to waking is illustrated without direct reference in traditional cognitive modes of dream recall, such as the arousal-retrieval (55) and the functional state-shift models (56). Both note the required cognitive demands of dream recall, along with

context-dependent memory effects during the transition to wake from sleep. It follows that carrying a dream memory over from deeper stages of sleep to wakefulness would be challenging, likely accounting, at least in part, for poor recall rates from non-REM sleep. The changing profile of chemical brain function during hypnopompia (transition to waking) illustrates the extent of contextual shift.

A further hormonal shift at this time is seen in the cortisol awakening response (57), which is a pervasive increase in the hormone cortisol, and its return to lower levels, within the first hour of waking. This reflects how cortisol is not merely a hormone associated with stress, but also daily readiness. Payne (58, 59) has theorised about the relationship between dreaming and cortisol, whereby cortisol disrupts hippocampal to neocortical communication as part of sleep-dependent memory consolidation processes. Such disruption may account for the fragmentary and seemingly-strange elements of memories featuring in dreams, especially within REM sleep. As such cortisol may reflect stressfulness, or negative emotions and tension, in dream content as well as challenges to recalling that content.

Finally, selective serotonin reuptake inhibitors can intensify dreaming (60).

5. Aren't dreams more motivated than being the passive product of the neurological context of REM sleep?

Proponents of the activation-synthesis accounts of dreaming argue that dreams are more random than meaningful, thus rendering a motivated dream to be impossible. In contrast, Solms (14) has investigated dreaming from a neuropsychological perspective, collecting dream reports from clinical patients with brain injury or disease. Whilst investigating which brain regions are implicated in dreaming, Solms reported that damage to the ventromedial quadrant of the frontal lobe lead to a cessation of dreaming. This region is involved in dopamine transmission and is responsible for reward and motivation. The pons, however; claimed by Hobson and colleagues (1) to activate dreaming, was not found to be essential for dreaming to occur. In addition, the occipito-temporo-parietal junction; concerned with converting perceptions into abstract thought, was found to be essential for dreaming (14). This was interpreted (14, 61) as reflecting Freudian notions of regression in dreaming, whereby thoughts are converted into perceptions, whilst in waking life perceptions and experiences are converted into abstract thoughts. Solms convincingly argues that dreaming is not equivalent to REM sleep, rendering the study of REM sleep virtually useless in the understanding of dreaming. Rather, motivated memories from the past are fused and "seen" in dreams. In contrast activation-synthesis accounts (1) posit that a threshold level of cortical activation such as that experienced in REM sleep is required in order to dream. That activation is claimed to involve random firings of neurons in active brain regions. The dream is the result of an individual trying to piece together these "random" thoughts and images that emerge from this activation. Solms' motivated and meaningful dreams, and Hobsons' random ones,

may both be “synthesized” upon waking and encoded to memory, as frontal deactivation renders encoding difficult during the dream experience itself. Thus, the two views may not differ hugely when considered in terms of accounting for the creation of a dream report upon waking.

The neurobiological elements that underpin synthesis, as well as those detailed elsewhere in this paper, are summarized in Figure 1, using a dream taken from (10) to illustrate how the typical REM sleep environment may give rise to specific elements of sleep mentation.

This model illustrates how the individual dream elements, as well as features associated with those specific elements, may be activated during sleep and form a dream memory. In Horton & Malinowski (10) it is emphasized that this process can occur either consciously by forming a dream memory, or nonconsciously by being forgotten. In both cases, the constituent memory elements will have been activated, creating conditions for consolidation. In contrast, Henrich (26) emphasizes the importance of conscious appraisal for emotional adaptation to occur in response to processing dream content.

6. Where should dream researchers go next?

Most typical over-arching characteristics of sleep experiences, or at least memories for dreams, can be accounted for by proposed underpinning neurocognitive activity. Dreams are reported to feature changeable activities and sequences, that would not occur in waking life, and are more negatively emotional than waking experiences also. As described above, they comprise hyperassociative autobiographical features, with unique creations as well as, occasionally, common over-arching themes. Most commonly, amnesia occurs for dream experiences. The neurobiological state of REM sleep, as well as deeper sleep stages that are difficult to wake from, may account for much of this amnesia. To understand dreams, then, one must study them both independently from sleep stage (REM in particular) and in association with the physiological conditions of the sleep stage from which the dream was reported, as well as measuring the time of night, or amount of sleep that preceded the dream sample. Furthermore, comparisons between the conditions of dream sleep and dreamless sleep will help to identify the contributions of dreaming cognition to an outcome of interest.

Whilst a substantive body of neuroscience reports on physiological characteristics of sleep, with increasing temporal and regional resolution, as yet no tenable consistent neurophysiological indicators of dreaming have been uncovered (45, 48), although EEG monitoring of the posterior “hot zone” has provided the most compelling evidence thus far (46). Real-time EEG provides a promising technique for monitoring neurocognitive activity in future, and as technologies develop, bringing this away from the sleep lab may offer enhanced approaches to study the existence of dreaming more continuously and in real-

world settings (62). Likewise, an emerging field of dream engineering links technological advances through wearables with concomitant sleep mentation and is most commonly applied to the field of lucid dreaming, in which dream content aims to be manipulated (63). Stepping back to use these technologies without influencing dream content, to observe naturally occurring neurocognitive features of sleep mentation, could indicate, for instance, the organisation of memory sources of dreams as it changes across the night (29) in greater detail, which could then provide clues about the nature of hyperassociativity within REM sleep, and in turn generate hypotheses about the neurological underpinnings of that more clearly defined context.

Nevertheless, some (e.g. 52) argue that dreaming is a subjective phenomenon that cannot be reduced to purely neurological foundations, but instead offer a fascinating insight into the nature of consciousness. Evidence of dreaming certainly relies upon subjective report, but that report could lead to hypotheses about the physiological underpinnings of that state (or states) of consciousness. Whilst it has been difficult thus far to demonstrate clear links between features of dreams and neurotransmitter activity (e.g. 65, exploring links between oxytocin and social interactions in dreams), a renewed effort to pursue this line of enquiry could be useful (see also 49).

Taken together, the associations between the reports of dream experience and concomitant brain activity do not allow a prediction to be made about the direction of causation, for example whether emotional and bizarre dream experiences afford the dreamer the opportunity to see links between aspects of their lives and memories in novel ways, leading to creativity and novel insights (65), or whether the emotion-processing functions of sleep give rise to associated dream content. Either way, sleep is necessary not only to dream, but also to experience countless benefits to health, wellbeing and cognition, and without it, dream experiences make their way into waking consciousness in dangerous ways, as visual hallucinations and psychosis (e.g. 66). As such, dreaming should occur in a healthy sleep environment, and sleep should be of sufficient quantity and quality to create those conditions in which all cycles of sleep can be experienced. With that in mind, the broader relationships between dream frequency and psychological, cognitive and/or neural “health”, such as cognitive flexibility, should be explored in order to provide additional insights into the neurobiological context and possible function of dreaming.

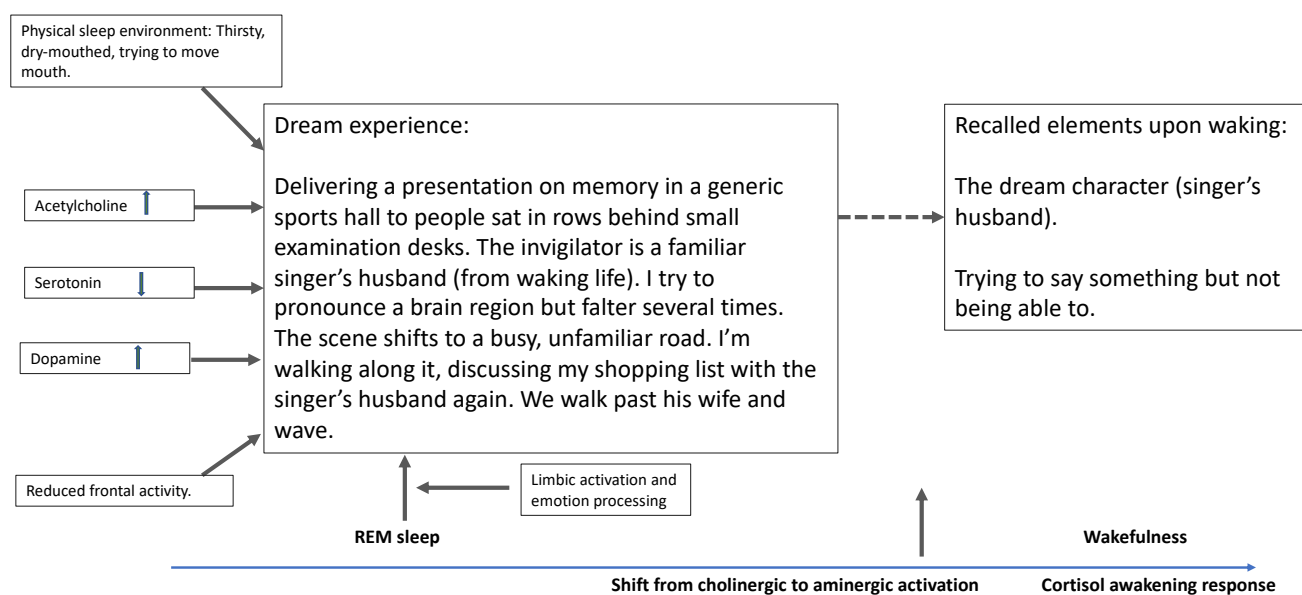


Figure 1: Author’s dream experience as outlined in (10), accounted for by neurobiological features of REM sleep, and highlighting how recall processes are affected by the cholinergic-to-aminergic shift upon waking.

The recalled elements comprise not only dream content, but also records of comprehensibility (i.e. a dreamers’ attempt to rationalize, or make sense of, the dream content), which often accompany a dream report. Recalled elements may also be details, actions, or feelings, associated with a dream.

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