Interfacing With Dreams

Novel Technologies and Protocols for Targeted Dream Incubation

by

Adam Jedidiah Haar Horowitz

Submitted to the Program in Media Arts and Sciences,
School of Architecture and Planning
on August 19, 2022, in partial fulfillment of the
requirements for the degree of Doctor of Philosophy in
Media Arts and Sciences at the
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Abstract

Scientific research into relationships between sleep physiology and waking cognition has progressed dramatically in the past few decades, but research on the basic science, function, and health consequences of dream phenomenology has not. This dissertation describes research into novel devices and protocols for improving dreamer control of dreams: their content and related function. Set within historical and cultural contexts for the import of dreaming, this thesis seeks to reorient science and everyday health practices toward a renewed respect for the contributions of the dreaming mind to overall wellbeing and cognition.

This thesis research emphasizes the use of a scientifically reliable dream incubation protocol (Targeted Dream Incubation: TDI) to influence dream content across multiple sleep stages, as well as reviewing historical context of dream science and cultural practices. Along with a wonderful team, I have developed a wearable electronic system (Dormio) and associated protocol (TDI) that cause experimental subjects to dream specifically and reliably of a chosen theme, using stimuli presented in pre-sleep wake and N1 sleep in combination with serial awakenings. The experimental work of this thesis centers on four experiments utilizing TDI. Our first experiment demonstrates that TDI does, indeed, induce cue-related N1 dreaming and can be used to augment creativity across a range of tasks related to incubated dream themes. Still further analysis shows that our TDI protocol can be used to augment creative self-efficacy, the belief that one has the ability to produce creative outcomes. Our second experiment shows that TDI can be used to influence daydreams as well as night dreams, and enables controlled comparisons of these brainstates. This experiment employs and validates a non-contact version of TDI, in which dream incubation is effective simply via timed audio cues on a Dormio web interface without any wearable sleep staging device. Pushing beyond bench science to clinical practice, a third experiment in collaboration with PTSD-focused psychiatrists examines the capacity for TDI to influence subjects' levels of self-efficacy regarding nightmares and dreaming (the belief one can control one's dream content, a key predictor of successful nightmare therapies). We show TDI can significantly increase self-efficacy, reducing feelings of helplessness and nightmare related complaints. Finally, a fourth pilot experiment extends our dream incubation protocols into the REM state, opening up avenues for influencing novel mnemonic and affective REM dream-related functions.

The results demonstrate the potential bench science and clinical relevance of our suite of dream incubation protocols and technologies. We identify new opportunities for interfacing with human cycles of memory, mind-wandering, emotional adaptation and creative cognition across the full 24 hour spectrum of thought. Our dream incubation system has spawned a series of experiments, both scientific and artistic, and been an impetus for the first conference and first collection of scientific papers on the new field of Dream Engineering. Beyond describing the creation and validation of dream incubation tools, this thesis explores applications and implications of incubating dreams, maps out methods of community building that could bring pluralistic perspectives into dream research, and extends our published writings on the ethics of this research in order to outline an appropriate future for this emerging field.

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Preface

"Protect yourself wanderer
with the road that is walking too"
Rilke, *The Duino Elegies & The Sonnets to Orpheus: A Dual Language Edition* (1923)

I've woken up to write in the dark because I love to think my thoughts in this drowsiness. Why should there be a sort of thought I love to think, tied to the time of day; why can't I think them anytime? Why should my sleepy awakening be a time where worries seem to move more slowly and my thoughts feel effortlessly associative? The brain sciences call this slow awakening state *sleep inertia*; The transitional state between sleep and wake, marked by reduced vigilance, and a desire to return to sleep. Cerebral blood flow velocity upon awakening remains lower than pre-sleep levels for up to half an hour.[1] Slow blood, slow brain.

Sleep inertia has been historically understood as a period of passing cognitive impairment.[2] Yet recent research suggests it is much more interesting than impaired thinking. It is a period of state carry-over during which waking cognition is changed depending on the functioning of the brain during the prior sleep period. Periods of sleep inertia are marked by experiences of synesthesia even in non-synesthetes, as the cross-modal perceptual qualities of dreams carry over into the wake state.[3] Increased time spent in drowsiness is correlated with increased performance on batteries of creativity tests, suggesting sleepiness has advantages over alert wakefulness.[4] Moreover, not all drowsiness is equivalent; Awakenings from REM provide a significant advantage in tests of flexible thinking compared with awakenings from non-REM sleep.[5] What may appear to be an impaired brain may instead be a brain with altered patterns which are in fact of use, and not so simple as we supposed.

As readers and researchers interested in sleep and cognition, it is easy to confuse difference and deficiency. Cognition affected by sleep or sleepiness, on the spectrum from drowsiness to dreams, can at first seem clearly impaired when compared to wake. This is the perspective of the Deficiency View of dreaming,[6] that stresses what the dream state lacks in contrast to the waking state.[7] This viewpoint treats dream cognition as unconscious, deluded, confabulatory, and irrational and draws stark lines between the sleeping and waking minds. This deficiency viewpoint stresses the four distinct stages of sleep (while identifying only one stage of wake) and discusses each in contrast to wake regarding loss of volition, loss of consciousness, and loss of rationality. This viewpoint goes so far as to dismiss dreams as epiphenomenal spandrels, without sense or order or function.[8,9] Just last year a leading sleep scientist assessed the possibility of studying dreams, saying "all we have are the stories people tell when they wake up" and admits "that deficiency has left an entire state of consciousness largely unexplored."[10] We pay so very little attention to these stories people tell, but what could matter more?

As you read this thesis, I believe the non-deficiency view of dreams will serve you better.[11] In this view the dream state is another kind of thinking, a mind-state enabled by a brain-state that is continuous with various waking mind and brain-states. We cannot claim with confidence that we are less conscious in dreams than in wake, only differently conscious, and it is unjustified to assume that even periods of unconsciousness lack ongoing intelligent processing.[12] Dreaming is not entirely without cognitive control, while waking mentation is not entirely under the direction of explicit control. Dream reports are not untrustworthy, but rather can be more revealing than reports of waking thought.[13] Dreams are not immaterial epiphenomena, but rather rooted in the concrete workings of the brain and the body, continuously constructed by the sleeper *and* the sleep environment.[14] Dreams are not random or impenetrable to influence, but clearly constructed by pre-sleep experience and emotion.[15] Waking cognition itself has physiological and phenomenological features of dreams, especially in periods of inattention and daydreaming. [16] To ignore this complexity and categorical blurring does a disservice to our understanding of ourselves and our science. To design sleep and dream experiments well we must understand that the mind exists on a 24-hour spectrum, and that differences from wakefulness are not markers of deficiency but differences that may hold great value.

Moving beyond the Deficiency View requires providing tools for capacity building around dream experimentation, in addition to instilling the viewpoint that dreams are *worth* studying. This thesis is centered around technologies (the Dormio device) and techniques (Targeted Dream Incubation) that enable dream science, yet to understand how they can best be put to use one must understand the path that has led us to a culture of science which too often dismisses dreams as silly, simple and unworthy of study. This path begins with the graphical method of charting physiology objectively, when the origins of brain imaging were intimately intertwined with dream science. Yet in the name of objectivity this science swings the pendulum hard away from the mind towards a colder and more precise biological psychiatry of the behavioral brain. As brain science is grappling with how to engage subjective experiential data, vacillating between behaviorism and cognitivism, dreams become largely the purview of psychoanalysis. Psychoanalysis is at first ascendant and widespread in psychiatric practice, and then famously dismissed as pseudoscience; Dreams become equated with the unscientific, and the field of brain and behavioral sciences loses interest in the study of dreams.

It's necessary to see these past turns because we are now finally swinging again, with a humbled biological psychiatry, back to the embrace of subjectivity in the brain sciences. Yet even as behaviorism fades, and the field admits ignoring mental experience cripples the study of the brain in wake, the subjective experience of sleep remains largely ignored. This can be changed with a shift in mindset that separates the study of dreams from pseudoscience, and with a toolkit that enables investigation of dreams using the scientific method. The question of how and why we dream is open to investigation at a scale and a precision previously unimaginable if we engage contemporary neuroscience tools and insist on the value of understanding experience in sleep. Technology of dream guidance and dream capture has a crucial role to play in how we will reconceptualize our most personal imaginaries– as does the reminder that scale and precision available to us now may still be a small part of truly understanding something as context dependent and dynamic as a dream. My hope is that changes in our understanding of dreams ripple out to alter notions of the boundaries of the personal and the imaginary, making each more interpersonal, porous, and real. My belief is that tools which enable dream science can have wide ranging impacts on clinical treatment, educational practice and self-understanding.

Introduction

This thesis centers on a collection of proposed steps forward in the scientific study of dreams; One novel technique (Targeted Dream Incubation, TDI), one novel wearable electronic device (the Dormio), and four experiments which demonstrate the relevance of dream incubation techniques to the study of creativity (Experiment 1), daydreaming (Experiment 2), self-concept, sense of agency and nightmare treatment (Experiment 3), and REM-dependent processing (Experiment 4). Taken together, these experiments provide tools for us to give renewed attention to thinking on a full 24-hour spectrum.

Dreaming is, after all, simply thinking while asleep; dream research is consciousness research extended into sleep. Dreams have been alternately pedestalized (in religious rites and psychoanalysis) and marginalized (by rationalists like Hobbes and biological psychiatrists like Hobson), but dream research must hold an intermediate perspective. Dreaming is indeed a form of emergent awareness, the narrativization of memory, embodied metaphor – all subjects which astonish us because they *are* us. Yet if we look at parallel studies on waking experience, we see that it is possible to both be humble about what we can know and pursue deep scientific inquiry. In researching waking mentation we can, for instance, simultaneously acknowledge consciousness is impossibly complex *and* test the hypothesis of conscious rehearsal-improving memory consolidation.

We do have to take special care while investigating waking or sleeping consciousness; While writing about the science of dreams we are writing about a subject which is core to many people's sense of self, practice of politics and personal growth. Consider, for instance, the common phenomenon of bereavement dreams wherein lost loved ones visit the dying at the hospice bed; This is perhaps at once a quirk of our biological memory systems and much more. The practice of dream science does not need to be methodologically and ontologically reductionist, explaining away such a thing as simply mnemonic function or reverberating neurons. And the products of dream science must not be elitist and arcane, or we risk rendering readers' self-reflection more opaque. A successful dream science should propose an explanation *and* respect an experience; *here is a link we see between dreaming and memory, here's how you can try it at home and see for yourself, testing how our thinking lines up with yours.* I want this thesis to propose new facts humbly and always interrogate the ethics of dream-science, so that people retain agency over their dreams even after scientists present claims about them. To keep humility front of mind for scientists, and to center agency for non-scientists, new dream science data must be presented in history and context with the admission of its limited lens. As such, this thesis includes historical chapters as well as novel tools and experimental findings.

In **Part 1** we outline necessary historical and cultural context for TDI. In **Chapter 1,** this thesis begins with an abridged history of sleep and dream incubation, including practice in the laboratory and spiritual frameworks. We then move on to outline states of mind which parallel, but do not mirror, the incubated dream: i.e. the daydream, the lucid dream, psychedelia and psychosis. The link between dreams and psychosis brings us to psychoanalysis, the most familiar touchstone readers are likely to have with the study of dreams. Psychoanalysis, whose ascendance in psychiatry was matched only by its fall from grace as a pseudoscience, brings us to questions of scientific legitimacy.

In **Chapter 2** we take up these questions of what constitutes legitimate data and ask whether we can trust subjective data today, and can we really put it to use? What, we ask, are dreams really useful *for* anyways? This thesis then proposes useful links between what we dream about and our daytime memory, learning, emotion and creativity that suggest dream incubation could improve performance. Yet *use* is not restricted to cognitive augmentation; dreams are also useful tools for gaining personal insight, for imagining freedom in conditions of political oppression, for negotiating and receiving powerful symbols in indigenous communities. With these uses in mind we move on to describe opportunities for more TDI today, in this world rife with novel sensors and human-computer-interaction frameworks. We deep dive into one such TDI-enabling sensor, the Dormio, which has been a key tool in the development of TDI.

In **Part 2, Chapters 3-6** describe Experiments 1-4 and their respective results. We test dream incubation across multiple stages of sleep, with multiple technological interfaces. Each experiment is an appeal to pay attention again to dreams. **Experiment 1** asks that you pay attention to unearth creative cognition that may evade you in wakefulness; There has been speculation on links between dreaming and creativity for ages, but no controlled experiment has yet demonstrated concrete creative gains tied to incubation of specific dreams. Experiment 1 closes this gap, demonstrating that TDI in NREM1 sleep (N1) benefits waking creativity. **Experiment 2** asks that you look deeply at daydreams; Many have speculated on shared properties of daydreams and night dreams, and while this comparison has been an important test case for theories of perception, hallucination, and imagination, no study has investigated their relationship in an experiment which incubates the *content* of dreams and daydreams and can thus compare specifically their *form*. Experiment 2 demonstrates the feasibility of this kind of controlled comparison, establishes key daydream/dream overlaps and divides, and insists any reader curious about the night must pay attention also to the wanderings of the daytime mind. **Experiment 3** asks that we attend to nightmares; We know they are significant predictors of depression, anxiety symptoms and suicide attempts but fail to prioritize them in clinical assessments and interventions. Experiment 3 offers dream incubation as a potential route to rapidly alter *attitude* towards disturbing dreams and nightmares, and in turn to reduce nightmare prevalence and complaints. **Experiment 4,** finally, asks whether TDI can be effective in altering dream content in REM as well as in N1 sleep, interrogates the creative benefits of REM incubation, and opens the door to altering mnemonic and affective REM functions. This question thus rounds out our experiments on the dreaming brain to include daydreams, sleep onset, nightmares and REM sleep. Many exciting possible uses of TDI emerge from these investigations.

In **Part 3** we describe the ongoing process of creating ethical and communal context for responsible use of TDI and related dream altering technologies. **Chapter 7** describes the community building work we have done to put our novel techniques and experimental findings to use across groups of engineers, academics, citizen scientists and artists. Yet we must acknowledge that a community is an unpredictable organism, and this brings us to an ethical dilemma: a growing collective of advertising agents interested in using TDI for nighttime product placement. **Chapter 8** details what we can do and have done as a dream science community regarding manipulation of the dreaming mind, including education and gatherings, collective calls for policy change, open sourcing technology, and designing experiments with an ethical core. In **Chapter 9** this thesis ends with a collection of future questions which are raised by this work, and a vision for a contemporary dream science that is practical and pluralistic.

Part 1: History and Context of TDI

Chapter 1: Sleep and Dream Science History

"Dream data may hold the potential for initiating an epistemological paradigm shift in the Kuhnian sense of a scientific revolution. This claim is not made lightly…in order to accommodate the peculiarities of 'anomalous' cognitive operations and the apparently constructive views that dream data provide, the potential exists to force, if not a cardinal paradigm shift, then at least a significant ordinal shift in conceptualizing the operations of the mind in both the sleeping and waking state"
Robert Haskell, *Cognitive Psychology and Dream Research* (1986)[17]

Figure 1 Illustrations from Beppe Giacobbe's *Visionary Dictionary* [18]

Inscribing Dreams

The neuroscientific study of dreams began with listening to the mute and weighing the weightless. In an insane asylum in 1877 in Turin, Italy, pioneering neurologist Angelo Mosso looked directly at the exposed brain of 11-year old Giovanni Thron while the boy slept.[19] Giovanni had taken a terrible fall from a terrace at 18 months old and the ensuing brain damage was so severe that, even a decade later, his days were plagued by epilectic fits, and he could only repeat the phrase "I want to go to school". While

Giovanni's mind was apparently inaccessible, his brain was close at hand; He had a large opening remaining in his skull above his right eye from the fall, and in this gap a pulsating cerebrum could be clearly seen under thin skin. On this pulsation Mosso placed a custom molding of gutta percha,[20] a rubber-like elastomer extracted from the leaves of the Malaysian gutta tree, crushed under granite boulders.[1]

In the center of the gutta percha molding sat a glass tube, and the delicate force of Giovanni's pulsating brain pushed air along it. This pressure change was transferred to a recording arm, which terminated in a single human hair. This hair, moved by air pressure changes transferred along the tube, in turn inscribed the waves of brain pulsations on a winding roll of parchment covered lightly in candle soot. Mosso was convinced that thoughts had physical weight, proxied by the weight of blood moving round the skull. And of course the weight of a thought was slight, and as such he designed a subtle mechanism made of soot and single hairs. Such a subtle machine required stillness, and so Mosso waited until young Giovanni slept before he set his parchment winding and let the boy's brain draw itself. Here is Mosso:

> *"It was one of the most interesting sights to observe in the stillness of night, by the light of a little lamp, what was going on in his brain, when there was no external cause to disturb this mysterious life of sleep…then came stronger blood-waves which flooded the convolutions, raising the height of the pulsations, which were automatically marked by the apparatus applied to the brain. We scarcely dared breathe. The one who was observing the instruments communicated with the other, who was watching over the patient, by pressing his hand. Looks full of interrogation and wonder would meet, and exclamations had to be forcibly repressed…Did the face of his mother and the recollections of his early childhood grow bright in his memory, lighting up the darkness of his intelligence and making his brain pulsate with excitement? Or was it perhaps only a morbid phenomena, like the jerky movements of a broken wheel, or the index of a machine out of order, swinging idly to and fro? Or was it an unconscious agitation of matter, like the ebb and flow of an unknown and solitary sea?"*
> Angelo Mosso, *Fear* (1896)[21]

Was this the first physiological evidence of a dream, consciousness extracted and etched? A dream held in the hand, observed in real time wave by wave, a map of another mind? Or simply the movement of brain material, unrelated to mental experience? And how would Mosso ever know the difference?

It is telling that Mosso's experiments were done on an essentially mute boy. They were the product of a scientific ethos which sought to move the study of the self beyond the need for language and self-report, beyond the mediation of subjectivity, to direct mechanized mapping. Étienne-Jules Marey, Mosso's colleague and the inventor of the graphical method used for displaying Giovanni's data, wrote, "let us reserve the insinuations of eloquence and the flowers of language for other needs; let us trace the curves of phenomena that we want to know and compare them." [22] Mosso called the waveforms produced by Giovanni 'autographs', a brain armed directly with a pen tracing its own immediate self-portrait.[21] The aims of Mosso and Marey are familiar to anyone in the brain sciences today: objectivity, quantification and generalizability. This work indeed marks a foundational moment in the field of neuroscience. To this day we image the brain with magnetic resonance imaging by mapping the movement of blood around a subject's brain. And still today it is unclear what truly mapping a dream – as opposed to simply mapping brain physiology in sleep – might look like.

Scientific exploration of a mental experience is especially difficult because the brain is dynamic and neuroplastic; the mind moves along a constantly changing path. [23] In the neurosciences this is called representational drift, the notion that neuronal representations of the same environments and repeated

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[1]Just 10 years prior, gutta percha latex had laid the foundation for intercontinental communication as the only viable natural insulation for submarine transatlantic telegraph cables. Submerged messages quivering across impossibly distant continents of mind and matter.

tasks reconfigure or 'drift' over time.[24] One cannot step into the same river twice[2] – but neither can we see, hear or imagine the same river twice. Amongst all this neural movement, Mosso hoped to learn by perturbing a dynamic system with a known element. Today the brain sciences call this 'combined neuroimaging and perturbation', often using electrical pulse perturbations or bursts of sound in limited frequency bands as static markers in a sea of brainwaves. 150 years ago it took the form of Mosso softly calling out to a sleeping boy, "Giovanni," and tickling his ear softly with a feather, all while looking for concomitant increases in blood flow.[25]

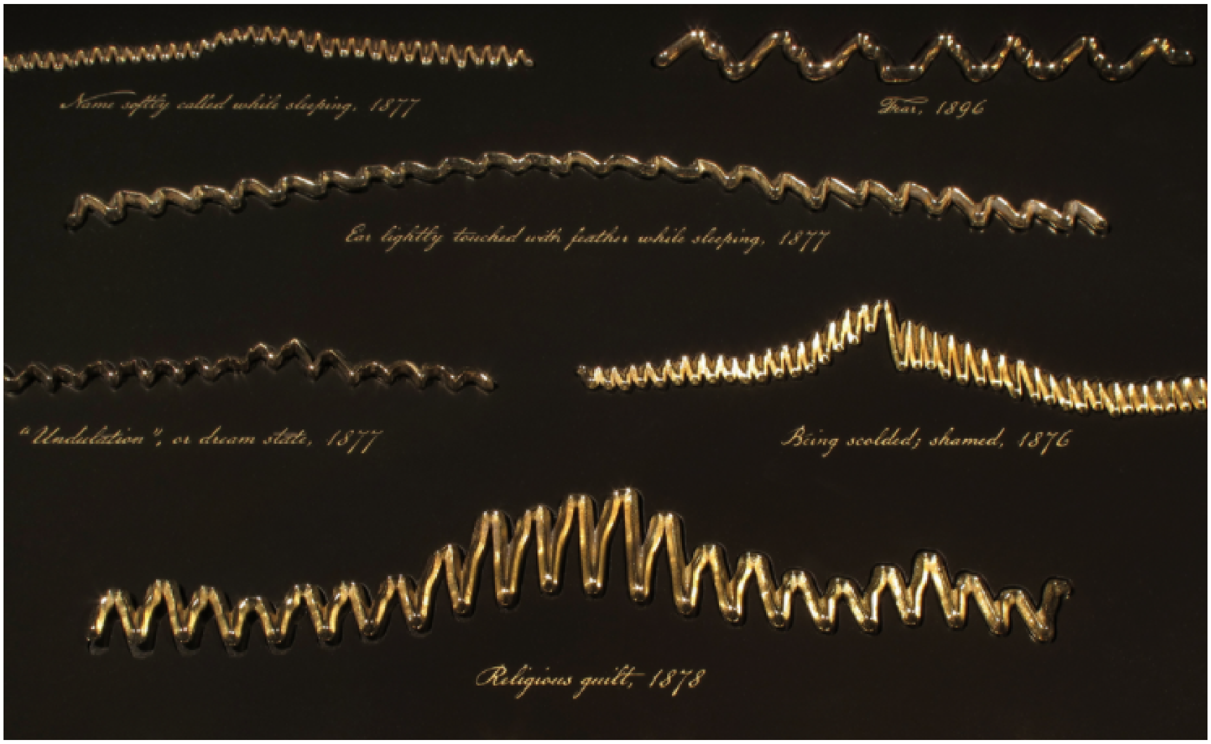

Figure 2 Cardiac cycles recorded by Angelo Mosso in the late 19th century. See perturbations caused by, for instance, light tickling with a feather while sleeping (center). *Unknown and Solitary Seas (Dreams and Emotions of the 19th Century),* Dario Robleto, 2018

In this origin story we have so much that is magnetic and challenging about researching dreams in the context of brain and behavioral science: the gap between measurement and understanding, between material and experience, scientist and subject, watcher and watched, conscious and unconscious. The delicacy with which we must whisper and weigh, balance our mechanisms and interactions to catch quiet thought. The uncanny gap between an inert body and simmering, shifting brain. The sudden burst in a polysomnography and the excited silence that follows. If there was no external cause, what internal cause is there but a dream, have I just captured it, and in these lines is it there if I squint just so? I have felt this very feeling a century and a half after Mosso.

> *As with poetry in a foreign language, you will need to use a dictionary, but the poetry is far more than what is in the dictionary.*
> George Lakoff, *How Metaphor Structures Dreams* (2021) [26]

As a scientist observing a sleeping subject, the moment the physiological mark of some 'internal cause' arrives there is a distinct feeling of having lost control to the incoming dream. An awake person is practiced in the act of being a scientific subject (please sit still, eyes open, solve a math problem) but a

[2] Heraclitus quoted in Plato, Cratylus, 360 B.C.E

sleeper is subject to no authority in a dream, not even their own. This reduction in cognitive control is what makes dreaming such a unique experience, enabling altered associative, mnemonic, experiential and introspective opportunities. And so we come upon our major methodological issues: to study dreams in a controlled manner we must control dreams (tickle the ear of Giovanni) and eliminate confounding variables, but to control a dream completely would destroy the dream itself.[27] And even if we did control the dream, how would we confirm that when it is a world away, and all we have is the stories people tell us upon awakening? Leaders of the sleep science field today are still plagued by these same methodological challenges centuries after Mosso: "The study of dreams is a formidable task, because dream consciousness is only accessible via report rather than direct observation and because it is difficult to manipulate dream content experimentally" (Dr. Yuval Nir, 2010).[28]

> *"the gap between the dream as biology and the dream as meaningful, intentional experience has yet to be closed, and it represents a continuing area of debate amongst academic psychologists"*
> Lee Irwin, *the Dream Seekers* (1994) [29]

Incubating Dreams

> *"We dream about specific experiences we've had, our own ongoing concerns and anxieties, real people and places that we actually know. We've been the god in the machine all along."*
> Brooke Jarvia, NYT, *Did COVID Change How We Dream* (2021) [30]

This thesis proposes a variant of an ancient practice, dream incubation, as a way forward for dream research. This section describes dream incubation in spiritual practice, while the following section details scientific practice of incubation. Purposeful incubation of specific dream content has been a widespread practice for millennia, typically in a spiritual context. If the sciences can learn from spiritual practice to initiate specific dreams, we can in turn ask controlled correlation, cause and effect questions about the influence of dream content on our waking state. Incubation practices involve the setting of specific intentions, environments and stimuli to initiate specific dreams, building on the simple realization that dreaming is influenced by pre-sleep experience and by the sleep environment. As the "centerpiece of a complex of charged ritual elements practiced to the present day," dreams have been a conduit for epiphany, supernatural remedy, divination, revelation, or warning.[31] These experiences typically result from supplicants sleeping in a sacrosanct place in order to receive a divine dream. In the 6th century B.C.E. at the Oracles of Trophonius and Amphiaros in Greece, and at Egyptian dream temples such as the Thoth temple in Khimunu, hunger and sleep were used to increase the vividness of dreams and call deities into sleep. [32-33] At the shrine of Asklepios on the Peloponnese, the sick slept in the great abaton of Epidauros in the hopes that the compassionate god, in the form of a great snake, might come prescribe remedies, or they slept in the sanctuary at Kos, where in dreams he wiped away disease with his hand. Pre-sleep rituals meant to invite divine dreams ranged from the eating of figs mixed with ashes from the god's altar to naked marathons in freezing rain and abstinence from bathing for weeks.[31] One of the earliest direct references to a pre-sleep method for incubating divine dreams is inscribed on the Chester Beatty papyri, found in Upper Egypt and authored c.1350 BCE. It describes a method of invoking the wisdom of Bes, helper of women in childbirth and god of art, dance and music. It translates as follows: *"...Make a drawing of Besa on your left hand and enveloping your hand in a strip of black cloth that has been consecrated to Isis (and) lie down to sleep without speaking a word, even in answer to a question. Wind the remainder of the cloth around your neck… come in this very night."* [34]

Figure 3 Asclepius, bending forward and extending his arms as he offers therapy to a sleeper on a *klinai*. A votive relief of Classical date, from the Asklepieion in Piraeus (Piraeus Archaeological Museum)

> *"Dreaming has shaped the religious history of humankind, from the Upanishads of Hinduism to the Qur'an of Islam, from the conception dream of Buddha's mother to the sexually tempting nightmares of St. Augustine, from the Ojibwa vision quest to Australian Aboriginal journeys in the Dreamtime."*
> Kelly Bulkeley, *Dreaming in the World's Religions* (2008) [35]

While these rites are thousands of years old, and today these Mediterranean abatons are ruins, readers should not assume these practices are either unavailable or irrelevant in contemporary life. Incubation places are anywhere and everywhere that is god-haunted. Probably the oldest sacred place to sleep in the Mediterranean was the earth itself. In ancient Greek religion, the earth was a goddess, the home of the deposed Titans and the dead, and Earth was believed to engender powerful dreams. In Euripides' Hecuba, the heroine, the wife of King Priam, addresses the earth, "O potnia Chthon, melanon pterugon meter oneiron" (O Lady Earth, mother of black-winged dreams).[36] Homer's ancient priests of Dodona, the Sel'loi, "with feet unwashed," sleep without covers directly on the ground in order to maintain their prophetic power and likely to incubate prophetic dreams (Iliad 16.235).[37] The Roman kings Latinus and Numa "both lie on the ground to incubate, even though they, as royal personages, could surely command beds." [37] The Abrahamic patriarch Jacob lies directly upon the earth, with a stone as his pillow, to receive the revelatory dream known as Jacob's Ladder. When he awakens he exclaims of a simple stone, *"Ma Nora HaMakom HaZeh, ein zeh ki im beit elohim, v'zeh sha'ar hashamayim* [how awe-inducing, fear-causing, how humbling is this place. It is none other than the abode of G-d, and this, this is the gate of heaven]." [38] The humbling place is *both* the dream and the locale that engenders it, a mixture of psychological and physical – and contemporary Jewish tradition continues to privilege dreams and dream-laden spaces as gateways to G-d.[39] In *Prophetic Inspiration After the Prophets,* Abraham Heschel writes that after the last Jewish prophet Malachi passed away "although prophecy had ceased, communication continued through a *bat kol* [heavenly echo] …another heavenly source from which later generations were to draw supernal knowledge was the dream." [40] Heschel goes on to quote the ancient Iraqi Rabbi Rava, "the Holy One, blessed be He, said: Even though I do not communicate with them any more [in the clear light of day], I shall continue to speak to them in dreams." The bedtime *Shema* prayer, recited by religious Jews around the world nights and mornings, continues this tradition of dream incubation. This is one amongst so many dream incubation traditions which survive today – ranging from the practice of *Istikhara* dream incubation in Islam, to Native American incubation traditions of the Great Plains,[3] to sleeping in holy sites in Bah'ai faith.[41]

Figure 4 El sueño de Jacob, Lo Spagnoletto (1639)

These dream incubation rites all entail pre-sleep intentionality, sleeping in a holy locale, and allowing oneself to become a vessel for epiphany.[31] Dream incubation is inherently a practice which involves contradictory active (intentional) and passive (epiphany) forces. While there is some pre-sleep control in the setting of conditions for such transformation, there is never an ironclad understanding of what is to come when one enters the dream; that would, indeed, run counter to the practice of supplication. A dream incubation is a request, a targeted placement of a problem and the patient practice of waiting for a prophetic answer. And crucially, the supplicant can direct the dream without compromising the power of the epiphany or prophecy which comes: "The progression from spontaneous dream to sought dream is a reasonable development. If one accepts the prophetic value of dreams in general, then, whether the dreams occur spontaneously or as the result of consciously setting out to have a dream, one still has received a prophecy." [42]

> *"Thus the process of incubation…emerges neither as conjuring magic (whereby the dreamer is all powerful) nor as a kind of slavery to the night terrors sent by a celestial despot (whereby the visiting dreamed god is all powerful), but instead as a delicate relationship, as paradoxical and symbiotic as any other two-sided affair. For millennia, human beings have sought the gods by sleeping in special places. The gods have freely responded as they chose by sending dreams whose purposes range from beneficial healing to dire warning"*
> Kimberley Patton, *A Great and Strange Correction* (2004)

[3] A deep dive into dreaming in Native American contexts is beyond this thesis, but it will absolutely expand your sense of what a dream is and can do. For more information see *Walking the Sky: Visionary Traditions of The Great Plains* by Lee Irwin (1994).

Incubation: A Novel Scientific Method

> *"Our tomorrow is the child of our today. Through thought and deed, we exert a great deal of influence over this child, even though we can't control it absolutely. Best to think about it, though. Best to try to shape it into something good"*
> Octavia Butler, *A Few Rules for Predicting The Future* (2000)[43]

This section offers a short survey of 20th century scientific practices of dream incubation. For a deeper dive into specific contemporary methodologies see Chapter 2 for the *Methods: Techniques and Technologies* section. Much like spiritual dream incubation, scientific practices of dream incubation must accomplish a paradoxical, incomplete control of dreams: using attention and intention to guide the content of a dream in a specific direction without disturbing the nature of a dreaming brain state that inherently involves failures of cognitive control. Within this paradox lies the power of the incubation method for dream science, wherein one can control conditions without controlling outcomes.

The methods of dream incubation tested in labs today are surprisingly similar to some ancient techniques. Somatosensory stimulation at sleep onset (like the cloth wrapping for Besa or hunger at Khimunu) has been shown to have some dream incubation effects. Dement and Wolpert (1958) collected 15 REM sleep dreams from three subjects who were deprived of fluids for 24 hours prior to sleeping in the laboratory on five nights. They found five of the dreams contained thirst-related content, though these did not depict the dreamer as thirsty or in the act of drinking. A similar relationship was found combining pre-sleep thirst and presentation of audio containing liquid-related words in REM: Dreams about liquids increased, and curiously, those who had dreams of satisfying their thirst drank less upon awakening than did subjects who had dreams of being thirsty and unsatisfied.[32] Sigmund Freud found similarly that "if I eat anchovies or olives, or any other highly salted food in the evening, I develop thirst during the night which wakes me up. But my waking is preceded by a dream, and this always has the same content . . . namely, that I am drinking." [44] A spray of water on the skin, application of a pressure cuff to a specific limb, or even application of electrical pulses to cause muscle contractions in a sleeper have each been shown to affect dream features, increasing vividness or movement sensations in dreams.[32] But while there is clearly a relationship between somatosensory experience during sleep and concurrent dream experience, experimental dream research hasn't yet provided a satisfactory description of how these systematically create dream content or can be used for specific transformations in dream content.

> *"The dreamer lends himself entirely to the bodily facts of breathing and of desire and hence infuses them with a general and symbolic signification to the point of only seeing them appear in the dream in the form of an image…We need to understand how respiratory or sexual events, which have their place in the objective space, detach from that space in the dream and are established within a different theater."*
> Maurice Merleau-Ponty, *Phenomenology of Perception* (1945)

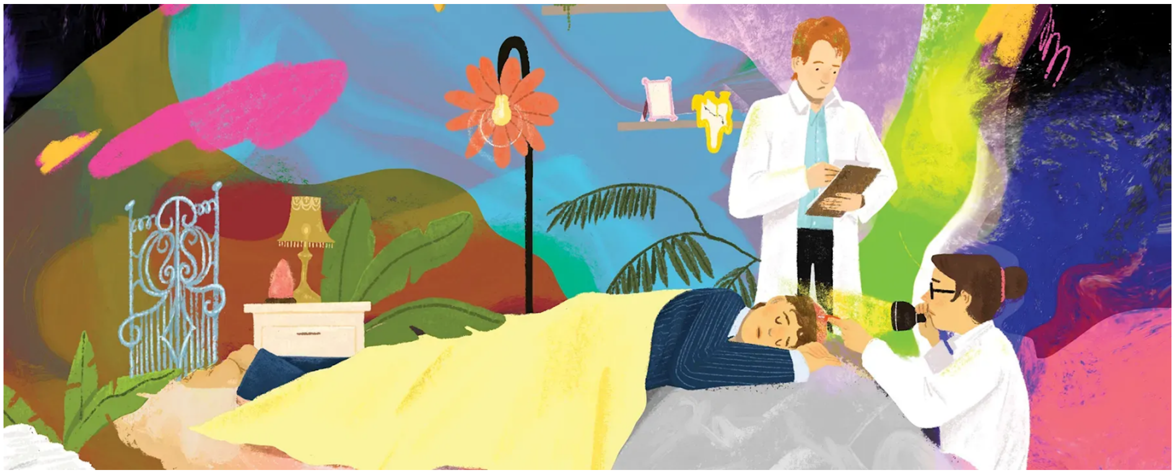

Figure 5 A figure from *The Scientist*, in an article covering our work on dreams. Note the position of the TDI subject mirrors that of the sleeper being healed at the Asklepion. [45]

To attempt incubation of content that is more specific than a sensation, empirical studies have used pre-sleep stimuli which might be meaningful to a sleeper, much like the drawing of Besa mentioned above. Pioneering researcher Alfred Maury was doing this work as far back as the 1840's, as self-experimentation: "*Scissors were whetted against a pair of tweezers. He heard bells ringing, then sounds of tumult which took him back to the days of the Revolution of 1848…Eau de Cologne was held to his nostrils. He found himself in Cairo, in the shop of Johann Maria Farina. This was followed by fantastic adventures which he was not able to recall.*" [46] Two centuries later, researchers tried to influence dreams with films presented before sleep but found little effect on dream content in subsequent REM reports (though pre sleep violent films did significantly alter the emotional tone of dreams).[47] Pre-sleep presentation of a stressful film and additional replay of that film's soundtrack in REM sleep slightly but significantly increases incorporation of film scenes into dreams. Static visual images presented before sleep are rarely incorporated into dreams as specific elements of dreams, though pictures presented do produce corresponding affective tone in morning dream reports. [48–50] An early experiment by Allan Rechtstaffen, a pioneering sleep scientist, even tried dream incubation while subjects slept with their eyes taped open and their pupils chemically dilated. Various objects were illuminated in front of subject's open eyes (including a red-covered book entitled *Human Behavior in the Concentration Camp* with a drawing of a man behind a barbed wire fence on the cover; a white handkerchief which was waved; and an aluminum coffee pot) but there was essentially no evidence for a correspondence between the reported dream imagery and the specific stimulus objects.[51]

While early attempts to influence dreams in the 1960's and 70s' were near uniform in their failure to detect significant direct incorporation of presleep experimental stimuli on dream content, they did *accidentally* incubate dreams. In an analysis of 813 REM reports collected across several studies, Dement et al. reported that 22% of reports unambiguously incorporated elements of the laboratory situation (i.e., the experimenter, the sleep laboratory itself, electrodes). Apparently the most salient aspects of our presleep experience are preferentially incorporated into dreaming, yet the pre-sleep stimuli were not more meaningful to subjects than the novel experience of sleeping in a laboratory while covered in sticky, beeping electrodes.[52]

To try and create this salience purposefully, other dream incubation strategies rely on intention setting of the participants to incubate dream content. Pre-sleep rehearsal of current concerns, as opposed to exposure to stimuli, has some efficacy in incubating dreams. Barrett (1993) asked college students to incubate a specific, personally relevant problem of their choosing. Using the simple incubation method of thinking about the problem for 15 minutes before sleep, participants rated 49% of their dreams as relevant and 34% of them as containing a solution while judges' ratings were 51% and 25%. Saredi et al. (1997) also report that for a small sample of participants in a sleep laboratory study, thinking of a question related to a current problem prior to sleep increased the likelihood that dream content reflected the problem, but that this effect was weakened when dream length was controlled for. Studies like these are informative, but they fail to separate the effects of waking thought from dream processes: Since participants are allowed to choose personally relevant problems, which they have likely been thinking about for a time period before the experiment and which vary immensely in task type, these are not controlled tests on dream incubation techniques or on dream content.

Stimulation type/Sleep stage and reference	Dream content	Incorporation quality
Electric stimulation to the wrist. /REM sleep. (Koulack, 1969)	"The thought was I felt a pinch in my hand. Electrical impulse."	Direct incorporation of the sensation
Somatosensory stimulation. Inflated blood pressure cuff on ankle. /Stage 1 NREM sleep. (Solomonova,2017)	"I felt the pressure from the cuff, and all of a sudden I thought about my cat jumping, because my cat sleeps all the time on my legs."	A direct incorporation + an associative image of the cat
Somatosensory stimulation. Inflated blood pressure cuff on ankle. /REM sleep. (Solomonova. 2017)	"Liza was there to wake me up. She turned on the lights and asked me about my dreams. I was answering her. I could feel the pressure pump on my leg. She asked me what does it feel like, I said it feels like a hug. She said: "Doesn't it feel like someone pulling on your leg?"	A direct incorporation of the pressure cuff + a false awakening and incorporation of laboratory personnel and of a dream interview
Somatosensory stimulation. Inflated blood pressure cuff on ankle. /REM sleep. (Solomonova, 2017)	"At first I was flying… there were mountain tops everywhere, there was snow (…) then I found myself on a boat, it was stormy. I was holding on to a prow when the boat was tilting, I could touch the water (…). Suddenly, a dolphin took me and I was swimming on its back."	An indirect incorporation: intensified movement (boat, tilting, being carried away)
Somatosensory stimulation. Inflated blood pressure cuff on a leg. / REM sleep. (Nielsen et al., 1993)	"…the farmer (…) is trying to put a saddle on the horse. (…) At one point the horse was rolling right across his body. I heard this 'unnffl' sound as if it hurt him when it rolled across his legs. (…) He got up and turned his back on the horse. The horse stood up too. He put the horse's right hind foot in this suitcase-like thing with a metal box so he wouldn't stray. (…) I looked … and saw it was not hurting the horse, just trapping his foot. The horse tried to pull his foot out and follow the farmer, but he couldn't…"	Projection of the feeling of pressure on the leg onto two other dream characters: the farmer and the horse
Somatosensory stimulation. Tensors on foot. / sleep stage unknown. (Cubberley, 1923)	"People are dancing on a verandah, which also resembles a lighted stage. I am watching from B little way off, as if I were a spectator in a theatre."	Feeling of something on the foot transformed into dancing imagery
Auditory stimulation. Name "Richard". /REM sleep. (Berger. 1963)	"Had been to a sale in at a big shot at the center of Edinburgh."	"Richard" – the name of the shop in Edinburgh
Dozing while sitting on a couch near an IKEA cash register, which abruptly sounds with a loud clatter. Auditory. /Stage 1 NREM sleep. (Nielsen, 2017)	"A bright, multi-colored clown/jester suddenly somersaults with a snapping, elastic motion. His black suit had patches of red, yellow, green, blue, and other colors."	A sound triggers a sudden awakening/ movement in the dream character

Figure 6 Examples of stimulation and accompanying dream experience. Adapted from Solomonova (2019) [53]

Why We Use The Term TDI

What can we name this paradoxical and symbiotic relationship with a dream that we target for incubation? It is the placement of a seed in the form of a stimulus, in soil that is the neurochemical soup of sleep. It is planting and waiting and watching. We will never know what a stimulus, perhaps the word “tree” played to a sleeping subject, will mean to a specific dreamer. We will not know what this tree will become on the canvas of this meaning, what memory it will stir, what emotions are tied to this memory, how these emotions will be rendered imagistic in this particular mind. The truth of it is that we are neither able to completely influence a dream nor able to comprehensively understand the extent of our influence. In a sense, no experiment in the brain sciences is truly in control of their experimental environment – when we ask waking subjects to focus on a task, let their minds wander, or recall an emotional memory we are always working with failures of attention, attenuated metacognition, and confabulatory recall.

> *“One of the things I learn with incubation is that I encounter a limit to how much I can influence my dreams. My unconscious has its own ideas...it's more about a negotiation between my dreaming self and my waking self rather than an attempt to bring my dreaming self under the control of my waking self."*
> Michael Clune, Dormio User, *Night Shifts*, Harper’s Magazine (2021)

We are not ‘engineering’ dreams in the sense of working with predictable mechanistic systems and mathematical solutions, but perhaps this is engineering in the sense of “the action of working artfully to bring something about” (Oxford Languages).[54] Maybe this is more of an *intercession*, a request, but this word is too intimately tied to prayer and will not survive in the sciences. We could call this work dream *initiation*, but this is a misnomer in the sense that we have initiated nothing – a dream begins during the day, in the web of memory that makes a life, certainly before we ever arrived with our sensors and stimuli.

The word *incubation* works well. The Latin etymology of *incubation* implies lying down, specifically lying down on eggs. The practice of incubation has historically been linked to a place, a *cubile*, the Latin roots of which suggest a bed, lair or nest. [31] There is a period of rest, a safe space for containing the delicate heat of transformation, and a hope that in time something new may hatch.[4] Yet the word has two edges; *incubare* refers to lying on eggs, but also forms the root of the *incubus,* a nightmare personified as a demon (male *incubus*, female *succubus*) who lies on the chest of a sleeper and creates bad dreams. We are reminded that this powerful practice can be used for many ends, and so we return always to the ethical implementation of experimental findings. Importantly, the word *incubation* also ties us to such a rich spiritual history of working with dreams, which must remain present as we try and understand dreams in our own narrow, contemporary, Western, analytical context, with our biases towards understanding as implicitly tied to quantification and technological control. The word *targeted* acknowledges a transition to the sciences, where specificity is key in experimenting with independent variables, even while *incubation* acknowledges the impossibility of the completely controlled experiment; *Targeted Dream Incubation.* Hopefully this terminology is the right choice for inspiring contemporary scientists to study dreams.

> “More than 50 years after the discovery of REM sleep launched the field of sleep research, the study of dreaming remains in its infancy”
> Erin Wamsley, *Dreaming and Offline Memory Consolidation* (2014)[55]

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[4] Today these etymological roots appear in the contemporary ‘cubicle’, sharing the *cubile* root, a characteristically small, enclosed, and perhaps unholy space for the birth of nothing new.

Sleep Staging and Associated Phenomenology

As we aim to put TDI to use in the sciences, our functional targets are likely to depend in part on sleep staging effectively. This is because changes in sleep stage neurophysiology, on average, correspond with changes in dream quality. Dream content often differs between the various sleep stages, as numerous laboratory studies have shown using polysomnography (PSG), in which sleep stages are classified according to patterns of electrical activity in the brain. [56]

Dreaming occurs initially in the form of brief hypnagogic imagery at sleep onset, in non-REM stage 1 sleep (NREM1 or N1). This transitional phase is characterized by a loss of EEG alpha activity and prominent theta activity (3–7 Hz).[57] Recent experiences and even experimental tasks are frequently incorporated into N1 imagery (e.g., Tetris – Stickgold, Malia, Maguire, Roddenberry, & O'Connor, 2000; alpine racer game: Wamsley, Tucker, Payne, Benavides, & Stickgold, 2010). N1 images are often described as surreal and have been associated with creativity and insight.[58] N1 has been divided into 9 distinct substages of sleep onset called Hori stages, which each have distinct physiological and phenomenological features.[59]

R&K stage	Hori stage	EEG composition	EEG appearance
W	1	Alpha wave train	
W	2	Alpha wave intermittent (>50%)	
S1	3	Alpha wave intermittent (<50%)	
S1	4	EEG flattening	
S1	5	Ripples of low-voltage theta waves	
S1	6	Vertex sharp wave solitary	
S1	7	Vertex sharp wave train/burst	
S1	8	Vertex sharp wave and incomplete spindle	
S2	9	At least one complete spindle	

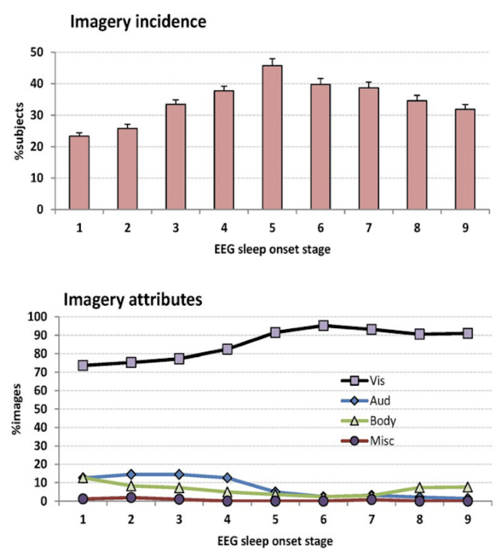

Figure 7 Relationships between Hori stage, EEG features and imagery experience.[60,61]

> *"In this scheme, hypnagogia would constitute the exemplification of Oneirosis. It has all the advantages of REM dreaming and none of its disadvantages. It may render us the same service as REM dreams do but without the necessity always to surrender consciousness as completely as we do for the emergence of REM dreams. As Marc (1840) once put it, it enables us "to dream without sleeping" (quoted by Baillarger 1846). According to Archer (1935), it constitutes 'waking dreams' or 'dream-activity proceeding under the observation of the waking mind' "*
> Andreas Mavromatis, *Hypnagogia* (1989)

NREM stage 2 (N2), which follows N1 sleep, is characterized by K-complexes (high voltage slow waves) which are frequently coupled with sleep spindles (bursts of 12–15 Hz oscillations).[62] Dream reports collected from N2 are longer than those from N1, and often contain reference to thought.[63] Functionally, N2 sleep and particularly sleep spindles have been linked to declarative memory consolidation, and sleep spindle density correlates with dream recall. [64,65]

NREM stage 3 (N3), also known as slow wave sleep, is characterized by prominent delta waves (0.5–4 Hz).[62] N3 is often termed deep sleep and is thought to be most important for homeostatic processes; dream recall frequency is lowest from N3, with dream reports that are short and phenomenally minimal.[66,67] Recent findings suggest that delta activity over parietal areas is a predictor of dreamless sleep; whereas fast-wave activity in the same areas, most typical of REM sleep, is a predictor of dream recall.[68]

Finally, REM sleep is characterized by higher frequency activity similar to N1 or wakefulness, with particularly increased theta oscillations.[62] REM sleep is functionally involved in emotion regulation although nightmares, intense negative dreams, can interfere with this function and cause distress in waking life.[69,70] Positive dreams in REM may have the inverse effect, associated with improved sleep quality and subsequent mood. Finally, REM sleep is linked to increased insight and creativity, with imagery described as hyper associative and metaphorical, likened to a form of creative expression in wake.[5]

Gold standard sleep staging is understood as a precursor to doing serious sleep studies. But there are some caveats which must be addressed; a recent meta-analysis of 11 sleep studies showed the Cohen's kappa rating of interrater reliability for manual sleep scoring by sleep stage were 0.70, 0.24, 0.57, 0.57, and 0.69 for the W, N1, N2, N3, and R stages, respectively.[71] Sleep staging via EEG is cumbersome, expensive, and in many cases poorly validated. Further, sleep is typically considered a global phenomenon that affects the whole brain uniformly and simultaneously and sleep and wakefulness are usually treated as two mutually exclusive behavioral states, with hardly any gray zone in between. This 'all-or-none view' of sleep has dominated sleep research for a long time, and is neatly reflected in the current classification of sleep stages, in which an unambiguous label of either sleep or wakefulness is attributed to each 30-s page of sleep recordings seen on PSG. However, it is now well established that sleep occurs and is regulated locally, and hallmark signals of multiple sleep stages can coexist in the same brain simultaneously.[68] Recent studies have shown that local aspects of sleep, such as low-frequency oscillations typical of NREM sleep, can also occur during extended periods of wakefulness and even during REM sleep. The occurrence of these local low-frequency oscillations may be tied to dream or daydream experiences, and may account for cognitive impairment and brain-region specific performance errors during sleep deprivation in both humans and animals.[68] Further, the choice to base sleep stages on brain signals, as opposed to changes in heart rate or body temperature (which also change in patterned ways during sleep) is largely arbitrary. If we had chosen to base sleep scoring off of a different signal, we would have different stages and these would likely have distinct phenomenologies on average. Lastly, some sleep scientists, like Mark Solms, claim "the only reliable difference between REM dream reports, sleep-onset reports, and certain other classes of non-REM dream reports is that the REM reports are longer." [72]

> *"Measuring sleep quality is a little more of an art than a science."*
> The Sleep Foundation[73]
>
> *"Evaluating the actual type of insomnia remains much more art than science for the majority of patients and providers."*
> Scott R. Taylor, *Sleep Wake Disorders in Late Life* (2018)

No matter the qualms we might have with sleep staging, it grounds an experiment in comparable literature. An experiment which tracks N3 sleep, delivers a stimulus, and in turn sees some demonstrable change in cognition will be compared to other studies on N3 sleep, and reviewed by experts in N3 sleep. To inspire work in dream science, one must ground the work in the legitimacy of sleep science. To do work in sleep science, one must stage sleep. Understanding relationships between physiology and phenomenology then lets us compare dreams to their neurological neighbors and experiential parallels, i.e. if a daydream and a night dream share the EEG slow wave features which stereotypically describe N3 sleep we may try and understand awake daydreaming as continuous with a kind of night dream.

Parallels: Mind Wandering, Lucid Dreaming, Psychedelia, Psychoanalysis

> *"Great philosophers have warned that we routinely mistake the limits of our personal perception for the limits of the universe. Nowhere is this rudimentary error more evident than in our posture toward REM/dreaming. We typically approach and investigate the dream from a biased, wake-centric perspective. Much like the ethnocentrism of early anthropologists, we presume that waking consciousness is the norm and view dreaming as a secondary, subservient state of consciousness. Wake centrism casts our dream experiences as weird and meaningless and discourages us from getting near, let alone going through, the looking glass"*
> Rubin Naiman, *Dreamless: the Silent Epidemic of Dream Loss* (2017) [74]

Now that we have a broad sense of sleep stages and their associated experiences, we can begin to compare and contrast dreaming with its psychological and physiological parallels. But as readers and researchers in the Dream Sciences, we are always already in a bit of a bind. As we consider the many ways to understand dreaming consciousness, by definition we are awake, exercising cognitive control and metacognitively aware of our alertness and cognitive capacity. It is difficult from this vantage point to escape the Deficiency View of dreaming.[6] This view stresses what the dream state lacks in contrast to the waking state, even characterizing dreams as superfluous spandrels: "In Hobson's theory…dreaming *as an experience* with vivid phenomenal content is seen as a kind of random epiphenomenon that merely *reflects* some totally different events going on at other levels of organization where such events may serve useful neurobiological or mnemonic functions".[7] This viewpoint treats sleep as simple, unconscious, deluded, confabulatory, irrational and draws stark lines between the sleeping and waking minds.

> *"It is striking that 100 years after Freud (1900), there is absolutely no agreement as to the nature of, function of, or brain mechanism underlying dreaming. There is even disagreement as to what constitutes a legitimate approach to the question. In this environment, it is perhaps not surprising that various researchers have staked out strikingly different positions that are often presented as incompatible with one another. An alternative interpretation, one that I will argue here, is that we are discovering, but in many cases ignoring, the rich complexity of sleep and dreaming"*
> Robert Stickgold, *Inclusive versus exclusive approaches to sleep and dream research* (2000) [75]

This thesis will argue in favor of the non-deficiency view of dreams.[11] In this view the dream state is another kind of thinking, a mind-state enabled by a brain-state that is continuous with various waking mind and brain-states. We cannot claim with confidence that we are less conscious in dreams than in wake, only differently conscious, and it is unjustified to assume that even periods of unconsciousness lack ongoing intelligent processing. The sleeping brain is organized, processing information, serving myriad mnemonic and affective functions, and engaging in varying levels of awareness and rationality. Dreaming is not entirely without cognitive control, while waking mentation is not entirely under the direction of explicit attentional control. The stages of sleep overlap physiologically, and can coexist within one sleeping brain in 'hybrid states' like Lucid Dreaming that mix features of wakefulness and sleep.[76] Waking itself has physiological features of sleep, especially in periods of inattention, mind-wandering, and daydreaming. The waking brain can exhibit phenomenal features of dreams in periods of mind-wandering, psychosis or psychedelia. [16] To ignore this complexity and categorical blurring does a disservice to ourselves and our science. To design solid experiments we must articulate distinctions between these parallel cognitive categories (dreams, mind-wandering, psychedelia) while understanding these are differences of degree and not of kind, that the mind exists on a 24-hour spectrum, and that differences from wakefulness are not markers of deficiency. The following three sections will articulate these differences of degree.

Mind Wandering, Daydreaming

> *"Rodolfo Llinás and his colleagues at New York University, comparing the electrophysiological properties of the brain in waking and dreaming, postulate a single fundamental mechanism for both — a ceaseless inner talking between cerebral cortex and thalamus, a ceaseless interplay of image and feeling, irrespective of whether there is sensory input or not. When there is sensory input, this interplay integrates it to generate waking consciousness, but in the absence of sensory input it continues to generate brain states we call fantasy, hallucination, or dreams. Thus waking consciousness is dreaming — but dreaming constrained by external reality."*
> Oliver Sacks, *An Anthropologist on Mars* (1995)

Mind-wandering and mind-blanking – the experiences which accompany lapses of attention, the former with recalled phenomenological content and the latter without– are both described in the cognitive sciences under the blanket term *spontaneous thought*, and described colloquially as daydreaming. Spontaneous cognitive events are often contrasted with goal-directed thought and described as largely independent of ongoing tasks. [77] Much like dreaming, spontaneous thoughts involve sensory attenuation, a dampening of incoming environmental and bodily stimuli, and cognitive contents which are more associative, self-focused, bizarre and emotionally negative than attentional thought.[78,16] Dreaming and mind wandering seem to be supported by overlapping neural networks, including the Default Mode Network (DMN).[16] As the DMN is observed most clearly when subjects engage in the task of self-reflection, it is theorized that both daydreaming and dreaming can be important routes to self-knowledge.[79,80] The similarities go further: recent research suggests that slow waves, a brainwave event which was thought to occur only in slow-wave NREM sleep, can in fact occur in local areas of the brain in wakefulness.[81] While the local *decrease* in slow-wave activity over parietal brain regions correlates with the occurrence of dreams, a local *increase* during wakefulness over the same regions correlates with a reduction in spontaneous thoughts. [82] Daydreaming, it turns out, is a colloquial term with deep insight.

> *"Language, in its unrivaled wisdom, long ago decided the question of the essential nature of dreams by giving the name of 'day-dreams' to the airy creations of phantasy. "*
> Sigmund Freud, *Creative Writers and Daydreaming* (1908)[83]

The early mind-wandering cognitive science literature focused on detrimental effects of inattention on cognitive performance and mood. There was a deficiency view of mind-wandering which assumed that a failure of attention implies a lack of ongoing functional processing, as in the case of 'mindless reading' when the eyes scan sentences without effectively intaking written information. [84,85] The newer literature complicates this deficiency view and emphasizes possible benefits of inattentive mind wandering such as creativity, future planning, and memory consolidation (note that these benefits are also essential to the non-deficiency view of night time dreaming). [86,87] Further, within a mind-wandering experience scientists now distinguish losses of cognitive control and metacognitive control, showing that mind-wandering can occur with and without intention; One can exercise volition and choose to continue letting one's mind be spontaneous, surveying that spontaneity and remaining attentive to the contents of inattention. [88] This work informs a non-deficiency view of mind-wandering which frames inattention as *different* versus *deficient*, as well as an understanding that kinds of inattention and attention can coexist simultaneously in the same brain.

While dreaming and daydreaming have many overlaps, we have to distinguish them for the sake of experimentation. Even if we accept that nighttime dreaming is an intensified form of mind-wandering, these mind-states are distinguished by their level of consciousness as daydreaming happens during wakefulness and dreaming during sleep. While daydreaming involves lapses in volitional control these are transient and short in comparison to nighttime dreaming,[5] and dreams are immersive in a way that even vivid daydreams are not. [16] The carefully orchestrated circadian and ultradian timing of sleep and dreaming sets them apart from daydreaming, which don't seem to adhere closely to either internal or external schedules. [90] Research on the dream-lag effect, on the other hand, suggests that night time dreams have a pattern for the incorporation of waking experiences, such that we are most likely to dream of events experienced the preceding day and 5–7days before, and less likely to dream of events from days 2–4 before. [91] As it is difficult to predict and direct mind-wandering, there is not much research on purposefully incubating the contents of a wandering mind, but I hope that readers of this thesis are inspired to experiment with incubated daydreams in the future.

> *"You ask me what it is that I do when I dream? I will tell you what you do when you are awake. You take me, the me of dreams, me the totality of your past, and you force me, by making me smaller and smaller, to fit into the little circle that you trace around your present action. That is what it is to be awake. That is what it is to live the normal psychical life. It is to battle. It is to will. As for the dream, have you really any need that I should explain it? It is the state into which you naturally fall when you let yourself go, when you no longer have the power to concentrate yourself upon a single point, when you have ceased to will. What needs much more to be explained is the marvelous mechanism by which at any moment your will obtains instantly, and almost unconsciously, the concentration of all that you have within you upon one and the same point, the point that interests you. But to explain this is the task of normal psychology, of the psychology of waking, for willing and waking are one and the same thing."*
> Henri Bergson, *Le Rêve* (1914)

Lucid Dreaming, Mixed Sleep States

> *…Wittgenstein's final philosophical remark, written down two days before his death: "I cannot seriously suppose that I am at this moment dreaming. Someone who, dreaming, says 'I am dreaming,' even if he speaks audibly in doing so, is no more right than if he said in his dream 'it is raining,' while it was in fact raining. Even if his dream were actually concerned with the noise of the rain." One might imagine a note of relief at the thought that, if you never wake up, this particular problem disappears.*
> Matthew Spellberg, "*Wittgenstein's Dream, 13 January 1922"* (2020) [92]

If mind-wandering can be understood as a form of dreaming while awake, lucid dreaming can be seen as its inverse, awakening in a dream. This type of dream involves becoming aware that one is dreaming while dreaming, and it has been documented since antiquity. In the 4th century BCE, Aristotle wrote in his *Parva Naturali,* that "often when one is asleep, there is something in consciousness which declares that what then presents itself is but a dream." Likewise, meditative practices like yoga nidra, designed specifically to bring a form of waking cognitive capacity to sleep and "apprehend the dream state," date back millennia. [93] During lucid dreams, individuals can be physiologically asleep, indicated by their EEG brainwave readings and lack of awareness of their surroundings, while at the same time aware that they are dreaming, able to intentionally perform dream actions, able to experience gaining insight and spontaneous thought, and in some cases able to remember their waking life. [94]

Lucid dreaming, like mind-wandering, faced a great deal of skepticism in the cognitive sciences as a legitimate subject of study or a potentially cognitively beneficial brainstate. Despite the fact that personal accounts of lucid dreams have been described for millenia, the lack of objective evidence for lucid dreaming initially troubled scientists.[95] In the late 1970s and early 1980s, however, building on prior research that showed that shifts in the direction of eye gaze within a dream can be accompanied by corresponding movements of a sleeper's eyes,[96] Dr. Keith Hearne asked lucid dreamers to move their

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[5] The opposition between dreaming and volitional control has a long history; Saint Augustine famously wondered whether he was morally responsible for sins committed in his dreams, such as adultery. [89]

eyes in a distinct, pre-agreed upon sequence as soon as they became lucid and ‘objective’ evidence of a lucid dream was achieved via eye tracking. [6,97]

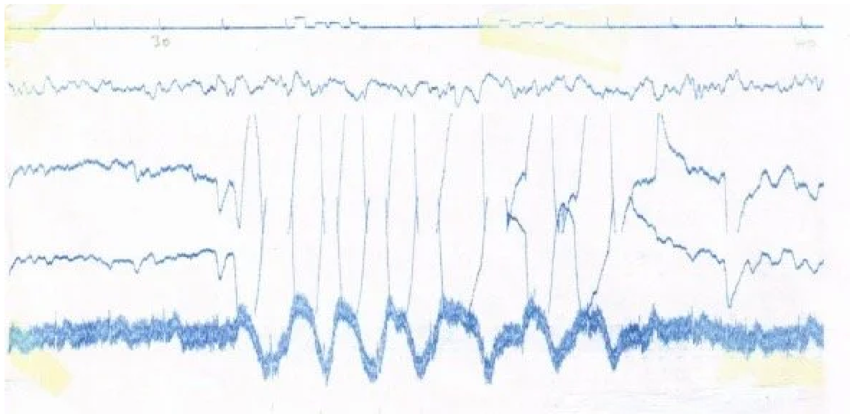

Figure 8 First ever recorded ocular signals from a person in a lucid dream, 4.12.1975[98]

The experience of lucid dreaming stretches one’s understanding of a cohesive self and exposes an interior other. One study from Gestalt psychologist Paul Tholey (who spent much of his career trying to prove that dreams occurred in color) had proficient lucid dreamers ask characters they encountered in their lucid dreams to perform specific tasks. These characters are often called *morphai* (adapted from Greek Mythology in Hesiod’s *Theogeny*) and they are *both* the dreamer and the creation of the dreamer, insofar as their minds are made by the dreamer’s mind. Tholey found the vast majority of *morphai* answers to even very simple math tasks, such as 2 + 3, were wrong, but they solved verbal tasks well. In a handful of cases, dream characters first gave a wrong answer, then corrected themselves. When one lucid dreamer gave a dream character what he thought was the correct answer to a math problem, the dream figure corrected him – and was right. Some of the characters had intensely emotional reactions to being challenged with a math problem. One character started to cry, another ran away, others replied that the question was too personal or the answers were either too subjective or important to be shared. It is amazing that I, as a dreamer, can create minds which surprise or evade me. Lucid dreaming specifically enables cognitive control within the dream and allows for a state of doubting and questioning that is typically absent in the dream experience. We are able, then, to interrogate the experience of the *morphai*, and ask whether we are always carrying so many characters within us, unseen and experiencing.

> *My fascination with dream characters began while I was in college. That’s when, in the midst of a dream in which I knew I was dreaming (a ‘lucid dream’), I had my first encounter with an older gentleman, who tried to convince me that, actually, my experience wasn’t a dream. Over the next two decades, this man appeared in several other of my lucid as well as non-lucid dreams. He always maintained he was real, one time going as far as to suggest that we were sharing a common dream or, even more unsettling, that I was a character in his dream….I never quite knew what he would do or say next.*
> Antonio Zadra, *What Dream Characters Reveal About The Astonishing Brain* (2021) [99]

Just as they stretch our understanding of the self, lucid dreams likewise push our sense of what a dream is. If a dream is by definition an unreflective, immersive experience, then is a lucid dream not a dream at all? Neurophysiologically, lucid dreaming constitutes a hybrid state with measurable differences from both waking and from REM sleep, particularly in frontal areas of the brain.[76] It is sensemaking that the unusual combination of hallucinatory dream experience with wake-like reflective awareness and agentive control is paralleled by significant changes in electrophysiology. But then again, even non-lucid dreams often involve the phenomenology of thinking,[100] and even lucid dreams don’t always feature fully reflective awareness, or complete agentive control. Consider this lucid dreamer from Tracey Kahan's *What You Cannot Do In a Lucid Dream:*

> "*In a lucid dream one is not completely lucid. In one of Alan Worsley's dreams he wanted to draw triangles in order to watch the movement of the drawing, and so get his eyes to move in a particular configuration as a signal to the EEG experimenters. He wanted to draw the triangles on a blackboard he had found, but was worried about messing up what was already written there. In short, he was lucid enough to know that he was going to do an experiment, but he was not completely lucid because he didn't appreciate that there was no-one there to complain about him altering the blackboard writing.*"[101]

While lucid dreams exist on a continuum of awareness, they all involve a degree of self-awareness within the dream. This self-awareness, in turn, is associated with changes in dream content. Lucid dreams contain more positive emotions than non-lucid dreams, fewer problems, less verbal aggression, fewer death themes, fewer verbal interactions and a lower number of dream characters. [102] Thus while lucid dreaming allows us to solve the experimental challenge of controlling dream content, it comes with a large caveat. Lucid dreams are not an ideal environment to interrogate the function and features of non-lucid dreams. The changes in phenomenology associated with lucidity, as well as the hybrid wake/sleep brain physiology, are experimental confounds. Consider the following experiment; Dresler (2011) combined brain imaging with polysomnography and asked lucid dreamers to perform a predefined hand clenching motor task during dreaming, and showed concurrent brain activation in the sensorimotor cortex.[103] While this supports the hypothesis that motor performance during lucid dreaming involves the same cortical areas as waking performance, it tells us very little about motor activation during non-lucid dreams. We can't eliminate the effects of lucidity as a contributing factor in the sensorimotor cortex activation the Dresler study shows. Lucid dreams are a fascinating creature, but a different animal than non-lucid dreams.

> *"I've had experiences with lucid dreaming but that interested me less than experiences with the Dormio precisely because with hypnagogia it is really an experience of consciousness without control...it's more about a negotiation between my dreaming self and my waking self rather than an attempt to bring my dreaming self under the control of my waking self"* –Michael Clune, *Night Shifts,* Harper's Magazine 2021

Psychedelia, Psychosis

> *"Pleasure in nonsense, as we may call it for short, is concealed in serious life to a vanishing point. In order to demonstrate it we must investigate two cases–one in which it is still visible and one in which it becomes visible again: the behavior of a child in learning, and that of an adult in a toxically altered state of mind".* Sigmund Freud, *Jokes and Their Relationship to the Unconscious* (1905)

While mind-wandering experience is dissociated from dreaming by degree of *uncritical immersion*, and lucid dreaming is distinguished from non-lucid dreaming by degrees of *metacognitive awareness*, both psychedelia and psychosis seem to engender experiences of waking dreaming which are entirely immersive and lack self-reflective awareness. Albert Hofmann, who researched psilocybin and was the first person to synthesize and ingest the serotonergic psychedelic lysergic acid diethylamide (LSD), wrote "The indolic alkaloids psilocybine and psilocine are the main hallucinogenic principles of the sacred mushrooms (…). The mushrooms cause both visual and auditory hallucinations, with the dreamlike state becoming reality."[104] LSD increases the cognitive bizarreness of mental imagery, a characteristic quality of dream content; LSD also facilitates REM sleep in humans when administered during sleep or before sleep onset [105] [106] and N,N-dimethyltryptamine (DMT, another serotonergic psychedelic) induces spontaneous eye movements similar to those observed during REM sleep.[107] A recent study shows that psilocybin causes a significant decrease in the positive coupling between the posterior cingulate cortex (PCC) and medial prefrontal cortex (mPFC) nodes of the Default Mode Network, the same system that is associated with spontaneous cognition during mind-wandering. The authors suggest their data “strongly imply that the subjective effects of psychedelic drugs are caused by decreased activity and connectivity in the brain's key connector hubs, enabling a state of unconstrained cognition,” and refer to this unconstrained cognition as a “waking dream.” [108] The waking dream engendered by psilocybin is distinct from the realistic eyes-closed visual imagery induced by amphetamines such as 3-methoxy-4,5-methylene- dioxyamphetamine (MMDA), wherein the user easily identifies such content as artificial, and which researchers refer to as “brain movies”.[109]

What distinguishes a psychedelic-induced ‘brain movie’ from a ‘waking dream’, and how does the experience of a sleeping dream compare to both? A recent study investigated the semantic similarity between a large corpus of subjective reports of psychoactive substances and reports of dreams, and found that the highest-ranking substance in terms of the similarity to high lucidity dreams was LSD, while the highest-ranking in terms of the similarity to low lucidity dreams were plants of the Datura genus, rich in deliriant tropane alkaloids. Reports from LSD and Datura experiences each included vivid multimodal imagery (ranging from elementary percepts to full-blown immersive hallucinations), altered sense of the relationship between the self and body boundaries, loss of the sense of agency, suppressed metacognitive function and heightened emotional reactivity, much like dreams. Conversely, reports of sedative, stimulant, antipsychotic, and antidepressant experiences were the lowest-ranking in terms of similarity to dream reports. An analysis of the most frequent words in the subjective reports of dreams and hallucinogens revealed that terms associated with perception (“see,” “visual,” “face,” “reality,” “color”), emotion (“fear”), setting (“outside,” “inside,” “street,” “front,” “behind”) and relatives (“mom,” “dad,” “brother,” “parent,” “family”) were the most prevalent across both experiences. [110]

A recent brain surgery in France enabled a chance encounter with another kind of waking dream; As Hebert (2014) performed an awake neurosurgery on an epileptic patient, they found that applying direct electrical stimulation to the left PCC (a key node of the DMN, S1 in Figure below) induced a reproducible transient behavioral unresponsiveness with loss of external connectedness. In all cases, when their patient regained consciousness, he described himself as in a dream, outside the operating room. These included experiences of a beach and of a sun. Note below that stimulation of brain regions outside of the DMN (S2, figure below) did not induce dreamlike waking experience.

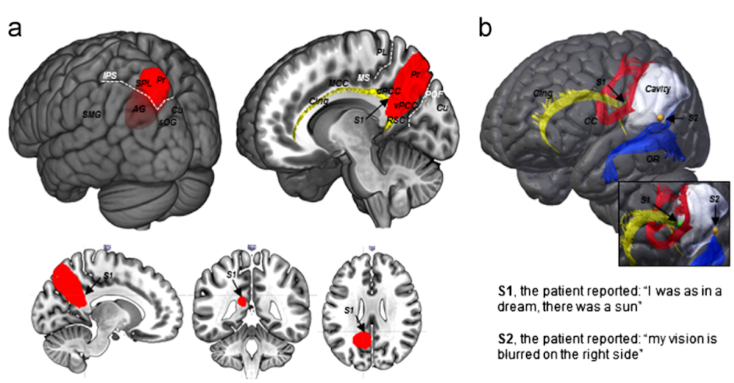

Figure 9 Anatomical location of the ‘dream-like state’ inducing electrical stimulation. S1 indicates white matter underlying the left posterior cingulate cortex (PCC). S2 indicates an area near the optic radiations (OR).[111]

Are these stimulation and hallucinogen induced experiences truly waking dreams, are they transient psychoses, and are these meaningfully different categories? Dreaming and psychosis share important phenomenological and neurophysiological features, including perceptions independent of external stimulation and a lack of rational judgment regarding the bizarreness of these experiences. [112] Both in psychosis and REM dreaming, prefrontal cortex hypofunction is thought to be causally related to the decreased criticism typical of these states. [113] According to Hobson in *The Dream Drugstore*, "the main point is that whatever the context—including dreaming—psychosis is psychosis is psychosis. To understand how psychosis can occur naturally, the best approach is to explore the physiology of normal consciousness and learn how the normal psychosis that is dreaming is engendered." [114]

The dream experience is significantly altered in psychosis, suggesting that whatever brain mechanisms engender the waking psychotic experience overlap with dream-generating neural mechanisms. This idea dovetails with evidence that patients with brain lesions that impair their waking cognition show corresponding deficits in dreams. For example, subjects with impaired face perception also do not dream of faces.[28] Using a graph-theoretical approach to represent and quantify word trajectories in dream reports, Mota (2014) found that the recurrence, connectivity and global complexity of dream reports are distinct in schizophrenia, mania, bipolar disorder type I and control subjects. This was possibly because their speech features are quite different during wake. Schizophrenic subjects frequently display alogia, speaking laconically and with little digression while subjects with bipolar disorder, especially during the manic stage, tend to present the opposite symptom called logorrhea, with much recursiveness in association with positive symptoms.[13] Notably, these differences in dream reports were more prominent and predictive of diagnosis than waking reports from the same patients. [13] The authors explain that dream reports are substantially more informative about the mental state of psychotic subjects than waking reports because dreams are not proximally anchored to events shared with non-psychotic individuals, but rather on memories matured and restructured over time by the patient's own thought process. This privileged window into thought would thus reveal introspective alterations magnified over and above their waking, proximally anchored thoughts.

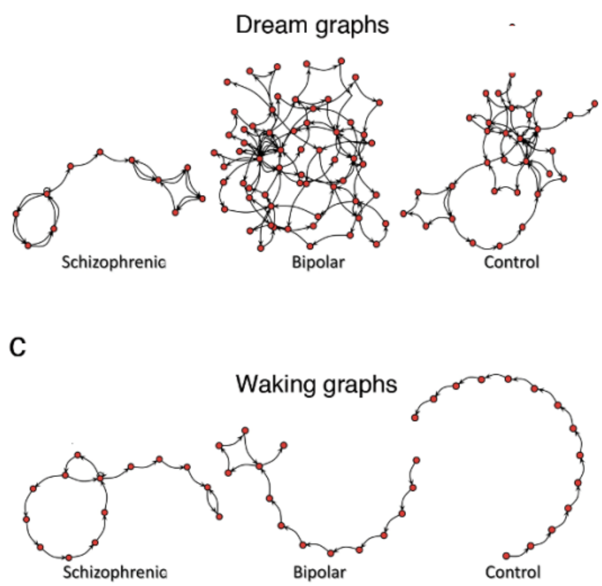

Figure 10 The speech graphs of schizophrenic, bipolar and control subjects are more varied for dream than for waking reports. Image credit Mota (2014) [13]

We are left with a murky, complex picture of the links and divides between dreams, psychedelics and psychosis. As we come to better understand what mediates dreamlike experience in psilocybin or electrical stimulation or delirium, perhaps we come closer to understanding the sleeping dream. It is tempting to link the DMN activity found in dreams, psilocybin use, and mind-wandering, but the research in all these fields is quite young and as we learn more about the brain we learn that functional localization is less reliable. It is tempting to think of a continuum of unconstrained cognition which begins with the inattentional waking mind, travels through the experience of psychedelic hallucination and stretches the spectrum to the non-lucid dream. But their similarities may be only at the phenomenological level while any physiological overlaps remain a relevance fallacy. Whatever such research yields, it will not give us a clear picture of the organic dream. A pharmacologically induced dream is, like a lucid dream, simply a different creature. The psychedelic dream comes from the substance while the incubated, sleeping dream comes from the subject. Whether we are working with dreams for creativity, introspection or therapy, the fact that a dream comes from within is a powerful thing. See a report below from a Dormio user comparing the experience of Targeted Dream Incubation with that of psychedelia.

> *"…this is just my experience in psychedelia, using psychedelics, I felt that hitting hypnagogia was just way more powerful and immersive, like, like, by many orders of magnitude. And also, it was that state of consciousness without control…And I think there's also with hypnagogia, or with dreams, there's more of a organic roots between, you know, it's just how you are, this is just natural, you know, and, and I think there's a kind of richness and benefit to that, that seems to me, really interesting and distinct, potentially, from psychedelics…You know, I think this is another moment where we're back, just fascinated by dreams again, and I think you're right, it is accompanied by or goes along with this renewed interest across, you know, medical communities, artists, filmmakers, so forth in psychedelics... I think people have a hunger for a kind of spiritual experience, a kind of creative experience that resists that kind of capture"*
> Michael Clune, *Night Shifts,* Harper's Magazine

Psychoanalysis, Pseudoscience

Figure 11 *The Artichoke,* Beppe Giacobbe.[18] The popular notion of a layered, concealed inner self is one of many cultural ripple effects of psychoanalysis.

Psilocybin, mind-wandering and dreams have all faced a great deal of resistance from the scientific establishment, perhaps because they share so much in common. Mind-wandering was regarded as an unproductive waste of time, too subjective to study; Psilocybin as dangerous, counter-cultural, sinful, mad.[115] Dreams have been all of the above. Worst of all, the study of dreams was damned as pseudoscience. To understand the lack of rigorous scientific research on the topic of dreams today, we must understand attacks launched over centuries on the possibility of serious dream study. This brings us to our final parallel line of research, Freudian psychoanalysis, a system of psychological theory and therapy which investigates the interaction of conscious and unconscious elements in the mind using dream interpretation and reflection on waking free association (daydreaming, mind-wandering). A central tenet of Freudian theory was the claim that dreams are significant, functional, and offer insight into the organized actions of the unconscious. For Freud, the dreamscape offered the possibility of reassembling the total person, merging psychology with physiology, the unconscious with consciousness, and past and present. Psychoanalysis was ascendant in psychiatric practice for the first half of the 20th century, before a sudden dismissal from the scientific establishment came at the hands of Karl Popper. Popper, a philosopher of science, targeted psychoanalysis as the canonical example of pseudoscience, calling for a philosophical shift from the scientific doctrine of induction via observation to one which emphasized predictive hypotheses and falsifiability.[116]

In the 1960's, Popper famously dismissed psychoanalytic theories as "simply non-testable, irrefutable. There was no conceivable human behaviour which could contradict them."[117] Popper rejected the view that observations are incorrigible evidence, and argued instead that science inherently involves subjective decisions sensitive to confirmation bias. Popper argued that to demarcate science from myth, a scientific theory must be falsifiable with criteria of refutation stated before testable observations are made.[118] His core qualm with psychoanalysis was that any observation could retroactively fit easily within the framework of psychoanalytic theory, and none could falsify it:

> "*The Freudian analysts emphasized that their theories were constantly verified by their 'clinical observations.' As for Adler, I was much impressed by a personal experience. Once, in 1919, I reported to him a case which to me did not seem particularly Adlerian, but which he found no difficulty in analyzing in terms of his theory of inferiority feelings, although he had not even seen the child. Slightly shocked, I asked him how he could be so sure. "Because of my thousand-fold experience," he replied; whereupon I could not help saying: "And with this new case, I suppose, your experience has become thousand-and-one-fold." What I had in mind was that his previous observations may not have been much sounder than this new one; that each in its turn had been interpreted in the light of "previous experience," and at the same time counted as additional confirmation…It was precisely this fact—that they always fitted, that they were always confirmed—which in the eyes of their admirers constituted the strongest argument in favor of these theories. It began to dawn on me that this apparent strength was in fact their weakness.*

Popper's dismissal of psychoanalysis as unscientific struck a nerve on both sides of the debate. Peter Medawar, Nobel Laureate cancer researcher, wrote that "the opinion is gaining ground that doctrinaire psychoanalytic theory is the most stupendous intellectual confidence trick of the twentieth century; and a terminal product as well – something akin to a dinosaur or a zeppelin in the history of ideas, a vast structure of radically unsound design and with no posterity". [119] Adolf Grünbaum, a philosopher of science and contemporary of Popper's, countered that "the inability of certain philosophers of science to have discerned any testable consequences of Freud's theory betokens their insufficient command or scrutiny of its logical content rather than a scientific liability of psychoanalysis". Grünbaum went on to point out instances in Freud's writings where he shows himself to be aware of the need for testability. Freud writes in his assessment of whether anxiety neuroses are due to disturbances in sexual life that "my theory can only be refuted when I have been shown phobias where sexual life is normal."[120] In another instance Freud writes "A Case of Paranoia Running Counter to the Psycho-Analytic Theory of the Disease", in which, as the title suggests, he saw a patient's symptoms as potentially falsifying psychoanalytic theory.[121] Regardless of Grünbaum's defenses, accusations accrued that Freud had misstated his therapeutic results and faked his alleged discoveries. Psychoanalytic theory was deemed sexist by Betty Friedan in "The Feminine Mystique," by Kate Millett in "Sexual Politics," and by Simone de Beauvoir in "The Second Sex."[122] Psychoanalysis was too marred, and too vague, and sleep science historian Kenton Kroker writes that by the 1980s "the American psychiatric establishment began a full-scale purge of psychoanalytic ideas from its diagnostic canon". [123] Freudians had written the first two issues of the Diagnostic and Statistical Manual of Mental Disorders, the psychiatric Bible; By the time of the DSM 3 publication in 1980, in a stunning fall from prominence, psychoanalysis was absent and the emphasis was placed on biological explanations for mental disorders.

It is worth noting that Freud gave much to the cognitive sciences, and that his ideas have old roots and still bear fruit today. In the *Republic*, Plato suggested dream images arose in sleep because, in this state, the rational soul slept while the desiderative soul that governed the appetite continued unrestrained.[124] It is hard not to see similarities to the Freudian *id*. Freud wrote his *Formulations on the Two Principles of Mental Functioning* in 1911 and differentiated the *primary process* (the primitive, unconscious element in the mind) and the *secondary process* (largely conscious and controlled) decades before Kahneman, who won a Nobel Prize for exploring parallels in System 1 and System 2 thinking. A leader of the contemporary affective neuroscience field, Dr. Jaak Panksepp, writes that emotion circuits in the brain function to "instigate goal-seeking behaviors and an organism's appetitive interactions with the world;" there are clear commonalities with Freud's *libidinal drive* - his theorized primary instigator of dreams - and neuropsychoanalyst Mark Solms notes that damage to affective circuits can cause both cessation of dreaming *and* a massive reduction in waking motivated behavior.[125,126] Beyond questions of scientific validity, it was psychoanalysis that moved the treatment of mental illness from institutionalization to the therapist's office. In 1940, two-thirds of American psychiatrists worked in hospitals; in 1956, seventeen per cent did. By 1966 three-quarters of psychiatrists reported that they used Freud's "dynamic approach" when treating patients.[122]

How could a theory become so dominant in the treatment of mental disorders? Many scholars have tried to explain why, but the explanation offered by anthropologist Tanya Luhrmann is simplest: alternative theories were worse. "Freud's theories were like a flashlight in a candle factory," she writes in *Of Two Minds: An Anthropologist Looks at American Psychiatry*. Science of the mind was not presenting many other convincing options in Freud's time: Treatments included hypnosis, electrotherapy, hydrotherapy, full-body massage, morphine, rest cures, excessive feeding, seclusion, female castration, and institutionalization. The most prevalent nineteenth-century psychiatric diagnoses, hysteria and neurasthenia, are not even recognized today and were clearly driven in part by sexism. Hypnosis was especially widely practiced, endorsed by the American Psychiatric Association, the American Medical Association, and even Pope Pius XII throughout the 1950s.[127] Each of these treatments were attempts at psychiatric science, and as is the case with all science, much of it failed and is relegated to history. The vitriol reserved for psychoanalysis, with this backdrop of hypnosis and hysteria, is striking. As a recent biographer of Karl Popper writes, "his brief critique of psychoanalysis never accounted for his intense hostility towards it."[128] The fall of psychoanalysis from grace was striking, but much of its concepts live on outside of the scientific laboratory. The influential literary critic Harold Bloom contends that Freud's insight into the human condition is clear, independent of his status as a scientist:

> *"It may be that Freud's importance to our culture continues to increase almost in direct proportion to the waning of psychoanalysis as a therapy. His conceptions are so magnificent in their indefiniteness that they have begun to merge with our culture, and indeed now form the only Western mythology that contemporary intellectuals have in common. As with every true mythology, a diffused version of psychoanalysis has become a common possession of most people in middle-class Western society, who may not be particularly intellectual, and doubtless are not always aware that psychoanalysis has provided the psychology in which*

they can believe without continual reflection or conscious effort…No 20th-century writer - not even Proust or Joyce or Kafka - rivals Freud's position as the central imagination of our age.“ [129]

The continued relevance of psychoanalysis means our own research on TDI cannot escape the affiliation with pseudo-scientific dream research. It is difficult to overstate the cultural relevance of Freudian theory beyond clinical uptake in the 20th century; it dwarfs other important models of the unconscious mind, like Bernard Baars *Global Workspace Theory*.[130] Something within the model and myth of psychoanalysis resonates with a population more expansive and diverse than the typically constrained consumers of neuroscientific theory. It formed a set of theories that are neither medicine nor psychiatry, neither religious doctrine nor artistic creation yet involve aspects of all of those. It attempted, for better or worse, to advance objective *and* subjective understanding of the mind and create a doctrine which made material *and* metaphysical claims. Like many great empires, psychoanalysis folded under the weight of its far reaching ambition at the cost of its own legitimacy. In this expanse of ideas, rather than defend or assail Freud it is more useful to have a sense of the ripple effects of psychoanalytic theory that Bloom describes above, a sense of the failures that Popper details, and a sense of what might constitute progress for dream research today. In this historical context psychoanalysis functions as both foil and forefather. We must build research tools and a discipline for the study of dreams which are both responsibly constrained at the level of method and expansively resonant at the level of mind.

“Science is wonderful at destroying metaphysical answers, but incapable of providing substitute ones. Science takes away foundations without providing a replacement. Whether we want to be there or not, science has put us in the position of having to live without foundations. It was shocking when Nietzsche said this, but today it is commonplace; our historical position-and no end to it is in sight-is that of having to philosophise without ‘foundations’.”
Hilary Putnam, 1987, p. 29 [131]

Figure 12 A collection of couches used in various psychoanalytic practices. Freud Museum, London.

Chapter 2: Sleep and Dream Science Today

> *"In rejecting Freud, society also rejected the notion of paying much attention to our dreams and their content."*
> Dr. Antonio Zadra, co-author of *When Brains Dream* (2021) [132]

Chapter 2 will now take up the question of pseudoscience and examine the trustworthiness of subjective data, detailing what functions dreams can be concretely understood to serve (contributing to memory, learning, emotional adaptation and creativity) and what technological tools are needed to test these operations with falsifiable hypotheses. After Popper's declaration of pseudoscientific dream science, the backlash against psychoanalysis in the brain sciences was swift and severe. A seminal figure in sleep research for the second half of the 20th century was Harvard's J. Allan Hobson. In his break-out 1977 paper, Hobson declared victory over Freud and the psychoanalytic community by reporting the discovery that dreams in REM sleep form based on random neurochemical changes in the brain.

Hobson contended that activity in areas of the brain primarily responsible for basic biological processes fires randomly and is then interpreted by the parts of the brain responsible for higher-order cognitive functions.[133] As Kelly Bulkeley notes in *The Wilderness of Dreams*, Hobson presented his work as a polemic against Freud, whose influence he accused of preventing scientific progress in the study of dreams. According to *Harvard Magazine,* "Hobson shaped the articles into an overt assault on the foundations of psychoanalysis. The result was encouraging. The pieces generated more letters to the editor, mostly from outraged psychoanalysts, than any articles previously published in the Journal. 'I would admit to having created some heat where light might have been more useful,' said Hobson later, 'but I can tell you, they weren't paying any attention until I turned the heat up a bit.'"[134]

> *"A specific example may help to clarify this concept: suppose you are dreaming and in your dream you see the back of a man who is standing at an intersection. Suddenly, the man turns to the left and runs across the street. The explanation for this event in the dream would be that REM-generating pontine cells activated nearby eye movement neurons, specifically those that move the eyes to the left. The cerebral cortex registered this activity and attempted to make sense out of it in light of what previously occurred in the dream. The logical solution, based on the speed and direction of the eye movements, was to move the man to the left and rapidly across the street"*
> Allan Hobson, as quoted in Seth Rogoff's *The Politics of the Dreamscape* (2021)
>
> *if we assume that the physiological substrate of consciousness is in the forebrain, these facts completely eliminate any possible contribution of ideas (or their neural substrate) to the primary driving force of the dream process"*
> Allan Hobson & Robert W. McCarley. *The brain as a dream state generator: an activation-synthesis hypothesis of the dream process* (1977)

Hobson's claim that the *primary driving* force of dreams is random does not entirely deny meaning to dreams, which could still be made meaningful in their later stages of higher order signal interpretation. But it does imply that the process is much more basic than the intelligent dream generation Freud had imagined, and casts doubt upon the merit of primarily studying the psychological significance of dreams. The Freudian notion that dreams can be assumed to be composed of meaningful, unconscious messages by design was now publicly dismissed by science. Dreaming is merely "an epiphenomenon of REM sleep," wrote Hobson in *The Dreaming Brain*. [135]

Here, though, the pendulum had swung too far. In retrospect, it seems incredible that for decades the leading theory in sleep science posited that dreams were generated primarily by random signals. What of repeated dreams? And the clear link between pre-sleep emotion and dream content? Of day residue and the dream-lag effect, organized and regular in theme and time? Of the relationship between what we dream and our current concerns and anxieties about the coming day? Of dream rebound, wherein attempted thought suppression at sleep onset increases likelihood of dreaming of the suppressed topic?[136] Whether we are talking about primary driving forces in the brain or secondary levels of higher order interpretation, nothing about these patterns suggests randomness to be the best explanation for dream content. The fact that such a theory, clearly antithetical to experience, was so widely accepted suggests much about the disciplinary blind spots of brain science.

> *"As scientific positivism intensified, the reaction against the legitimacy of a self study of dreaming began to take shape. The clarity required by science demands that researchers turn away from the philosopher's tendency to study one's own thoughts and experiences and that only the sleep of others is the proper object of any future research.*"
> Kenton Kroker, *Sociability of Sleep Salon, Jan 8 2022*

Within a scientific ethos that sought to distance itself from psychoanalysis, dream content was de-emphasized; As psychoanalysis had focused on subjective experience and subjective interpretation and been dismissed as pseudo-science, a true science of sleep would have to examine the objective, material facts of sleep. Thus while sleep science has flourished over the past half century since Hobson's 1977 paper, dream science did not grow apace. Sleep studies focused on comparing cognition before and after periods of sleep, and simply did not gather data on dream content experienced in the intervening period of rest.

> "*DSM-III, New Psychiatry, and the emergence of 'targeted' neuroscience converged to create by the 1990s the dominant and dominating figure of contemporary medicine, society, and culture—the drug-prescribing psychiatrist, a marginal figure in the 1970s. It would take the professional annihilation of the Freudian establishment to secure its power, and a central pillar of Freudian power was its hold on the interpretation of dreams."*
> Seth Rogoff, *J. Allan Hobson's Dreamstage In Context* (2021)

One of the most clear findings of these sleep studies, and one of the most clear omissions in dream research, is the active role of sleep in memory processing. The role of sleep in memory formation is extensive and complex, and the publication rate in the field of sleep and memory has doubled every 4-5 years since 1990.[137] We have learned that at the synaptic level, information from the previous day is being rehearsed for strengthening and re-storage in sleep, and patterns of brain activity expressed during training can be seen reappearing in subsequent REM and NREM sleep. The extent of learning during practice is correlated with the amount of reactivation during sleep. [138,139] At the brain network level, as we sleep, encoded information from the day undergoes a shift from storage based in short-term representation (dependent on the hippocampus, which has limited storage capacity) to long term representation (spread throughout the neocortex with far greater storage capacity). Because reactivation of memories is related to their effective encoding, inducing memory reactivations by re-exposure to memory cues during sleep (called targeted memory reactivation or TMR) consistently benefits memories when cues are presented during sleep. [140] A search of *pubmed.gov* shows 505 papers on TMR in just the last decade. In contrast, a leader of the sleep and memory field, Björn Rasch writes in a 2019 paper that "while waking events are clearly incorporated into dreams, it is still unclear whether incorporations are related to memory consolidation. To our knowledge, only two (non-pilot) studies have examined this question."[141] Dreams had been so marred as a data type that more than *500 studies* simply did not bother to ask their subjects, upon awakening, what they had dreamt of in the intervening period of sleep and what relationship could be found between mental experience and post-sleep memory task performance.

The notion that subjective experience is irrelevant to learning outcomes has not been taken seriously – in the study of the waking mind – since behaviorism collapsed in the 1950's and the Cognitive Revolution ushered in the study of cognition. As Chomsky remarked, defining psychology as the science of observable behavior was like defining physics as the science of meter reading. George Miller, one of the founders of modern cognitive science, writes that the Cognitive Revolution in the 1950's proclaimed that "if scientific psychology were to succeed, mentalistic concepts would have to integrate and explain the behavioral data." [142] There are organizing principles of the mind that give rise to behavior, and measurement of the observable outcomes of these principles is not akin to understanding mental organization. Somehow this notion was not extended to the sleeping brain, where scientists often assume mental content is not relevant to behavioral data. It seems the failure to take dream reports seriously was an attempt to distance sleep science from unserious psychoanalysis, as the value of dream reports only became a target of serious interrogation in the second half of the 20th century after Popper's critique.[143]

Trusting Self-Report Data

> *"Even when investigation shows the primary exciting cause of a phenomenon is psychical, deeper research will one day trace the path further and discover an organic basis for the mental event. But if at the moment we cannot see beyond the mental, that is no reason for denying its existence."*
> Freud, *The Interpretation of Dreams,* (1900)

The push toward a purely objective sleep science can only be overcome by learning to trust subjective dream reports as scientific data. There are reasonable objections to self-reporting, but they are objections that essentially apply to all cognitive neuroscience. Working with first person self-report data is an ongoing challenge for the cognitive sciences, in both wake and sleep. A leader of the affective neuroscience field, Joseph LeDoux, wrote in 2018 that "the study of subjective experience represents a significant challenge to cognitive scientists, but one that is beginning to be increasingly addressed." [144] LeDoux argues that "it has long been known that subjective experiences of fear and anxiety do not correlate well with measures of behavioral and physiological responses," and as such we cannot reduce the study of emotion to the study of the brain and behavior. LeDoux advocates for an emphasis on subjective data, and in response his colleagues wrote this "would push us back well over a century to what was truly the dark ages of psychiatry."[145] The issue of the value of subjective self-report remains divisive, but this has not led to a lack of study. As LeDoux writes "despite its dubious reputation in corners of the field that have a lingering connection to behaviorism, research on consciousness is thriving in both psychology and neuroscience."[144] This is not the case, however, for dreams, where doubt about the soundness of subjective data has led to scientists simply ignoring dream data.

"All we have are the stories people tell when they wake up," says Ken Paller, a TMR pioneer and leading sleep researcher, "that deficiency has left an entire state of consciousness largely unexplored."[10] Why is it that while recent decades have seen a sharp increase in publications on consciousness, the same has not been true for dreaming?[143] Why is it that the issue of 'stories people tell us' does not limit researchers who work with waking consciousness? Dream researchers themselves have long portrayed the reliance on dream reports as a weakness, suggesting that in order to make real progress, the trustworthiness of dream reports would have to be verified by independent objective means such as brain imaging.[146] One reason for doubting the veracity of dream reports raised by philosophers Norman Malcolm and Daniel Denett, is a question of whether one can have an experience at all while sleeping – or whether all such reports are fabrications upon awakening. Yet this is just a philosophical quarrel about the word *experience* rather than a research methodology issue: Thomas Nagel responds, "it is a mistake to invest the demonstration that it is impossible to have experiences while asleep with more import than it has. It is an observation about our use of the word 'experience', and no more. It does not imply that nothing goes on in our minds while we dream".[147]

Contemporary science offers *objective* confirmation of subjective dream data. We know that in dream-enactment behavior occurring in REM Behavior Disorder, for instance, that patients show complex behaviors such as running or fighting off an attacker during REM sleep and they often report dreams involving the same actions after awakening.[148] In typical sleepers, imaging studies have shown that REM sleep is characterized by a shift in regional activation patterns wherein the pons, thalamus, temporo-occipital, motor, as well as the limbic and paralimbic areas are highly activated, while the dorsolateral prefrontal and inferior parietal cortices are comparatively quiescent. These brain data fit in perfectly with the predominance of visual and motor imagery during dreams, the frequency of intense, often negative emotions and cognitive deficits such as the loss of self-awareness, mnemonic deficits and the delusional belief in the reality of dream events.[146] A recent study showed that scientists can reliably predict dream report content based on brain activation by mapping activity in these regions during waking perception and watching reactivations during sleep,.[149] And in lucid dreams, a recent experiment demonstrated that real time, two-way communication during REM sleep is possible via eye movements and light flashes such that dream elements can be created by outside stimulation and then reported out by sleeping subjects. [150,151] It seems absurd that these brain activations, eye movements, enacted behaviors and more are inventions that coincidentally accord with reported experiences. In a recent paper from a group of prominent sleep apnea and narcolepsy clinicians, urging colleagues to make use of dream date, they write "Importantly, these studies convincingly show that dream reports can be trusted as a research tool, and that they do not represent confabulations or unreliable indications." [152]

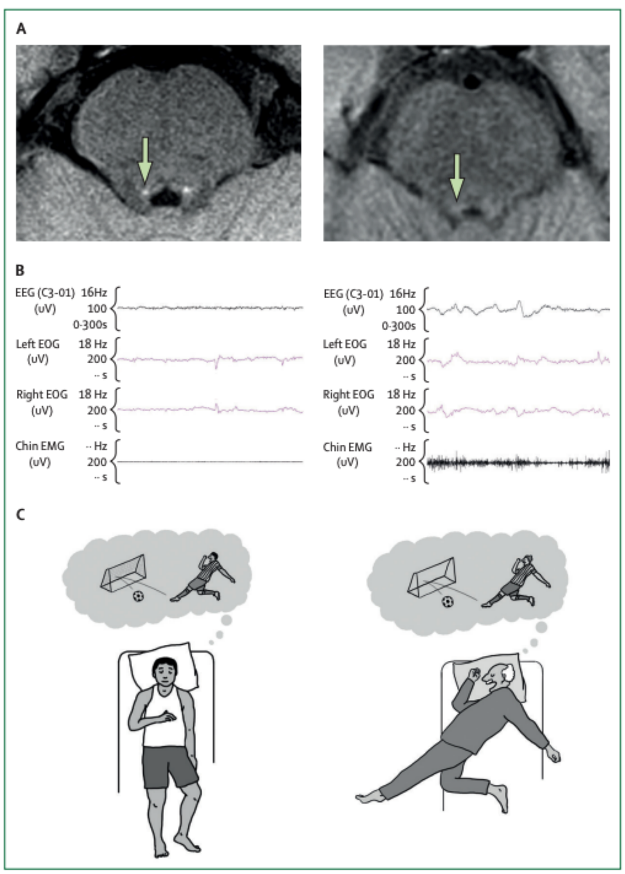

Figure 13 REM sleep behavior disorder—a model of enacted dreams (A) Patients with isolated REM sleep behavior disorder (right panel) have lower signals than healthy controls (left panel) in the subcoeruleus and coeruleus complex in the posterior part of the pons. (B) normal REM sleep (left panel) shows a flat line for the chin EMG (ie, atonic, paralysed), whereas abnormal REM sleep (right panel) shows a similar EEG and EOG to normal REM sleep, but the chin EMG is abnormally high. (C) Contemporaneous with this polysomnography signal, the normal sleeper is quiet and relaxed while dreaming of scoring a goal (left panel), whereas the patient with REM sleep behavior disorder dreaming of scoring a goal has leg and arm movements of playing football (right panel). EOG=electrooculography. EMG=electromyography. Figure from Siclari (2021) [152]

If we accept the veracity of dream reports, what about the density and quality of dream report data? Rechtschaffen claims that "when laboratory subjects are awakened from the REM stage of sleep, they generally have little difficulty in giving a fairly long, detailed report of dreams, with transcripts sometimes running to several typed pages. Indeed, it is often easier to get detailed, articulate reports of ASCs [altered states of consciousness] than detailed reports of normal waking consciousness".[153,154] Stickgold et al. (2001) collected a total of 1748 reports from 16 subjects over a period of 14 days. During the daytime, subjects responded to a pager, at night, their sleep stages were monitored by a Nightcap sleep monitoring system, an antecedent to Dormio. They found that median report lengths varied more than 2-fold over the sleep-wake cycle, with REM reports being the longest, followed by reports from active wakefulness, quiet wakefulness, NREM sleep, and sleep onset. This finding has recently been replicated by Siclari et al. (2013). In addition, when they asked their subjects how far back in time they could recall the content of experience and how rich and complex it was (measured by how long it would take to recount it), they found the same pattern, with the highest rating occurring for REM sleep reports. Perhaps dreaming, far from being a clear target for skepticism about first-person reports, is in fact more readily recalled than waking experience.

Much of the critique of first-person experiential data seems to stem from a popular misunderstanding of how objective brain data is acquired. As an example, consider a recent study from the field of emotion neuroscience. This particular study, by Putkinen (2021), published in a serious neuroscience journal, employed functional magnetic resonance brain imaging to reveal the neural bases of emotions by playing emotion-inducing music to subjects in a scanner. The authors find associations with activity in the auditory, somatosensory, and motor cortices, cingulate gyrus, insula, and precuneus. These authors then create a beautiful image of the brain (Figure 14) and proclaim these to be "brain regions responding to fear, happiness, sadness, tenderness and liking." But how do the authors know these musical clips induce these emotions specifically? It turns out that excerpts were chosen from a set of movie soundtracks based on high ratings for happiness, sadness, fear, or tenderness in a previous study. The authors simply asked people to self-report on how clips made them feel – and not even the subjects in their study, but other people. And how did these authors choose which brain regions to focus their analysis on? Using an emotion localizer paradigm, in which subjects view film clips with positive and negative emotional content – and these clips are rated on emotion again based on self-report, again by other individuals– before listening to affective music. The brain images produced, which are unobjectionable to the critics of subjectivity based on their aesthetic, derive all of their validity from self-reporting. These are in fact images of the brain regions *associated with music which is associated with subjective reports in unrelated individuals of* fear, happiness, sadness, tenderness and liking. This is accepted as serious scientific data on emotion, regardless of the fact that during waking "we make gross, enduring mistakes about even the most basic features of our currently ongoing conscious experience, even in favorable circumstances of careful reflection, with remarkable regularity."[155] If we are to take science seriously that grounds itself in waking self report, either as direct data or as reference point for imaging, we have no ground to doubt self-report which originates in awakenings.

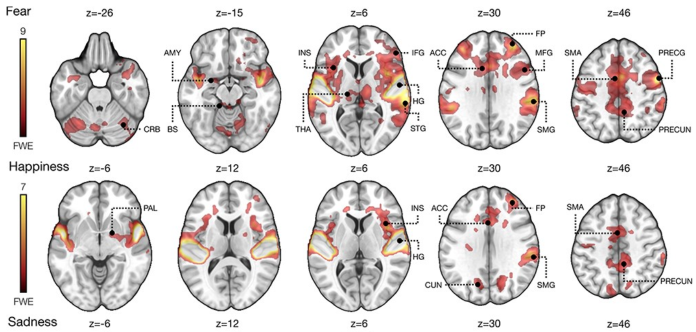

Figure 14 “Brain regions responding to fear, happiness, sadness, tenderness and liking.” Putkinen (2021)

> *“Although the field of Psychology is interested not just in behavior but also in subjective experience, it seems that current views of mental health do not tend to take into account characteristics of nocturnal consciousness when defining or diagnosing psychopathology.”*
> Nirit Soffer-Dudek, *Arousal In Nocturnal Consciousness* (2017)[156]

Using Self-Report Data

> *“It is scarcely surprising that neurological disorders can alter dreaming either quantitatively or in striking and specific ways. Every practicing neurologist must be aware of this, and yet how rarely do we question our patients about their dreams. Though there is virtually nothing on this subject in literature, I think such questioning can be an important part of the neurological examination, can assist in diagnoses, and can show how a sensitive barometer dreaming may be of neurological health and disease.”*
> Oliver Sacks*, Trauma and Dreams* (2001)[157]

In this section, we will consider what it means to trust a dream report, and the clinical implications of using self-report data. A methodological choice (mechanistic instead of subjective models) has consequences in both lab and clinical settings, and one of the aims of TDI is to bring us back to a more balanced relationship between the two. We happen to be in a reckoning moment for the field of biological psychiatry right now, with the field coming to terms with the fact that a half century of search for neurobiological underpinnings of mental disorders has largely failed to improve mental health and subjective data must be given more weight.[158] Perhaps the most damning report on biological psychiatry comes from Tom Insel, head of the National Institute for Mental Health (the largest research organization in the world specializing in mental illness) from 2002-2015. Here is Insel, writing after stepping down from the role at NIMH:

> *“During my tenure as the ‘nation’s psychiatrist,’ the nickname for my role, I oversaw more than $20 billion for mental-health research, and I was eager to share evidence of the agency’s scientific success. I clicked through my standard PowerPoint deck featuring high-resolution scans of brain changes in people with depression, stem cells from children with schizophrenia showing abnormal branching of neurons, and epigenetic changes as markers of stress in laboratory mice. We had learned so much! We were making so much progress!*
>
> *While I could see heads nodding in the front row, a tall, bearded man in the back of the room wearing a flannel shirt appeared more and more agitated. When the Q&A period began, he jumped to the microphone. “You really don’t get it,” he said. “My 23-year-old son has schizophrenia. He has been hospitalized five times, made three suicide attempts, and now he is homeless. Our house is on fire and you are talking about the chemistry of the paint.” As I stood there somewhat dumbstruck, he asked, “What are you doing to put out this fire?” The scientific progress in our field was stunning, but while we studied the risk factors for suicide, the death rate had climbed 33 percent. While we identified the neuroanatomy of addiction, overdose deaths*

had increased threefold. While we mapped the genes for schizophrenia, people with the disease were still chronically unemployed and dying 20 years early."

Tom Insel, *What American Mental Health Care Is Missing,* The Atlantic (2022)

If mechanistic, third-person treatments fall short in terms of efficacy, are they effective in furthering our *understanding* of mental health? In many ways the popular notion that understanding medication which affects the symptoms of a disorder will help us understand the roots of that disorder is not logical. It is like saying 'I have pain so I must have an aspirin deficiency.'[159] To understand mental health symptoms which manifest in conscious experience we need to take both the subjective mind *and* the mechanistic brain seriously. In wake, this entails adjusting the emphasis on biological psychiatry while in sleep this means taking experiential dream data seriously. This is not to say we should turn away from mechanistic frameworks entirely, but to uncover the damage caused by turning away from experience as legitimate and worthwhile data. We must not make the same mistake in sleep, ignoring dream data and only looking at the sleeping brain.

"We need to recognize the crisis of the over-medicalization of psychiatry," writes sleep scientist Sidarta Ribeiro. Ribeiro makes a strong case for the inclusion of dream data in psychiatric care and in introspective practice outside of the clinic in his 2021 book *The Oracle of Night.*[160] Ribeiro writes that dreams have been shown to be valuable prognostic data, diagnostic data and avenues of intervention.[13] Dream data holds clues for the construction of a successful therapeutic setting, and points to the fact that many mental health problems go beyond the brain and reflect impoverished environments or traumatic pasts.

Why should we suppose that dream disturbances might be linked intimately with psychiatric disturbances? We know that sleep disorders are strongly comorbid with a number of mental disorders. [161] Sleep disturbances may be an early sign or even the cause of some psychiatric disorders, and early treatment of sleep problems might halt progression to full manifestation of a disorder. Sleep disturbances are less stigmatizing and less difficult than other psychiatric symptoms for both patient and provider to discuss. We know that improving sleep not only provides immediate relief of sleep related symptoms, it may also lead to improvements in co-occurring pathology such as depression, and a successful course of sleep-focused therapy can instill confidence in the patient that therapy works and is worth the investment.[162] While we know all this about sleep, we know little about the dream content in populations with comorbid sleep and psychiatric conditions, and we know nearly nothing about whether intervening in disturbed dreaming might alleviate waking symptoms and alter the course of waking disease. To quote sleep clinician Francesca Siclari (2020): "Sleep medicine has greatly developed in the past decades, mostly through knowledge gained from managing millions of patients with sleep apnea and insomnia, but the phenomenology and physiology of dreaming have been overlooked, even though they bear relevance to sleep clinicians."

Why should we suppose that dream content holds valuable prognostic and diagnostic insight? Consider disturbed dreaming in the form of nightmares; Studies find 71-90% of trauma victims diagnosed with PTSD have frequent nightmares, compared to only 2% to 5% of the general population. A nightmare is both an aggravating symptom and a window into the disorder. Knowing more precisely how nightmares function would bring us closer to finding out how we remember and ruminate in both wake and sleep, what happens when memories return unbidden and fail to evolve, and in turn improving treatments of disturbed daytime rumination and dreaming. Nightmares are linked to a fourfold increased risk of renewed suicide attempts, and distinguish those who stop at one suicide attempt from those who will try again even while other commonly assessed waking symptoms are not significantly differentiating. Michael Nadorff, a clinical psychologist specializing in suicide says "depression doesn't, anxiety doesn't, all these common risk factors are not differentiating. I ask suicide clinicians all the time, when you do a risk assessment, do you ever ask about nightmares? And no one ever does. No one ever does." To be clear, these nightmares offer insight over and above waking assessments: The American Academy of Sleep

Medicine has said “The pathways between nightmares and suicidal behaviors appear to operate independent of comorbid insomnia and depression." [163,164]

The relationship between disturbed dreaming and psychiatric illness in wake is not so simple though, as some bad dreams actually predict amelioration of symptoms. A study by Rosalind Cartwright showed that in a sample of severely depressed patients, 72% could be classified correctly as remitted or not remitted at follow-up based on the presence of negative dreams in the first vs. second half of the night. Subjects reporting more negative dreams at the beginning and fewer at the night's end were more likely to be in remission one year later than were those with fewer negative dreams at the beginning and more at the end of the night, suggesting early negative dreams may reflect a within-sleep mood regulation process taking place, while those that occur later may indicate a failure in the completion of this process. Clinicians have noted a relationship between depressive symptoms and antidepressants (ADs) on the one hand and dream recall frequency (DRF) and dream content on the other. “Though there are clear-cut pharmacological effects of ADs on DRF and dream content, publications have been surprisingly scarce during the past 60 years. There is evidence of a gap in neuropsychopharmacological research. AD effects on dreams should be recognized and may be used in treatment.” [165]

In the case of psychosis, dream reports are informative in distinct ways from waking reports. As noted above, the speech graphs of schizophrenic, bipolar and control subjects are more varied for dreams than for waking reports, and these reports hold more precise diagnostic value.[13] Understanding how the brain generates perceptions and beliefs in dreams without the influence of external inputs could offer insight into the waking hallucinations and delusions frequently encountered in neuropsychiatric disorders. In the case of substance use disorder, recent research shows dreams of drug use can predict likelihood of relapse.[166] These dreams do not simply reflect daytime cravings and drug use; Colace [167] showed that subjects who used heroin constantly did not have drug dreams, whereas subjects who became abstinent began to have frequent dreams of seeking or using heroin, correlated with degrees of physical withdrawal. Addiction specialists currently face a formidable problem in terms of measuring craving for alcohol and drugs. Drug-use dreams might represent a craving measurement with solid construct validity.

The dreamt body holds clues that can also be distinct from the sleeping body; in dreams, patients with congenital paraplegia can walk, those with sleep apnoea rarely suffocate, and those with phantom limb pain can see it disappear. Moreover, the alterations in body representation seen in dreams can have consequences for higher-order emotional and cognitive processes. In a nationwide study, Bekrater-Bodmann et al. surveyed a large cohort of amputees for the presence of residual limb pain, and found that patients having an impaired body in dreams predicted presence of phantom limb pain.[168] A recent pilot suggested that a Virtual Reality experience which encourages participants to move a ‘frozen’ phantom limb is tied to both novel dreams of an intact body and a reduction in phantom limb pain. [169] Directionality in such studies is impossible to determine, and this may indicate that suffering in the awake state influences body representation in dreams, or that body schema might influence waking pain and a dream incubation might relieve waking pain. Recent evidence suggests that frequent aggressive dreams in newly diagnosed Parkinson’s Disorder can predict early motor and cognitive decline.[170] Data from such patients are valuable for dream science in illuminating the form and formal features of dream construction, and dream science is valuable for these patients in providing novel prediction and treatment options.

> "For every parent discipline such as psychology...there is a more fundamental field, an anti-discipline — in this case, brain science – that challenges the precision of the methods and claims of the parent discipline...The parent discipline is larger in scope and deeper in content and therefore cannot be wholly reduced to the anti-discipline...This is what is happening in the merger of cognitive psychology, the science of mind and neural science, the science of the brain, to give rise to a new science of mind.”
> Eric Kandel, *The Age of Insight* (2012)[171]

What Dreams Are For: NEXTUP, Memory, Emotion, Creativity

NEXTUP

Research showing dreams can be prognostic in psychiatric illness, and even intervention opportunities, suggests that dreams are *for* something. It is evident that the processing our thoughts undergo in sleep is far different from, and differentially beneficial than, waking cognition – this is why periods of sleep offer benefits for memory and emotional processing over and above time-matched periods of wake.[136,137] Yet the question of the use of *dreams* isn't just a question of the utility of overnight reactivation and reprocessing of waking thoughts in sleep — it is a question of the utility of the dreamt *experience* of that reactivation. While our daytime experiences are being processed in sleep, we are simultaneously having conscious experiences of at least some of these processes. So, do dreams have a purpose? And does that purpose rely on dreams being conscious?

As we probe the use of experience in sleep, we should also hold a parallel question in mind: What use is waking consciousness? What use is waking metaphor, visualizing, imagining? In waking life, most learning has a conscious phenomenology: we take in new information, reference the past, project to the future, feel the emotions engendered by each of these narratives and plan accordingly. In *The Feeling of What Happens*, Antonio Damasio argues that none of this could happen without consciousness, and without narrative conscious experience specifically. [172] Without the ability to tell stories we could not synthesize or simulate effectively, and information could not be integrated and assessed across scales of space and time. Even for problems where internal narrative experience and emotion appear irrelevant, like fitting puzzle pieces together, we hover above the board and imagine the future feeling of fitting a held piece into a vacant space and act accordingly. Dream experience, like waking consciousness, could offer parallel advantages beyond non-conscious brain processing.

"For every two hours we spend awake, taking in new information," Robert Stickgold and Antonio Zadra write in their 2021 book, *When Brains Dream,* "it appears that the brain needs to shut down all external inputs for an hour to make time to figure out what it all means." Stickgold and Zadra are the creators of the NEXTUP model of dreaming. NEXTUP, short for Network Exploration To Understand Possibilities, focuses on the more complex kinds of memory processing that are benefited by a night of sleep—namely the extraction of meaning and gist, and the connection of a wide web of memories to create contextual understanding, creativity and emotionality—and suggests dreaming appears to play an important role in how memories are selected for these processes and how they subsequently evolve across the night. NEXTUP argues that dreaming allows the sleeping brain to enter an altered state of consciousness in which it can construct imagined narratives and respond emotionally to them. While dreaming, the brain identifies associations between recently formed memories and older, often only weakly related memories, and monitors whether the narrative it constructs from these memories induces an emotional response in the brain. If an emotional feeling is detected, the brain tags the association as potentially valuable, strengthening the link between the two memories and making the association available during subsequent wakefulness.[173] An association could be valuable because of its semantic, creative, or personally relevant emotional properties.

NEXTUP argues that the linking of weak associations would not happen "in the glare of day, when our brains are dealing primarily with new incoming sensations and the balance of neurotransmitters in our brain is optimized for processing the here and now."[173] While that kind of optimization serves an obvious purpose, the opposite mode is necessary, too, so at night our brains wander as widely as they can. Our dreams thus serve to explore and expand the solution space, helping us to discover new possibilities.

This theory accounts nicely for the brain environment which has evolved to instantiate dreaming. Because the dreaming brain cannot access and incorporate complete episodic memories, narrative construction during dreaming is based on *semantic* associations of these events, giving dreams their metaphorical quality and allowing for a more expansive investigation of associative links.[174,175] Further, the neurochemical modulation of the brain is altered during sleep, and especially during rapid eye movement (REM) sleep, when the release of norepinephrine and serotonin in the brain is shut off while levels of acetylcholine reach their peak in regions such as the hippocampus. These shifts bias memory networks toward the activation of normally weak associations, perhaps explaining the bizarreness of many dreams, especially during REM sleep. Further, REM sleep is accompanied by a general activation of the limbic system, presumably explaining the enhanced emotionality seen in REM dreams, while also biasing the brain toward creating emotional responses to imagined dream narratives.

Moreover, NEXTUP does not leave out daydreaming: We have seen earlier that in instances of mind-wandering, whenever the waking brain doesn't have to focus on some specific task, it activates the default mode network, identifies ongoing, incomplete mental processes and tries to imagine ways to complete them. If a task remains incomplete, NEXTUP theorizes, the brain sets the problem aside after tagging it for later sleep-dependent processing. Thus we see DMN activity in mind-wandering, linked to creative problem solving, and continued DMN activity in hypnagogic sleep onset (where dreams are most likely to contain direct incorporations of pre-sleep experience). [176] NEXTUP proposes that brief hypnagogic dreams appear to extend the DMN's work into the sleep period, identifying and tagging current concerns for further sleep-dependent processing, and perhaps then beginning to identify associated memories for later consideration.

The experience of dreams should reflect their theorized function. If we suspect that earlier in the ultradian cycle dreams are meant for tagging memories and transitioning daytime unfinished problems into sleep, while later dreams are meant for exploration of the solution space, we would expect earlier incorporations to be direct and later incorporations to be indirect, weak associations. One of Stickgold's seminal studies used the skiing arcade game Arctic Racer: when reports were collected at the start of the hypnagogic period within 15 seconds of sleep onset, dreams were eight times more likely to show direct incorporation of the skiing game (i.e. skiing in a dream) than indirect incorporation (i.e. a snowstorm). But after just two minutes of sleep, the rates of occurrence had become the same for both direct and indirect incorporations. Another group of participants were allowed to sleep for two hours before any reports were collected. After two hours, they were awoken and then allowed to fall back asleep. They were then awoken again within two minutes and their sleep-onset reports collected. This time the ratio of indirect to direct incorporations was five times higher than for those collected right at the start of the night.[15,177] Yet another study had participants practice the Nintendo game Grand Slam Tennis before collecting eight sleep-onset dream reports that night. Overnight improvement seemed to depend on how similar dream incorporations were to the actual game for the first four of these sleep-onset dreams, but not for the last four. Perhaps only the earlier, more direct incorporations successfully tagged the game memories for NEXTUP.[178] The overarching theory of NEXTUP suggests that these N1 dreams are largely focused on incorporating relevant current concerns into the dreaming brain, while the rest of the night involves a shift from recent and direct to remote and indirect associations.

Memory and Learning

> *"...with each new bit of learning, a furrow is made and the surface is transformed, acquiring more and more indentations, valleys, and creeks. The contact with reality, like the pressure of water against the rigidity of stone, sculpts our synaptic topography until we reach old age and become a grand canyon of experiences accumulated on top of one another, a vast, deep central valley surrounded by countless other smaller valleys, each trenched and molded by autobiographical incidents. Thus the brain becomes like a palimpsest of events lived and imagined, a mental map of a whole life made up of superimposed experiences from the remotest past we can remember to the most distant future we can imagine"*
> Sidarta Ribeiro, *The Oracle of Night*

> *“There is no dream but in forgetting a word.”*
> Edmond Jabès “Outside Time: The Dream of the Book” p.27

The different mnemonic functions of REM and NREM seem to be reflected in their typically differing dream phenomenologies. Hippocampus-dependent memory seems to benefit particularly from NREM sleep, and subjective reports from NREM sleep stages are more likely to contain (hippocampus-dependent) episodic memory sources. Memory for emotional material is preferentially enhanced by REM sleep, and dream experiences from REM have uniquely intense emotions.[179]

Dream phenomenology further correlates with task performance in the laboratory. Novel waking-life experiences are incorporated into the content of NREM dreams, particularly with the formation of new memories, suggesting dream content can reflect the reprocessing of newly learned material. There is evidence that dream content drives memory consolidation for recently learned facts and for language learning, wherein low latency of incorporation of a newly learned language into dream content positively predicts language learning.[180] Morning recall of short stories encoded the night before sleep shows a correlation between story-related words in dream reports and memory for stories the following morning.[179] Testing a word-picture memory task, a recent paper showed that incorporation of stimuli into NREM sleep dreams – but not incorporation into REM sleep dreams – positively predicted memory performance the next morning.[141] Another recent study suggests that when something new is learned and this new learning is incorporated into dreams, the extent to which this occurs is associated with improved performance, and also with the capacity for reasoning in general.[178]

Perhaps most convincing is the work done by Erin Wamsley and Robert Stickgold in 2010.[181] Participants were trained on a 3D virtual maze task prior to a 1.5-hour nap opportunity or equivalent awake period. All subjects were prompted three times during this 1.5 hours to verbally report “everything that was going through your mind”. In the sleep group, participants who referred to the maze task in their subjective dream reports improved ten-fold at retest compared to Sleep participants who gave no task-related reports – yet thinking of the maze while awake did not provide any performance benefit. Dream experiences here are clear reflections of learning-induced reactivation of memory networks during sleep, and the experience of this reactivation correlates with hugely enhanced memory performance. Importantly, the dreams in this experiment did not veridically replay waking experience of the maze task, but were fragmented and mixed with older memories. Again, experience apparently matches the mnemonic function of the sleep state: the fragmented, mixed form reflects the memory consolidation process being more complex than simply strengthening memories in their original forms, instead integrating new information into established cortical memory networks, extracting meaning and more. Wamsley & Stickgold recently replicated this study, reproducing results of a significant relationship between task inclusion in dream reports and enhanced performance post-sleep (and a non-significant trending relationship between performance improvements and inclusion of task in waking reports).[177] Within the recent history of a dream science that seems to strain to ignore dreams, these studies stand out as clear-eyed and open to all of the important data sources which present themselves.

> *“My dream experience was kaleidoscopic...I seemed to be thinking with the intention of trying not to. It felt similar to most nights I start off trying to fall asleep. Then things became more intertwined: thoughts of the people in my life would bubble to the surface of remaining consciousness, mixed with more intentional thoughts of a "tree." These latter thoughts manifested as an overhead view of a conifer forest, along with reverence for the beauty of tree root systems, specifically. I thought of large, robust and thirsty tree roots extended into the ground like capillaries. Also, regarding the contents of my thoughts/dreams, time seemed to flatten a bit: people from my past bubbled into consciousness thoughts that contained items and people from my present. Halfway in, I did not feel like I was in or identify with ML, Kendall Square, Cambridge etc. That was surprising.”*
> Subject 9, Sleep Tree-Incubation, Dormio Creativity Study

Emotion

Following from evidence that dream content reflects ongoing memory processes, the strong emotional tone of dreams suggests that there is also ongoing sleep-dependent affective processing. The most apparent link between daytime events and subsequent dream content is current emotional concerns and themes, *not* actual daytime events.[182] There are direct effects of waking life on dream emotions and, in turn, of dream emotions on waking-life: The two feed off of one another, wherein the intensity of the negative effects of daytime events on dream content predicts—in addition to emotional intensity of the dream—the effect of that negative dream on next-day mood.[183]

One of the theorized functions of REM sleep is to reprocess upsetting memories from the previous day in a neurochemically calm thinking environment: REM sleep is the only time throughout the 24 hour circadian cycle when your brain is completely devoid of noradrenaline, a key stress-related neurotransmitter.[184] REM sleep and dreaming may thus serve a mood regulatory function, desensitizing affect-laden daytime events. High activation of fear-related brain regions in frightening dreams lowers the response of these same regions to threatening stimuli in wakefulness.[185]

Findings relating daytime mood with dream mood, and relating REM with affect regulation, have clear clinical importance in the context of reactive depression. Recently divorced women who initially suffered depression dream of their ex-spouses more frequently and with stronger emotion than those not depressed. Of those who suffered depression, those who were in remission one year later were the same patients that had significantly more such dreams.[186] These findings indicate a potential functional connection between dream content and recovery from emotional conflict or trauma, although the directionality of causal relationship is unclear.

Patients who develop PTSD after a traumatic experience have abnormally high levels of noradrenaline during their REM sleep, and are left with repetitive nightmares replaying veridical narratives of their trauma experience. These nightmares are such a reliable PTSD symptom that they form part of the list of diagnostic features for the disorder.[187] In turn, prazosin, a blood pressure drug which happens to suppress noradrenaline in the brain, reduces repetitive trauma nightmares in PTSD.[188] These nightmares which replay traumas exactly as they happened in the day can profoundly exacerbate PTSD, while changes in dream content alleviate symptom severity and are correlated with reductions in suicidality.[189]

Working with dream content specifically can be helpful for those suffering from trauma, nightmares or grief. In bereavement dreams following the death of a loved one, dream phenomenology mirrors phases of mourning and thus offers mental health workers diagnostic clues to the stage of mourning the survivor is experiencing. Dreams of the deceased appear highly prevalent among, and often deeply meaningful for, people who are grieving. Effects of the dreams on bereavement processes include increased acceptance of the loved one's death, comfort, spirituality, sadness, and improved quality of life.[190]Reflecting on dream content during the day offers benefits to people in clinical as well as non-clinical settings. Evidence from therapeutic work suggests that focusing on dreams increases ratings of deepened self-perception and personal insight over and above reflection on waking thought content.[191] Considering all this research, the content of dreams appears to be a key factor in emotional healing throughout the 24-hour cycle

> *"I wandered in thought about all the activities that took place around those trees...I saw the darkness of my eyelid, but it was in the shape of a tree and kept fluctuating...I was playing dodgeball during recess in elementary school. One of the older kids threw a ball at the ground where I was and hit my head, which pushed my chin into the ground. I recall crying at that time. This time, I was curious to know what was going through in the older kid's head, so I tried to envision what he saw and how he felt. That's the first time I was 'woken up.' From then on I tried to recall past memories, and explore what other people saw and might have been thinking...Where it got most interesting was where I ended up envisioning a house that felt like I lived in, and I had a spouse (which is the girl I'm currently interested in) and I imagined sending off 'our kid.' It was*

something like, "OK have fun, and be back before midnight! Oh they grow up so fast" kind of dialogue. And it never happened, but it felt very real and I fell asleep. In the last dream, I was trying the same technique of visiting an old memory and trying to see someone else's perspective. This time however, there were no one else around that time when I was looking at the tree. So I couldn't try to imagine what other people might have seen or thought. However, I realized new things about the tree...So when I saw this tree (that I've seen in the past many times) in my dream, I realized for the first time just how old and magnificent this tree was. I also had to wake up at this time, and there was great internal struggle to do so because I wanted to keep on exploring. Since I was trying to imagine what others saw or thought, there were many times I would place my perspective in their perspective and have their vision. There was no hesitation in trying to experience what I decided to do. Anything that I did not like, I decided not to explore it. As a consequence, anything that I decided to explore, I had no hesitation about. Use this for therapy. For perspective taking, and taking a new perspective on memories. Ego death. I think I experience a lot of insecurity, insecurity at work. And in this state I experienced no insecurity. I had heard about this state of mind but never experienced it. Now I know how real it is."
Subject 11, Sleep Tree-Incubation, Experiment 1

Creativity

"There is one very remarkable thing in dreams, for which I believe no one can give a reason. It is the formation of visions by a spontaneous organization carried out in a moment—a formation more elegant than any which we can attain by much thought while awake. To the sleeper there often occur visions of great buildings which he has never seen, while it would be difficult for me, while awake, to form an idea of even the smallest house different from those I have seen, without a great amount of thought. [. . .] Even such unnatural things as flying men and innumerable other monstrosities can be pictured more skillfully than a waking person can do, except with much thought. They are sought by the waker; they offer themselves to the sleeper. There must therefore necessarily be some architectural and harmonious principle, I know not what, in our mind, which, when freed from separating ideas by judgment, turns to compounding them."
Gottfried Leibniz (1956, Vol 1, pp 177-178)[90]

Mary Oliver, America's eminent walker-in-the-woods and Pulitzer prize winning poet, writes that the creative inspiration which "supplies a necessary part of the poem — the heat of the star as opposed to the shape of the star, let us say — exists in a mysterious, unmapped zone: not unconscious, not subconscious, but cautious".[192] This notion is familiar to many of us, that we hide much of our thinking from ourselves, especially the thoughts that are perhaps too strange or too dark, metaphors too tenuous or associations too loose to be considered useful by our attentional, executively controlled waking minds.

The decline of executive control in dreams is a form of disinhibition, and as such, dreaming can be understood as a form of fully immersive, disinhibited imagination.[90] Both dream recall frequency and complexity have been correlated with higher creativity.[193] The acceptance of implausibility present in dreams affords an opportunity to explore non-obvious associations in sleep, and being able to access and remember one's dreams could provide a larger pool of ideas from which to draw inspiration. Ability to transcend the here and now – involving imagination of vivid simulations across temporal, spatial, social, and hypothetical domains – is correlated with improvements on creativity assessments in the laboratory and creative achievements in life and is exemplified by dreaming.[194]

REM sleep, associated with the most vivid dreaming mentation, has been shown to facilitate cognitive flexibility and creative problem solving.[5] This cognitive flexibility could lead to an expansion of a problem space experienced as objects and characters embedded in dreams, helping dreamers reach new solutions. Dissociated states which mix REM sleep and wakefulness in narcolepsy have a positive impact on scores for the Test of Creative Profile and the Creativity Achievement Questionnaire. This higher performance may be due to more frequent opportunities to incubate and associate ideas during sleep and to remember them upon awakening, specific to dissociated REM states. Within narcoleptics there is a further significant correlation between prevalence of hypnagogic hallucinations, experienced as semi-lucid and easy to remember, and creativity scores. A tighter link between sleeping and waking consciousnesses apparently facilitates creative ideation across the sleep-wake cycle.[4]

The link between creativity and dreaming has been a topic of intense speculation, mainly based on anecdotal reports of artistic and scientific discoveries made while dreaming: these include the periodic table of Mendeleyev, the Beatles' "Yesterday", Salvador Dalí paintings, Otto Loewi's discovery of the neurotransmitter acetycholine, and more. Paul McCartney wrote "The Yellow Submarine" in sleep-onset dreams, in "a nice twilight zone just as you're drifting into sleep and as you wake from it". The philosophical insights of Socrates, the literature of Fyodor Dostoevsky, and the cinema of Akira Kurusawa, Federico Fellini and David Lynch all have been credited to creative inspiration found in their experience of dreams. Deirdre Barrett, a psychologist at Harvard Medical School, has found participants who are asked to 'incubate' a problem in their dreams (by writing it out and reflecting on it before sleep for a week) frequently dream a solution useful to solving their problem: Well over half of the visual artists and fiction writers she has interviewed say they have used dreams in their work, and within STEM fields those who benefit from visualizing problems in three dimensions are most likely to report helpful dreams. To validate these anecdotes empirically, Barrett asked college students to incubate a specific, personally relevant problem of their choosing. Using the simple incubation method of thinking about the problem for 15 minutes before sleep, participants rated 49% of their dreams as relevant and 34% of them as containing a solution, while external judges' ratings of the same dreams were 51% and 25% respectively. A similar study by Walker et al. (2002) found that when woken from REM sleep, participants had a 32% advantage in the number of anagrams solved compared with NREM awakenings, which was equal to wake time performance. Another recent paper examining the impact of sleep on mathematical insight showed that time spent in N1 sleep more than tripled 'Aha' moments of insight compared to periods of wake or N2 sleep.[195]

> *"The most fertile region seems to be the marshy shore, the borderland between sleep and full awakening, where the matrices of disciplined thought are already operating, but have not yet sufficiently hardened to obstruct the dreamlike fluidity of the imagination..."*
> Arthur Koestler, *The Act of Creation* (1964)

These studies leave us with evidence of a tantalizing link between dreams and creativity, but we are left unsure whether creative advantages are conferred by the altered brain state which allows sleep and dreams to occur, or dreams offer an actual *experience* of a creative solution. Historically, creativity studies which focus on waking incubation effects (wherein a break from a task confers a creative benefit) refer to the idea that setting a problem aside for a while helps creative thought and problem solving as *unconscious* processes are working on the problem while the individual is daydreaming, not consciously thinking about the problem.[196] In contrast, conscious work theories have ascribed incubation effects on creative performance to relaxation[197] and to the effects of facilitating cues from the environment.[198] Moreover, sometimes old and inappropriate ideas can cause mental fixation, impeding the generation of new and appropriate ideas.[199] Therefore, in addition to relaxation and facilitating cues, it has been suggested that incubation effects can lead to forgetting of fixating elements and to mental set-shifting wherein wrong cues become less accessible, leading to a fresh, new and unbiased start.[200] Few theories contend that the actual *experience* of mind-wandering which occurs in incubation periods drives creativity, using metacognitive awareness of mind-wandering to survey and extract meaningful content. In dreaming, to answer the parallel question (what creative benefit is seen after a period of *dreaming* incubation) we would need, but have not had until now, a protocol for a controlled experiment on the link between dreams and post-sleep cognition, with techniques for incubating dreams purposefully. This thesis, in Experiment 1, offers clarity on this old question.

"Experiences are both the quicksand on which we cannot build and the material with which we do build. . . .

A method has to be found that makes it possible to work on experiences, and to learn from them."
Frigga Haug, *Memory Work* (2000)

Proposed Dream Function	**Evidence Specific to Dreams**	**Evidence Related to Sleep**	**Evidence in Parallel Literature**
Creativity	Dreams benefit problem solving on a wide range of subject-chosen themes[201] Self-reported high effects of dreams on waking-life creativity[193] Incubated dream content improves performance on content related creativity tasks [202,203]	REM sleep specific improvement of anagram solving[5] Time spent in N1 sleep triples Eureka! moments discovering hidden rule in math task [195] Improved creative performance in Narcolepsy, mediated by higher hypnagogic hallucinations and lucid dreaming [4]	Increases in reported mind-wandering improve Unusual Uses Task performance[204] Incubation periods off task increase creative problem solving over periods of focus [205]
Memory	Dream content related to navigation task improves performance[177] Low latency of incorporation of a newly learned language into dream content positively predicts language learning.[180] Incorporation into NREM sleep dreams positively predicts memory performance on word-picture association task[141]	Periods of sleep benefit declarative memory, procedural memory, gist extraction and more [137] Targeted Memory Reactivation in sleep improves waking memory [139,140]	Classic psychedelics increase the vividness of autobiographical memories and stimulate the recall of autobiographical memories, specifically memories that are affectively intense[206]
Emotion	Fear in dreams corresponds with reduced brain response to fear-eliciting stimuli in wake [185] Dream content predicts progress of depression, PTSD and suicidality [48,186,189] Anxiety and waking rumination is tied to negative affect in dreams [207,208] Imagery Rehearsal Therapy that changes nightmare content is comparably effective to pharmaceuticals in improving PTSD outcomes [188]	Sleep deprivation specifically disrupts encoding of emotionally positive memory [209] Extent of fear extinction is correlated with amount of REM-sleep [210]	Anxious waking rumination is related to nightmare prevalence, insomnia and increased suicide risk [211] Dreamlike effects of psychedelics are theorized to underlie their benefits to emotional well-being[212]
Personal Insight	Focusing on dreams increases ratings of self-perception and personal insight vs focus on waking thought content [80] Bereavement dreams offer clinical insight in the grieving process [190] A large majority of sampled participants (~80%) experience	Improved sleep quality is correlated with improved emotional coping in cancer patients [214] Sleep quality predicts treatment outcome in CBT for Social Anxiety Disorder[215]	The subjective, experiential effects of psychedelics are necessary for their enduring beneficial effects on personal insight and these subjective effects account for the majority of their benefit.[216]

	personal insight in dreams at some point in their lives and about 40% do so regularly[213]		
Empathy	Dream sharing increases empathy in dyads more than sharing waking thought content[217]	Sleep deprivation significantly lowers emotional empathy[218]	LSD dose-dependently increases implicit and explicit emotional empathy, with the highest LSD dose having a significant effect compared with placebo[219]

Figure 15 Proposed dream functions and evidence from across the neurosciences

Methods: Techniques and Technologies for Dream Research Today

"So my emphasis today is going to be on the pivotal role of technologies of inscription and the role that they played in transforming our understanding of sleep over the past two centuries and more precisely I guess how technology has had a decidedly lesser role in our understanding of dreaming in the same period. The relationship between sleep and dreaming is refracted by our technology's representation and intervention, and that the more such technologies come to define our life world, the more sleep comes to dominate the configuration of the sleep and dreaming dyad...the sleep and dreaming dyad is progressively configured in such a way that dreaming is frequently imagined as a form of resistance, a resistance that might best be described as a resistance to a technoscientific social order"
Kenton Kroker, *Sociability of Sleep Salon, Jan 8 2022*

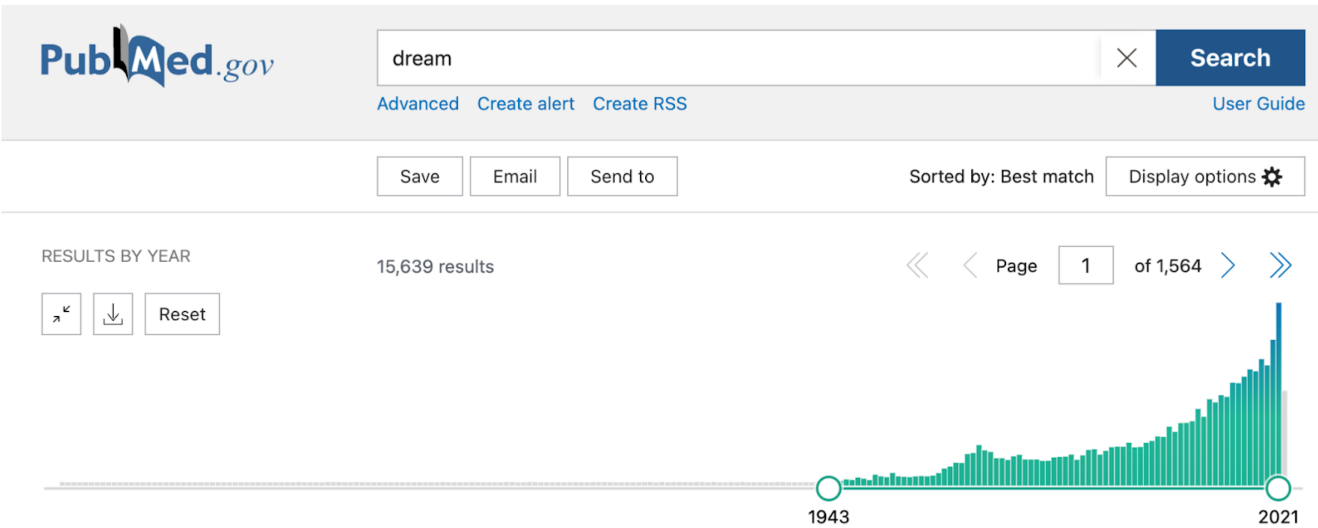

Figure 16 References to “dream” in the NIH paper database have doubled in the last 5 years. Source: *pubmed.gov*

Now that we have a sense of the history of incubation and the present state of dream science, we can move to the central topic of the dissertation: dream incubation techniques, their efficacy, uses, and methodology. Interest in dream altering technologies has boomed during the COVID-19 pandemic, and a host of technological solutions are growing in popularity, although questions remain over safety and effectiveness.[220] Sleep science historian Kenton Kroker, quoted above, writes that “the relationship between sleep and dreaming is refracted by our technology's representation and intervention,” and that this framing has thus far emphasized sleep. This emphasis is in the process of shifting, and technologies of dream alteration and capture will play a pivotal role in how the public comes to understand and interact with the dream state. This shift stems from a realization that the sleeping brain is processing more of the sleeping environment than we had supposed.

Sleep science of the past half century supposed that the dreaming brain was cut off from inputs like sound and sight in the sleeping environment due to a gating of sensory inputs, with sounds or images failing to even reach the cortex. While this was traditionally thought of as a consequence of the brain shutting down to external inputs to maintain sleep, it is now acknowledged that incoming stimuli can still be processed, at least to some extent, while sleep continues.[221] Sleeping participants can create novel sensory associations between tones and odors, reactivate existing semantic associations, can prioritize intelligible speech over unintelligible speech. A recent study had awake participants classify words as either animals or objects (experiment 1) or as either words or pseudowords (experiment 2) by pressing a button with their right or left hand, while transitioning toward sleep. Their brain responses after sleep onset revealed that sleepers can still extract task-relevant information from external stimuli and covertly prepare for appropriate motor responses.[221] A recent study using fMRI showed that a spoken narrative (from the film *Taken*) elicited auditory network and a frontoparietal pattern of activity consistent with high-level narrative plot-following, in both wake and REM sleep.[222] Pre-sleep thirst combined with presentation of liquid-related words in REM sleep increases dreams about liquids, and those who dreamt of quenching their thirst drank less once awake than those who dreamt of being thirsty. [223] De Koninck and Koulack (1975) presented a stressful film prior to sleep, then re-presented the film music during sleep: this led to increased film elements in dreams, and increased emotionality the following day. [224] While this is amazing science, it shouldn't be surprising to the lay reader; We each know the sleeping brain can recognise important sounds and can differentiate words based on their meaning. Consider the experience of being awakened by the cry of a baby, or your own name, or the word 'fire' when a similar volume word without the same semantics would have let us continue sleeping.

Beyond processing of the sensory environment in sleep, the most recent research suggests continued processing of bodily cues influences sleep and dreaming, and the dream is understood as in a constant feedback loop with the body.[14,225] Research suggests this sensing continues across the sleep cycle, yet future research is needed to understand how sleep stage specifically contributes to changes in sensory gating of incoming interoceptive and external bodily sensation. [53] This means the body is a permeable barrier that can be used to interface with the dream world. Neurocognitive accounts of dreaming agree that memory shapes the content of dream experience in a top-down manner—Dreams are affected by everything from basic perceptual and semantic knowledge, to emotional and autobiographical memory, and socio-cultural and evolutionary biases. But dreams are also affected by bottom-up incorporation, and each avenue of influence can become a technique for incubating dreaming. Consider the common experience of dreaming being influenced by muscular twitches during sleep onset when the experience of a sudden hypnic jerk is associated with vivid imagery of falling.[226] Application of electrical pulses to cause these muscle contractions in a sleeper have been shown to affect movement features and sense of orientation in dreams. [227,228] A recent study showed that using transcranial direct current stimulation to inhibit sensorimotor cortex activity specifically decreased the presence of repetitive actions in REM sleep dreams.[229] The authors interpret these findings as evidence that the sensorimotor cortex is causal in the generation of dream movement. It's known that bodily states such as fever,[230] hunger and thirst have been associated with changes in dream quality.[231] Recently, Rozen and Soffer-Dudek (2018) found that occurrence of teeth dreams (one of the most common dream themes reported by 39% of the population), correlated with the experience of dental irritation, but not with other measures of sleep disturbances or psychological distress.[232,233]

A spray of water on the skin,[96] application of a pressure cuff to a specific limb, or application of electrical pulses to cause muscle contractions in a sleeper have each been shown to affect dream features, increasing vividness or movement sensations in dreams.[234] In Nielsen (1993), pressure application to the leg resulted in visual-kinesthetic synesthesia, direct incorporation of pressure and squeezing sensations, and increased bodily bizarreness in dreams.[234] Schredl et al. (2009) show that pleasant scent increases dream positivity whereas unpleasant scent increases negativity.[235] Induction of lucid dreams has also been facilitated through audio and visual stimulation during sleep.[236] Within a Targeted Lucidity Reactivation (TLR) protocol, audio and visual stimuli are associated with a lucid mind-state prior to sleep, and then re-presented during REM sleep; this technique induced lucid dreams in 50% of participants in a morning nap.[237,238] Touch, sight, sound, smell and more are permeable barriers that can be used to interface with the world of dreams, altering dream lucidity, affect and content.

Parallel work in Human-Computer Interaction (HCI) has utilized the body as an interface to increase the immersion of virtual environments in Virtual Reality by engineering multimodal devices that can simulate sensations such as touch, temperature, and inertial forces as well as audio-visual or olfactory sensations. HCI researchers have spent decades exploring how to generate simulations through a variety of sensory stimulation, which have potential to be adapted to dream engineering purposes. These systems are prime candidates to influence dreams on demand and in ambulatory settings, likely to be put to use by researchers in the coming years and by the lay public far sooner as demand for dream influencing technologies is high.[220]

As we learn about techniques to influence dreams, we must keep in mind that much of the evidence for the benefits of dreaming is recent, and unreplicated. Dreaming is not a panacea, nor is the scientific community always too conservative regarding inclusion of dream-based subjective interventions in treatment paradigms. Yet regardless of resistance to dream data in the scientific community, popular interest in dreams is surging. Having a sense of the tools available to the public and to the scientific community is necessary to chart the best possible path for inclusion of dream incubation techniques and technologies in our knowledge production and personal practice.

A search of *pubmed.gov* spanning both humanities and the sciences shows a doubling of references to dreams in the past 5 years. Groups dedicated to dream interpretation are thriving.[80] Within the world of Human Computer Interaction, studies show a growing interest in altered states of consciousness (ASCs) and mindfulness, lucid-dreams, and hypnagogic states have become subjects of technology and design studies.[239] Part of the recent surge in interest is that, according to dream scientist Tore Nielsen, “the world is dreaming about COVID… a surge of this magnitude had never been documented. This upwelling of dreams is the first to occur globally and the first to happen in the era of social media, which makes dreams readily accessible for immediate study. As a dream ‘event,’ the pandemic is unprecedented.”[240] Borrowing a metaphor from sleep scientist Antonio Zadra, the usual state of the world — in which busy, sleep-deprived people fail to notice dreams — is a bit as if we all lived in a bright city, unable to see beyond the artificial lights that surround us. With the arrival of lockdowns, many people weren’t setting alarms, were sleeping longer and sleeping later, waking gradually rather than rushing to work. In France, the Lyon Neuroscience Research Center found that dream recall increased by 35 percent the month after lockdowns began, while a survey of 3,000 Americans found that nearly a third noticed themselves suddenly remembering more dreams.[240] The sudden surge in dreaming, Zadra says, was as if a catastrophic event put out all the outdoor lights, and people were amazed to see so many stars. As we create and implement new technologies for influencing dreams, it’s crucial to keep in mind that the stakes are serious insofar as our tools frame our perspectives on both our environments and ourselves.

> *“Incubation without preparation, as a means of invoking the god and attracting his or her attention, would have been unthinkable—but also impossible. In light of this, one wonders what kind of ‘dreams’ the sleep laboratory produces; perhaps it is no surprise they are fragmented, incoherent, or apparently “without meaning” if they entail no preliminary ritual communion with the god of the place, who is, in the end, a machine.”*
>
> Kimberley Patton, *A Great and Strange Correction* (2004) [31]

Stimulation Techniques

Stimuli meant to alter sleep and dreams can be applied pre-sleep, during sleep, or both. Cue stimuli can be meaningful via implicit association, as in the case of identifiable sounds like ocean waves, or by explicit association cemented in wake. Choices in the presentation and pairing of cues are likely to influence both dream incorporation and post-sleep effects. This thesis focuses on targeted dream incubation (TDI, also called targeted dream reactivation)[14], one amongst many potential methods for incubating dreams and altering sleep.

Pre-sleep priming presents a stimulus before sleep, e.g., a video or music to influence dream content in subsequent sleep.[47] *Dream incubation* involves pre-sleep intentional rehearsal of content, such as visualization of a rescripted nightmare, repeating an intention to become lucid, or focusing on a personal problem to incubate a creative solution.[241] *Dream direction* applies a sensory stimulus during sleep and relies on implicit associations to sensation to direct dreams: a pleasant scent to ameliorate dream emotion, muscle stimulation to augment dream movement, speech to direct dream narrative.[235] Of note, pre-sleep priming, dream incubation, and dream direction may affect dream content in relatively metaphorical or idiosyncratic, but nonetheless functional ways. *Rhythmic entrainment* acts on physiological rhythms during sleep, from fast rhythms like neural oscillations to slower rhythms like respiration or circadian changes in temperature; while entrainment does not necessarily influence dream content, it may improve sleep functions and may alter dream experiences by altering sleep architecture.[242] Finally, in *targeted reactivation*, a stimulus is paired with specific content during wake, and when the stimulus is re-presented during sleep its associated content is reactivated. Targeted reactivation can enhance consolidation of specific memory traces (*targeted memory reactivation*),[243] induce lucidity (*targeted lucidity reactivation*),[238] or trigger imagery that was rehearsed prior to sleep (*targeted dream reactivation, i.e. TDI*).[225]

Sense	Technique	Technology	Function
Sound	Targeted Reactivation[1] (TMR, TDR, TLR), Dream Direction (DD), Rhythmic Entrainment[1] (RE)	Bone conduction, Dormio, Bluetooth speaker	Improving sleep depth and sleep efficiency (RE), alleviating nightmares (TDR, TLR), augmenting creativity (TDR), ameliorating dream valence (TLR, DD), enhancing memory (TMR)
Visual	Targeted Reactivation (TLR), Pre-Sleep Priming (PSP), Rhythmic Entrainment (RE)	Light stimulation masks (e.g. DreamLight), Head-Mounted Displays, video monitors	Augmenting creativity (TLR), ameliorating dream valence (TLR, PSP), alleviating nightmares (TLR, PSP), improving sleep depth and efficiency (RE)
Temperature	Dream Direction (DD), Rhythmic Entrainment (RE)	ChilliPad, thermal sheet, heated eyemasks, hand warmers	Ameliorating dream valence (DD), alleviating nightmares (DD), reducing sleep onset latency (RE), improving sleep depth and efficiency (RE)
Haptic/ Proprioceptive	Dream Direction (DD), Rhythmic Entrainment (RE)	Pressure cuff, Electrical Muscle Stimulation, Galvanic Vestibular Stimulation, rocking	Ameliorating dream valence (DD), reducing sleep onset latency (RE), motor learning (DD)
Smell	Targeted Reactivation (TMR, TDR), Rhythmic Entrainment (RE), Dream Direction (DD)	Essence, olfactometer, scent diffuser	Enhancing memory (TMR), improving sleep depth and efficiency (TMR, RE), alleviating nightmares (TDR, DD), reducing sleep onset latency (RE), ameliorating dream valence (DD)

Figure 17 Techniques, targets and functional avenues for dream influencing. Table adapted from Carr et. al. (2020)[14]

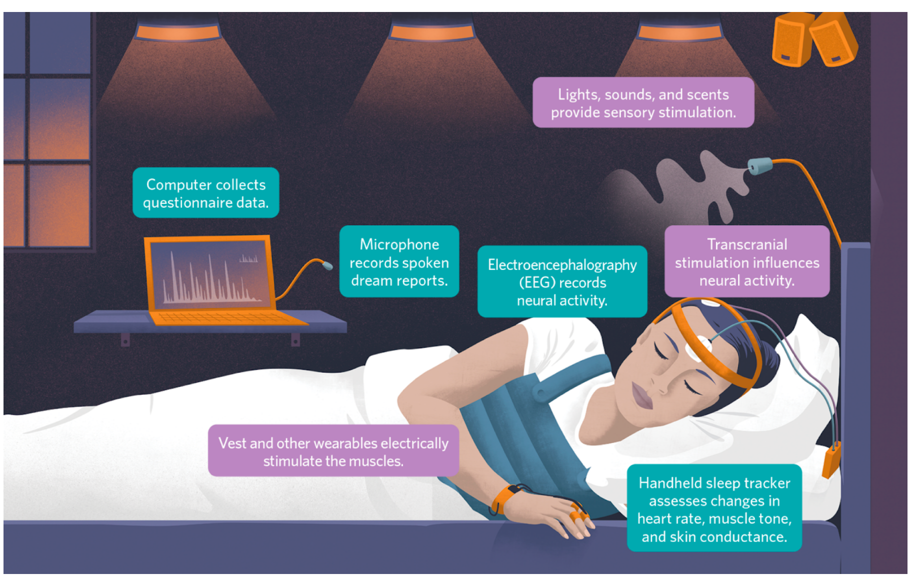

Figure 18 A vision of one possible future involving dream influencing devices. Image from Offord (2020).[45]

There is a necessary caveat here regarding specificity. One-to-one correspondences between a physiological and a psychological variable in thought content are not common in the neuroscience literature either in wake or in sleep. More commonly, multiple physiological responses accompany a single psychological variable or vice versa. [244] EMG activity in the smiling muscle zygomaticus is associated with both positive dreamed affect and dreamed communication, though often there is no isomorphism between dream action and waking muscle movement.[245] In wake, a smile means different things at different times of day, in different social contexts, in different cultural frameworks – in societies with high corruption indicators, trust toward smiling individuals is reduced.[246] We should not expect that stimulating a muscle, then, creates the same mentation across many sleeping individuals – let alone expect a smell or sound to have consistent effect across individuals. Stimulation and concomitant dreams need to be understood in light of the minds being stimulated, and accordingly as a field in which we will need to develop consistent measures of 'successful' incubation that are effective in diverse subject groups.

Dream Incubation Devices: Using the Dormio Device for TDI

Stimulation techniques rely on sleep staging technologies, as different sleep stages have differing functions and differing levels of sensory gating.[247,248] For the purpose of this thesis, it is only necessary to understand the *Dormio* device in depth, built for staging N1 sleep. The Dormio system is used in Experiments 1, 2, and 3 in this thesis (Experiment 4 uses a Hypnodyne ZMax EEG, described in the Experiment 4 section). The Dormio device consists of a handworn sleep tracker and an associated app, used to communicate with users and record dream reports via laptop or cellphone. The user interaction of the Dormio system crosses multiple stages of consciousness including wake, NREM 1 and NREM 2.

The core novelty of the Dormio system is a technique for serial dream incubation, called Targeted Dream Incubation. The tidal shifts in brain function which occur during sleep do not reverse immediately upon awakening; The properties of the preceding sleep stage linger. Experimenters have used this brief window of altered brain function, called sleep inertia, to probe the properties of each preceding sleep state.[249] Upon awakening, blood flow is rapidly re-established in the brainstem, thalamus, and anterior cingulate cortex but it can take up to 20 minutes to be fully re-established in dorsolateral prefrontal cortex — this may contribute to heightened suggestibility.[28] The Dormio system takes advantage of this window of altered, semi-sleeping brain function, and inserts a dream theme incubation during each inertia-laden awakening, creating a serial dream incubation paradigm.

The Dormio user interaction is detailed below. The Dormio hardware and sensors are described in the *Hypnagogia Detection, Hardware & Software* sections below. To use the Dormio, while awake, the user first decides (or the experimenter decides in a controlled experiment) the dream theme to incubate. The user launches the Dormio phone app or web app to record a personalized dream prompt message (R1) using their voice, i.e 'Remember to think of X'. The dream prompt will remind the user to dream about a specific topic (see the following paragraph for specific timing of prompts) and guide their thoughts during hypnagogia. Users then record a dream report message (R2), i.e. 'Please tell me what is going through your mind'. This will be used to prompt the user to report on their experience at regular intervals during hypnagogia. Note that our Experiments have used both the voice of the Experimenter for these recorded prompts (Experiment 1) and the voice of the subjects for these prompts (Experiment 2) without a significant change in efficacy. Next, the user selects the desired biosignal calibration period, number of rounds of hypnagogia and depth of hypnagogic experience: shallow (1 minute), medium (1:30 minutes) or deep (3 minutes) for each round. This time period reflects the period of time that users will be allowed to sleep without interruption after the system detected N1. Next, the user puts on the handworn Dormio sensor and lies down to sleep either for a daytime nap, immediately after wakeup from a morning alarm or at the onset of a night of sleep. The use of the system in naps or after morning awakening, as opposed to use immediately before a full night of sleep, does not put normal nightly sleep architecture at risk.

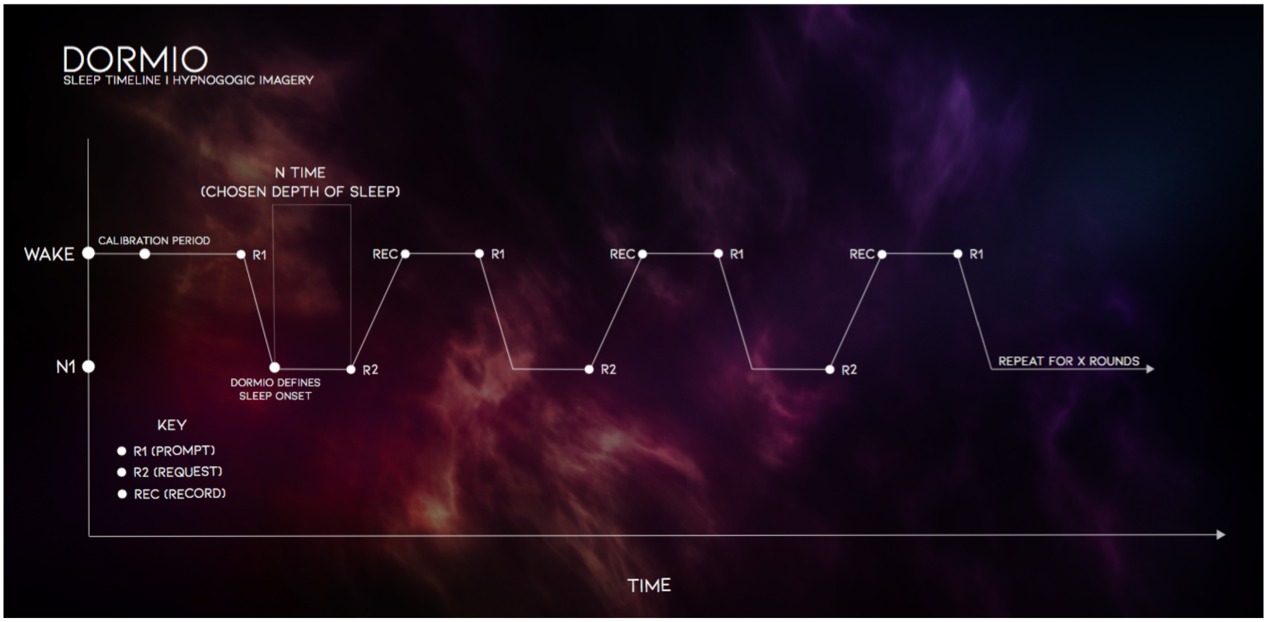

Figure 19 The Dormio system, combining prompt, request and record features. R1 refers to the *prompt* message, R2 refers to the *record* message, as described above. N time refers to time selected for depth of hypnagogic experience, as described above. Figure by Christina Chen.

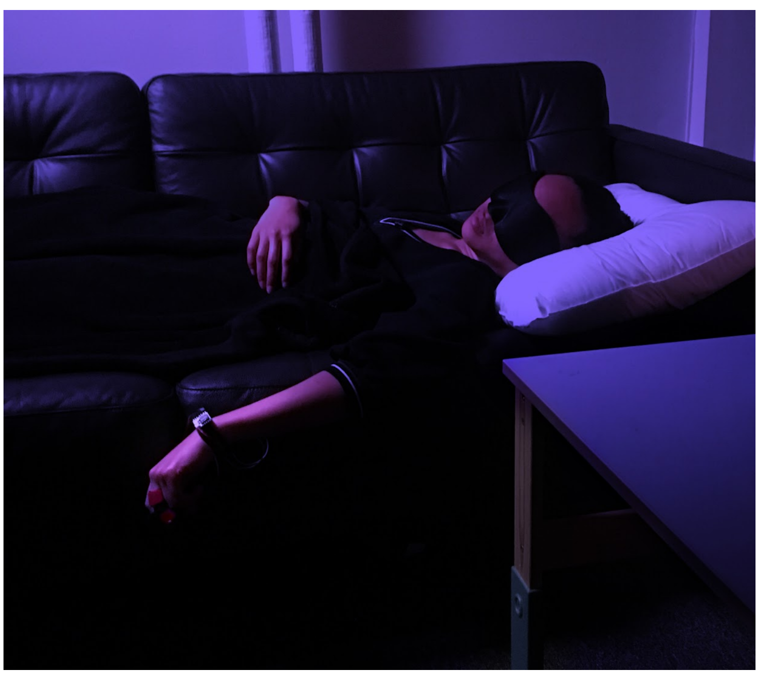

Figure 20. The Dormio system, in use. Image by Oscar Rosello.

From the moment the user lies down wearing the hand sensor, the system tracks heart rate, finger muscle flexion and electrodermal activity. Subjects are asked to close their hand, and hold it closed, when they first lie down, and finger flexion lessens as subjects forget or fail at this behavioral task as they descend into sleep. Changes in these signals — heart rate, skin conductance and muscle tone — have been historically used as markers of sleep onset, each offering insight into Hori stages of sleep onset, and passive behavioral measures have shown to be unobtrusive sleep onset trackers which offer information in addition to physiological measures.[250] Each of these signals is normalized over a customizable calibration period once the user starts the Dormio session, as discussed in the *Hypnagogia Detection* section below. Once the calibration period is done, the dream prompt message plays once, and subjects begin falling asleep. When the descent into hypnagogia is detected, the Dormio system starts a timer corresponding to how deep the user selected to go into hypnagogia. This timer can be customized to vary over the course of the session, and can do so pseudo-randomly. After this timer elapses, the system plays back the user's voice with the recorded dream request message. This has the function of gently awakening the user and gathering hypnagogic experience data via voice report. After the dream report is gathered by recording verbal responses to the 'report' message, the system plays back the recorded dream prompt again to guide subsequent dream content. This process is repeated the desired number of times or for the desired length of time. Finally, the user can wake up to the sound of an alarm and find their stored audio dream reports, or set no alarm and continue sleeping after Dormio interaction finished. In sum, a prompt is administered during full wakefulness, then the first dream report follows the initial sleep onset, the subsequent prompt is given after this report is finished during the following period of sleep inertia, and the cycle continues.

A few examples are below of dream reports collected after prompting of the theme "Tree", i.e. "think of a tree" during N1 sleep. Note the many ways in which the theme enters these dreams, in terms of semantic association and also varied sensory experience:

> *"I started to go down a story path every time the word tree was mentioned, and when I was told that I was sleeping and to think of a tree again I switched back to the tree and took a different path. Very interesting, relaxing, and really made me think."*
> Subject 1, Sleep Tree-Incubation, Experiment 1

> *"Each scene was slightly different with each wakeup. It was like chronological. The first one was animals going here and there around the trees. Then there were people and the cats were going on the trees and not coming back. After the first prompt people are burning down trees. And then in the third one it was a nice garden with a single tree and you were swinging over it with an apple saying 'it was better back then'....Animals and people were all there and doing certain activities. But I was having no control in guiding the dream. It was all spontaneous. I thought I only slept like for 10 mins but It was 40-45 mins. I felt I was in an open environment observing things...Yes I was more of an observer looking from a distance. I woke up laughing because I had a very funny dream. About you on a tree."*
> Subject 2, Sleep Tree-Incubation, Experiment 1

> *"My dream was pleasant and mysterious. I never knew what the next part of my dream was going to be. My dream did involve a tree. I was following the roots with someone and the roots were transporting me to different locations. At each location I was trying to find a switch. It was unclear why I had to turn on the switch, but a[t] the final location it a window with a bright light was revealed. I saw a familiar face, but I couldn't place where I'd seen them. In the background, the moon was shining bright and illuminating the face. I was dreaming this while awake and not fully asleep. I could hear myself talking to someone about finding a switch. I could hear my breathing, my footsteps, the wind, and an air conditioner. When I bumped into objects, I can hear the noise of the collisions. I could hear the roots of the tree pulsating with energy as if they were leading me to some location."*

Subject 3, Sleep Tree-Incubation, Experiment 1.

"This was surprisingly pleasant - I assumed that being drawn closer to sleep and pushed away repeatedly might be frustrating in some capacity. But I really felt like being allowed to explore thoughts in an in-between state was more pleasant than actual sleep, since I can never seem to recall my dreams and this allowed me to consciously think beyond the everyday without feeling like I was consciously pushing myself along very much."
Subject 10, Sleep Tree-Incubation. Experiment 1

Hypnagogia Detection

One of the main challenges and contributions of the Dormio system is enabling interaction with hypnagogia without the need for PSG sensors which affect sleep quality and comfort. Hori stages are classically defined via EEG changes, yet there has been broad disagreement and poor inter-rater reliability surrounding classification of hypnagogia with EEG. This is a definitional gray area, with nine stages all classified as a sleep onset process and the line between sleep and wake blurry throughout; picking a point of objective sleep onset along a continuum of change is simply arbitrary. Further, there has been limited work on EEG signatures of hypnagogic phenomenology, and these signals do not reliably indicate experience or onset of subjective sleep. There is evidence that sleep onset imagery occurs in a range of 15 seconds to 5 minutes post sleep onset, and there is evidence that sleep onset imagery exists from early drowsiness into the early minutes of stage 2 NREM sleep. As there is a wide margin within which sleep onset imagery will occur, and this system is built to incubate sleep onset imagery, our hand-worn system can tolerate a large temporal margin of error for sleep onset detection and still function to incubate hypnagogic dreams.[60,251] This version of the Dormio device thus aims simply to detect hypnagogia, or the sleep onset period (SOP), without making claims to detect exact Hori stages or an exact moment of sleep onset.

The Dormio system uses three measures of sleep onset in conjunction. First, users are asked to gently close their hand when they lie down to sleep, allowing the flex sensor to monitor progressive loss of muscle tone via hand opening. This is a passive behavioral measure of sleep onset, specifically indexing changes in the Flexor Digitorum Profundus finger muscle, used in the past for reliable SOP detection.[252] Loss of muscle tone is specifically temporally tied to onset of hypnagogic imagery, while more recent papers have demonstrated that drops in heartbeats per minute (BPM) and shifts either up or down in EDA coincide with loss of muscle tone to confirm descent into hypnagogia. These are physiological indicators of sleep onset.[253,254] Values of each signal are averaged over a customizable calibration time, default of 120 seconds, after the subject lies down. Each signal is assigned an adjustable threshold for deltas in the app, such that Heart Rate delta (BPM) > X or Electrodermal Activity delta > Y or Muscle Flexion delta > Z, wherein a delta of X, Y or Z amount will trigger the 'sleep onset detected' audio interaction. Deltas were determined based on pilot data (n=5) of descent into sleep with wake-ups and self-report of sleep state, i.e. "were you asleep/halfway/awake?". Reports were used to determine sleep stage transitions and associated deltas, employing a past method to validate detection of hypnagogia via assessment of changes in perceived sleepiness and appearance of hypnagogic dream features. For the purposes of this experiment, Heart Rate (BPM) delta > 5 beats per minute or Electrodermal Activity delta > 4 conductance units or Muscle Tone (Flex) delta > 8 resistance units were used, determined based on pilot data of physiological signals tied to reports of state of sleep and hypnagogic phenomenological features. BPM units for delta calculation are beats per minute, while Electrodermal Activity and Flex units are raw analog-to-digital units which index changes in conductance (μS) and resistance (KΩ) respectively. Further, during experiments, subjects were asked upon each wakeup "were you asleep/halfway/awake?", for subjective confirmation of sleep onset. For users at home with the iOS app and web app, we also developed a semi-supervised anomaly detection method to recognize sleep onset based on the Histogram Based Outlier Score (HBOS) method. Histograms are calculated for the three physiological signals over the calibration time, each histogram representing the distribution of the awake state. Then, 15-second time windows are continuously compared against the histograms, to generate a Histogram Based Outlier Sleep Score (HBOSS) which is used to demarcate sleep stage transitions. HBOSS allows for differential weighting of each signal, if one seems abnormal or more informative in a specific individual. Based on pilot data, HBOSS is highly correlative to sleep onsets detected by a human sleep scorer from the Dormio signal record.

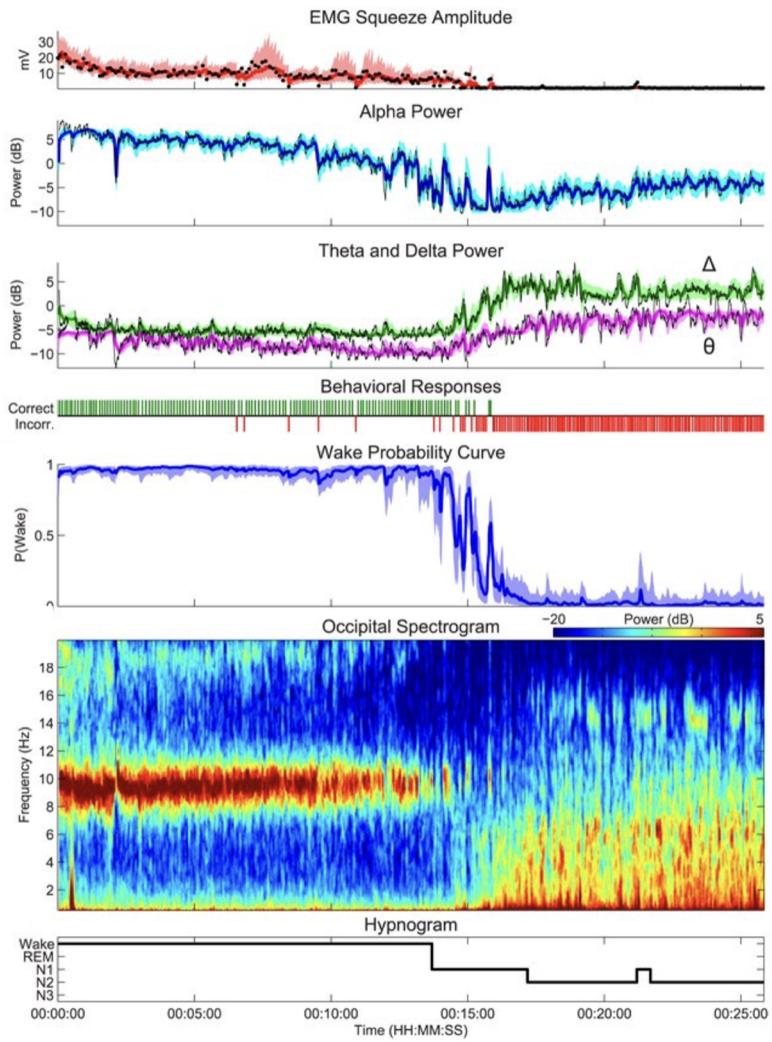

Figure 21 Illustration of the correspondence between passive behavioral measures of FDP (finger flexion muscle) EMG squeeze amplitude and EEG dynamics at sleep onset. (A) The simultaneously observed EMG and EEG observations, and behavioral responses from the experiment are used to estimate (B) the wake probability curve, which shows Pr(Wake), the probability of wake given the EEG and EMG data, over time. The wake probability curve agrees well with features of (C) the EEG spectrogramand (D) the clinical hypnogram. Image from Prerau et. al. 2014.

Hardware

Form Factor

We designed our own custom 30 x 15 mm circuit board using Autodesk Eagle and fabricated it in-house using a Modela MDX-20 3-axis milling machine. The hardware design process was a collaboration with Tomás Vega, while glove design was done in tandem with Oscar Rosello, Ishaan Grover, Abhinandan Jain and Pedro Reynolds-Cuéllar. To handle sensor input, logic and networking, we used an RFD22301 module, a Nordic nRF51 microcontroller with integrated Bluetooth based on the ARM Cortex-M0 core. This board sits on the user's wrist. The Dormio system is designed to be free of wires for comfortable sleep. We embedded a 3.7V lithium-ion battery to power the Dormio glove for over 20 hours of uninterrupted monitoring. In addition, all the communication between the glove and the OpenSleep iPhone application relies on Bluetooth Low Energy (BLE). The Dormio glove is designed to be breathable, lightweight and comfortable. We fabricated a series of adjustable nylon straps around the wrist, middle and index fingers that hold the sensors and PCB in place while exposing the hand to air for cooling. Each of the three Dormio sensors is sampled at 100hz. The user's heart rate is monitored by means of the Adafruit's Pulse Sensor Amped on their middle finger, muscle tone is tracked using a voltage divider composed of a resistor and a 4.5" Sparkfun flex sensor wrapped around the index finger, and EDA is monitored using a constant voltage source, a voltage divider and a low-pass filter to measure conductance between two electrodes placed on the bottom of the wrist.

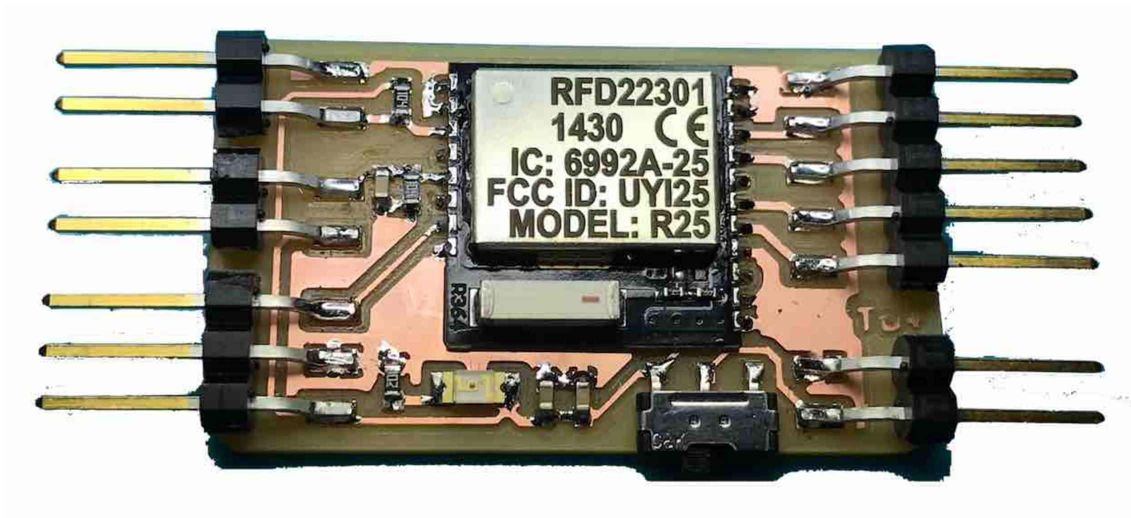

Figure 22. The Dormio circuit design. Image credit Tomás Vega.

Figure 23. The Dormio PCB and handworn system, dorsal side. Flex sensor is visible on the pointer figure. Photo credit Oscar Rosello

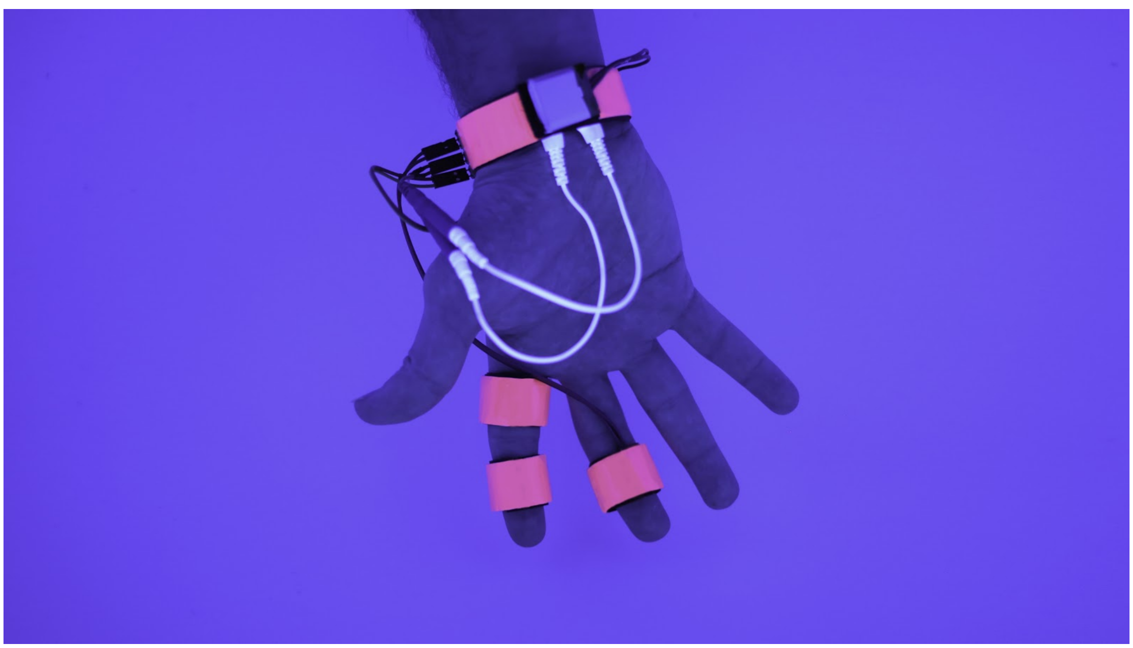

Figure 24 The Dormio PCB and handworn system, palmar side. Heart rate sensor is visible on the middle finger, while two EDA sensors are visible on the palmar side of the wrist. Photo credit Oscar Rosello

Software

iOS App

The Dormio iPhone app, together with the Dormio glove, provides an interface for users to control their hypnagogic experiences from their smartphones. The software design was a collaboration with Tomás Vega, Eyal Perry, Matthew Ha and Christina Chen. The interface allows users to set up the system and customize it according to the desired dream theme. There are features for recording the dream prompting message and the dream report request, a text-field for inputting the desired number of hypnagogic rounds and the signal deltas to determine wakeup, a combo-box for choosing the desired depth into hypnagogia, and a toggle button to initiate the interaction. There is further a silence detection feature, so that recording does not continue when unnecessary.

The app has two modes, signal based and timer based. The signal based mode (used in Experiments 1, 2, 4) is for people with Dormio hardware, and does recording and prompting based on signal deltas. The timer based mode (used in Experiment 3) is for users who do not have the Dormio hardware, and bases interaction only on user estimates of sleep onset latency. A drop detection feature is included, so people can hold their phone and use the equivalent of the 'Steel Ball Technique' to determine sleep onset latency.[255]

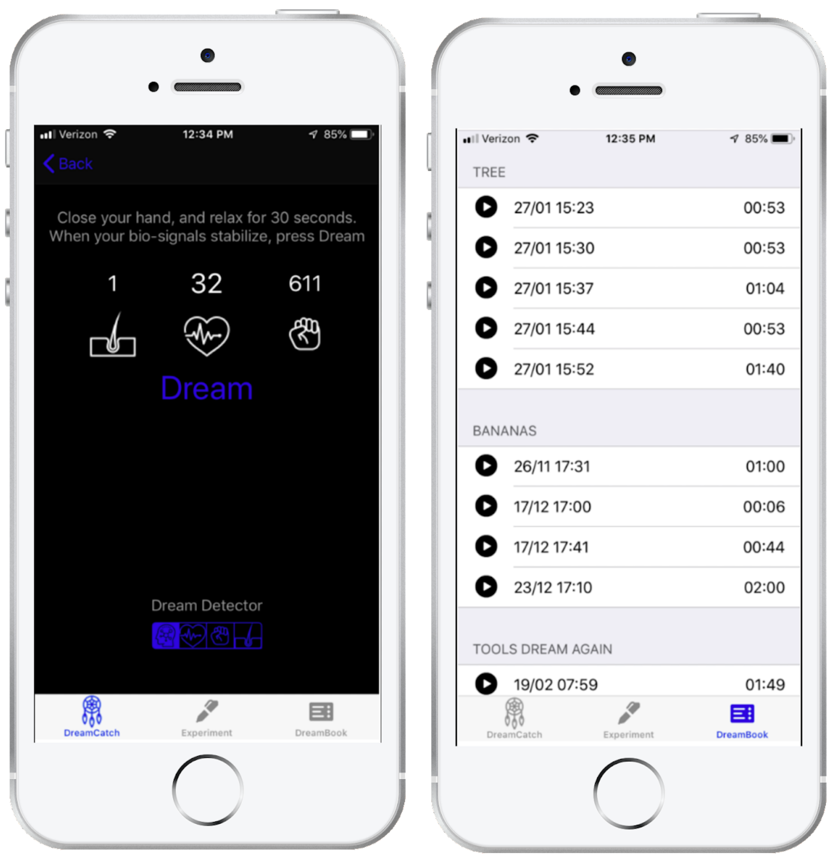

Figure 25 Screenshots of the Dormio application. Biosignals are displayed live from the Dormio sensor (left). After the user is awake, they can access and share a list of their dream recordings (right). Image credit Eyal Perry.

Web App

For those who do not have an iPhone, the Dormio web app enables easy hypnagogic interaction online via laptop or desktop. The Dormio web app also has two modes, signal and timer based, and captures audio and biosignals from each user. Because bluetooth connectivity and audio recording function differently on the web than on iOS, a separate Dormio software system is necessary. To gather and store sensor data, the Dormio Web App makes use of OpenSleep, a framework built for biosignal tracking and analysis. OpenSleep communicates wirelessly with the Dormio glove, using the CoreBluetooth framework to receive heart rate, muscle tone, and electrodermal activity via BLE. OpenSleep streams signals to the Dormio web UI, which monitors sleep, visualizes time-stamped sensor data and logs biometric information and audio data. The back-end of OpenSleep Desktop is written using Node.js. To receive the data sent from the glove, we use Noble, a Node.js Bluetooth Low Energy (BLE) central module. We handle server communication with the client using socket.IO, a real-time bidirectional event-based communication framework. The UI is a web application written in JavaScript, using client-side socket.IO to communicate back and forth with the server. The client listens for the streaming of the sensor values and plots the data in real-time using D3.js. Group, gender, age, dream theme, audio recorded and biosignals are logged into a zip file when each session is ended.

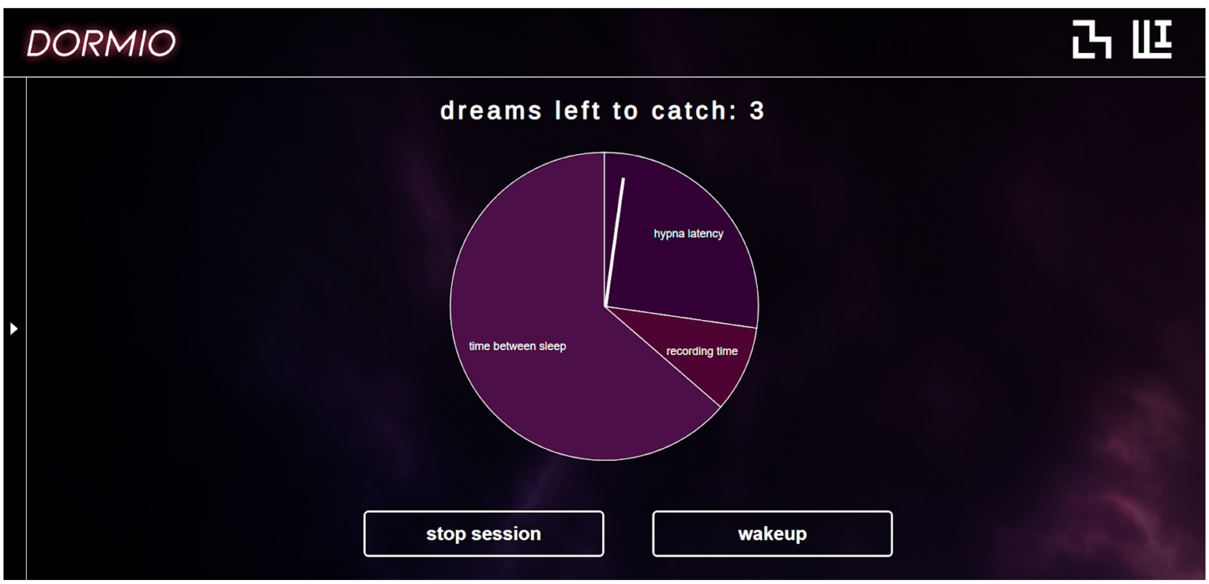

Figure 26 Dormio Timer based website. UI led by Christina Chen

Data Analysis Platform

To give users a window into session dynamics and control over their own signal detection deltas, we have built a custom data analysis platform. This platform is connected to the server which the Dormio iOS app can automatically upload to, if users choose to upload data. Alternatively, it can accept local files which the Dormio iOS app or Web App each saves. It will parse and plot these, along with markers for wakeup and report times, so users can see biosignal changes and corresponding changes in phenomenology. The next time they sleep with their device or timer, they can adjust their incubation protocol according to this data.

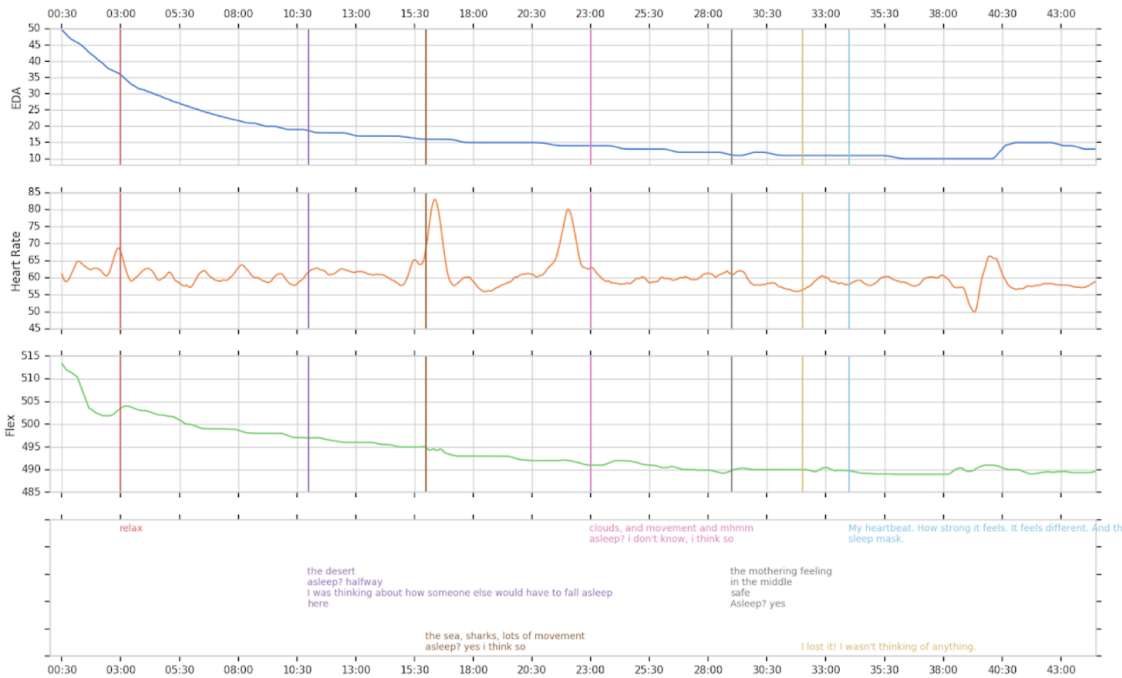

Figure 27 Dormio analysis platform, automatically plotting physiology and time matched dream reports.

Part 2: Experimental Findings

The experimental work of this thesis is contained in Experiments 1-4. Each experiment aims to build a culture and practice of dream science as well as increase our knowledge about dreams. We designed these experiments aware of a complicated history, with dreams as a flashpoint for debates over the merits of psychoanalysis and subjective study, the value of imagination and rest. We are also in a complicated present, where dream consumer technology is proliferating faster than science, where clinical data demonstrates the potential value of dreams but precise instruments for practice are lacking. These four experiments are not done in a vacuum, as they lessen the gap between the dream as ineffable experience and the dream as object of investigation and tool for intervention. Presentation of their findings may influence directions that readers take in future dream experiments, and so questions of capacity and ethical concerns have to be held front of mind—should we enable incubation of dreams while we don't understand them? What will be the ripple effects of more individuals introspecting in novel ways, effects of using dreams? What role does analytic, experimental science have to play in understanding a state of mind which is definitively irrational? What kind of community can we foster so that the use of dreams is done with care? We will return to these questions in Part 3, addressing ethical issues raised by our work and the responses we have marshaled as a dream science community so far.

Holding these concerns and questions, see below for 4 chapters, each detailing one experiment. Each experiment was accomplished collaboratively with a cadre of scientists, engineers, designers, and clinicians. The main findings of each are detailed below.

1. **Dormio Creativity Study (Experiment 1) n=50**
    a. Establishes a Targeted Dream Incubation (TDI) protocol for incubation of dream content.
    b. Offers evidence for a causal link between incubating dream content and increasing post sleep creativity on tasks related to incubated dream themes.
    c. Suggests TDI can change self-concept, in the form of improving creative self-efficacy.
2. **Non-Contact TDI (Experiment 2, collaboration with Seli Lab, Duke University) n=80**
    a. Moves beyond the wearable form factor and offers evidence that TDI can effectively incubate dreams without a sensor.
    b. Finds marked differences between N1 dream content and daydreaming content, based on both phenomenological assays and computational semantic analyses.
3. **Locus of Control (Experiment 3, collaboration with Westley Youngren, Michelle Carr) n=25**
    a. Investigates clinical utility of TDI in nightmare treatment
    b. Identifies significant increases in locus of control after TDI
    c. Offers evidence that TDI can reduce nightmare related complaints up to one week after the dream incubation experience.
    d. Offers EEG-based TDI as a comparison to Dormio TDI and Non-contact TDI
4. **REM Incubation (Experiment 4) n=15**
    e. Pilots TDI in REM sleep and shows specific incorporation of experimenter-chosen themes in REM dream content.
    f. Offers evidence suggesting REM incubation is significantly less beneficial for post-sleep creativity than N1 dream incubation.

Chapter 3: Dormio Creativity Study (Experiment 1)

This chapter is composed of two papers. The first paper is published as Horowitz, A. H., Cunningham, T. J., Maes, P., & Stickgold, R. (2020)[225] and covers the efficacy of TDI dream incubation in N1 and physiological data collected via Dormio. The second paper, composed of further analysis on data from the same experiment with the same subjects, is currently under revision as Horowitz, A., Esfahany, K., Gálvez, T. V., Maes, P., & Stickgold, R. Targeted Dreaming Increases Waking Creativity (2022).[256] All figure and table numbers are contained within papers, as opposed to referencing table and figure counts across the entire thesis.

Creativity Paper 1: Dormio: A Targeted Dream Incubation Device

Consciousness and Cognition 83 (2020) 102938

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Dormio: A targeted dream incubation device

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ABSTRACT

Information processing during sleep is active, ongoing and accessible to engineering. Protocols such as targeted memory reactivation use sensory stimuli during sleep to reactivate memories and demonstrate subsequent, specific enhancement of their consolidation. These protocols rely on physiological, as opposed to phenomenological, evidence of their reactivation. While dream content can predict post-sleep memory enhancement, dreaming itself remains a black box. Here, we present a novel protocol using a new wearable electronic device, Dormio, to automatically generate serial auditory dream incubations at sleep onset, wherein targeted information is repeatedly presented during the hypnagogic period, enabling direct incorporation of this information into dream content, a process we call targeted dream incubation (TDI). Along with validation data, we discuss how Dormio and TDI protocols can serve as tools for controlled experimentation on dream content, shedding light on the role of dreams in the overnight transformation of experiences into memories.

1. Introduction

Dreaming is a phenomenon experienced by virtually all humans (Pagel, 2003), and possibly by other animals as well. It is generally thought of as delusional hallucinated experiences during sleep, although research differs dramatically on exactly which of these nightly experiences should be labeled dreams (Pagel et al., 2001). The relationship of dream content to waking life experiences is unresolved, although since the time of Freud (Freud, 1910), it has been thought to relate to events from the prior day ("day residue") as well as older, often related, memories. The mechanism of construction and function of dreams remain essentially unknown.

1.1. *Sleep "Hacking"*

Studies using auditory, somatosensory, vestibular and olfactory input during sleep demonstrate that sensory processing continues during sleep. This can be seen through the impact of such stimulation on brain event related potentials (Weitzman & Kremen, 1965), the formation of new memories (Arzi et al., 2012), enhancement of prior learning (Rasch, Buchel, Gais, & Born, 2007) and dream content (Leslie & Ogilvie, 1996). This opens up an avenue for simple sensory modulation of brain activity during sleep. Interventions can work at the sensory level via entrainment of cortical oscillations or at the symbolic level via reactivation of memories. Targeted Memory Reactivation (TMR; Oudiette & Paller, 2013) is the best researched sensory-level intervention to "hack" sleep mechanisms at

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the cognitive level. In TMR, a cue that was previously linked to a learning task during wake is re-presented during sleep to drive specific memory reactivation (Vargas, Schechtman, & Paller, 2019). Using this technique, reactivation of specific memories during sleep can enhance post-sleep memory performance. For instance, presenting humans with auditory cues during non-rapid eye movement (NREM) sleep that were previously presented during the learning of the location of specific objects enhanced post-sleep recall of the targeted locations (Rudoy, Voss, Westerberg, & Paller, 2009).

TMR is believed to target specific memories during sleep, augmenting their sleep-dependent reactivation and consolidation, and has been shown to improve subsequent performance on tests of declarative memory, skill learning, and spatial navigation (Oudiette, Antony, Creery, & Paller, 2013; Shimizu et al., 2018). It may also have an effect on fear networks, as re-presenting an auditory or odor cue during sleep can create stimulus-specific enhancement of fear extinction in mice and humans (Hauner, Howard, Zelano, & Gottfried, 2013; Wixted, 2013). Arzi et al. (2014) suggested that sensory presentation during sleep can lead to the formation of new associations as opposed to simply reactivating existing ones. They showed significant reduction in cigarette smoking when participants were presented with paired odors of cigarette smoke and rotten eggs during sleep, apparently forming a new association between the two. Importantly, this effect was shown following olfactory aversive conditioning during both Stage 2 NREM sleep and rapid eye movement (REM) sleep, but not during wakefulness (Arzi et al., 2014).

But what remains unknown is the experience of the sleeper during this sensory modulated reactivation. As we will discuss, one potential marker of successful memory reactivation is incorporation of the memory or associated imagery into dreaming. This raises questions of whether TMR participants dream about the presented stimuli, and the possible impact of such dream incorporation on the efficacy of TMR. There is, indeed, evidence that sensory stimulation during sleep can impact dream content (St. Denis 1867; Schredl, Hoffmann, Sommer, & Struck, 2014).

1.2. Dreams of daytime learning

A seminal study in the dream incubation literature provides a sense of the phenomenology that accompanies dream incorporation of waking learning tasks, and suggests that such incorporation might be related to sleep-dependent memory consolidation. Stickgold, Malia, Maguire, Roddenberry, and O'Connor (2000) had 27 participants play the computer game Tetris for 5–7 h over 2–3 days and collected sleep onset dream reports from participants over the first hour of sleep each night. Awakenings were performed by the Nightcap sleep monitoring system (Ajilore, Stickgold, Rittenhouse, & Allan Hobson, 1995), and reports were collected as participants were attempting to fall asleep as well as after intervals of 15–180 s of Nightcap-defined sleep (Stickgold et al., 2000). Out of the 27 participants, including 5 amnesiac patients, 17 (63%) reported at least one Tetris-related dream. Out of 526 reports, 64 (12%) contained task-related thoughts or images, demonstrating that specific themes can be induced in sleep onset (hypnagogic) dreams. A follow-up study using the arcade game Alpine Racer showed similar results, with reports of task-related imagery during hypnagogia in 24% of post-training dream reports (Wamsley, Perry, et al., 2010). The Tetris and Alpine Racer studies of hypnagogic replay inspired development of Dormio, a novel device that focuses on dream incubation during hypnagogia, but with exposure to "training" stimuli within the actual hypnagogic period, as opposed to hours earlier.

1.3. Dreams and sleep-dependent memory

Studies that do collect dream reports after task presentation suggest that dream experiences can directly reflect ongoing sleep-dependent memory processing, and the different mnemonic functions of REM and NREM seem intimately tied to their typically differing dream phenomenologies. Hippocampus-dependent memory seems to benefit particularly from NREM sleep, and subjective reports from NREM sleep stages are more likely to contain episodic, hippocampus-dependent memory sources (Baylor & Cavallero, 2001). In contrast, emotional memory is preferentially enhanced by REM sleep, and dream experiences from REM have uniquely intense emotions (Smith, Nixon, & Nader, 2004; Wamsley & Stickgold, 2011). These studies suggest dream reports can provide a valuable window into cognitive processing ongoing in the sleeping brain.

Several studies have found that dream content correlates with post-sleep task performance. Novel learning experiences are incorporated into the content of NREM dreams, which is thought to reflect the processing of newly learned material (Wamsley, 2014; Antrobus & Wamsley, 2017). There is also evidence that dream content drives memory consolidation for recently learned facts and for language learning, with faster incorporation of a newly learned language into dream content positively predicting language learning (De Koninck, Christ, Hébert, & Rinfret, 1990). Morning recall of short stories encoded the night before is correlated with story-related words in dream reports collected during the intervening night (Stickgold & Wamsley, 2011; Wamsley & Stickgold, 2011). The extent to which participants show improved coordination on a tennis video game task is correlated with how richly novel gameplay experiences are incorporated into hypnagogic dreams, but only for early hypnagogic dreams (the first four dream reports), not for late hypnagogic dreams (the last four dream reports) or for daydream incorporation (Fogel, Ray, Sergeeva, De Koninck, & Owen, 2018).

A particularly noteworthy instance of the association between dream content and sleep-dependent memory enhancement is a study associating dream content with spatial memory consolidation (Wamsley & Stickgold, 2019; Wamsley, Tucker, et al. 2010). Participants were trained on a 3D virtual maze task prior to a 1.5-hour nap opportunity or equivalent period of wakefulness. All participants were prompted three times during the 90 min to verbally report "*everything that was going through your mind.*" In the Sleep group, participants who referred to the maze task in their subjective dream reports improved ten-fold at retest compared to Sleep participants who gave no task-related reports. Yet thinking of the maze while awake was not associated with any significant performance benefit. Dream experiences here are clear reflections of learning-induced reactivation of memory networks during sleep, and the experience of this reactivation correlates with dramatically enhanced memory performance. Unfortunately, the participants who dreamed about the task also performed significantly worse in the pre-nap test, making conclusions about the causal relationship between the dreams and improvement impossible. The difficulty of making such causal claims provided impetus for the development of Dormio.

Importantly, the dreams in this experiment did not veridically "replay" waking experiences of the maze task, but were fragmented and mixed with older memories. Again, this suggests that the experience matches the mnemonic function of the sleep state: The fragmented, mixed experience may reflect that the memory consolidation process is more complex than simply strengthening memories in their original form. Instead new information is integrated into established cortical memory networks, allowing for the extracting meaning, novel associations, and more. Wamsley and Stickgold (2019) recently replicated this study, reproducing results of a significant relationship between task inclusion in dream reports and enhanced performance post-sleep (but see failure to find such effects in Klepel and Schredl 2019; for review see Schredl, 2017).

1.4. *Targeted dream incubation (TDI)*

Similar to TDI, targeted dream incubation is a protocol for reactivating memories during sleep in a manner that leads to incorporation of the targeted memory, or related memories, into dream content. Previous research, discussed above, indicates that such incorporation is most frequently accomplished during the hypnagogic sleep onset period, and the TDI protocol using the Dormio device described here aims at such hypnagogic incorporation.

Entering hypnagogia from sleep rather than from an extended period of wake also affects the ability to induce such targeted incorporation. The global shifts in brain function that occur during sleep do not reverse immediately upon awakening. The properties of the preceding sleep stage linger, leaving participants in a hypnopompic wake state that maintains some of the preceding sleep state's physiology. Upon awakening, blood flow is rapidly re-established in the brainstem, thalamus, and anterior cingulate cortex, but it can take up to 20 min to be fully re-established in dorsolateral prefrontal cortex, which may contribute to heightened suggestibility (Nir & Tononi, 2010). Experimenters have used this brief window of altered brain function to probe the properties of each preceding sleep states (Carr & Nielsen, 2015; Noreika, Valli, Lahtela, & Revonsuo, 2009; Stickgold, Scott, Rittenhouse, & Hobson, 1999; Tassi & Muzet, 2000). The aim of the current study is to assess the ability of Dormio to identify the sleep onset period and successfully manipulate the content of hypnagogic dream report through pre-sleep verbal prompts. We hypothesize that Dormio will be found to be an effective dream incubation device, with > 50% of awakenings yielding dream reports that incorporate the auditory prime, 'Tree', automatically captured by Dormio's audio recording system. Such a tool would provide substantial control over hypnagogic dream content, enabling more controlled experimentation on the relationship between dream mentation and post-sleep cognition.

2. Material and methods

2.1. *The Dormio targeted dream incubation (TDI) protocol*

For this initial study of TDI, we have used the Dormio system, which consists of a hand-worn sleep tracker and an associated app, used to communicate with users and record dream reports via bluetooth to a laptop or cellphone. The user interaction with the Dormio system occurs across multiple stages of consciousness including wake, sleep onset, sleep, and hypnopompic wake.

Dormio takes advantage of the window of altered hypnopompic brain function by suggesting a dream theme during each of a series of hypnopompic awakenings, creating a serial dream incubation paradigm. This dream-report system is an adaptive, automated version of the serial awakenings paradigm described earlier that has been used to collect hypnagogic dream reports with repeated awakenings during sleep onset, using either polysomnography (PSG) or the Nightcap (Wamsley, Perry, et al. 2010; Noreika et al., 2009).

Dormio's user interaction is detailed below (see Fig. 1). In its most autonomous mode, the user decides what they want to dream about. This can range from a creative problem they are working on to an experience they want to reflect on or an emotional issue they

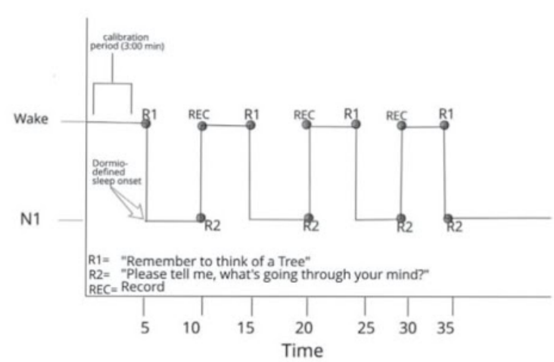

Fig. 1. Schematic of typical use of Dormio to elicit sleep onset hypnagogia and dreaming.

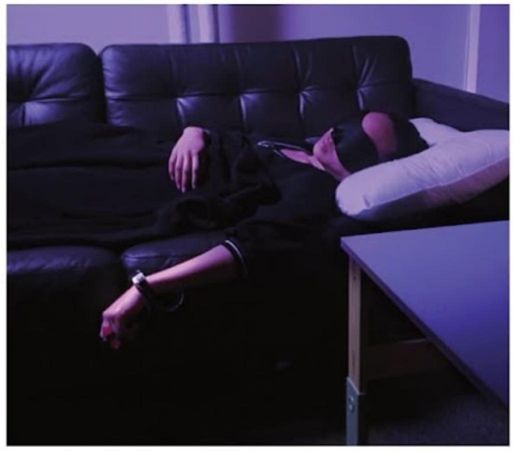

Fig. 2. The Dormio system, in use. Image by ***Oscar Rosello***.

want to develop a new perspective on. The user launches the Dormio app and records a personalized dream prompt message (R1) using their voice, such as 'Remember to think of a tree'. The dream prompt is then played as the user prepares for sleep onset. After falling asleep—an event detected by Dormio— and being allowed to sleep for a predetermined time, Dormio wakes the user and plays the recording to guide their thoughts during subsequent hypnagogia. After receiving the prompt, the user returns to sleep and then, again after a predetermined period of Dormio-defined sleep, is awakened and prompted for a dream report message (R2; 'Please tell me what was just going through your mind'). Their response is recorded, the dream prompt repeated, and they return to sleep. This cycle of sleep, reporting and re-prompting is repeated a predetermined number of times, set by the user (see Fig. 2).

From the moment the user lies down wearing the hand sensor, they are asked to close their hand as they descend into sleep and Dormio begins tracking heart rate, finger flexion and electrodermal activity. As the user begins to drift off to sleep, finger flexion begins to decrease as they forget or fail at this passive behavioral task. Changes in these signals—heart rate, skin conductance and muscle tone—have been historically used as markers of sleep onset, each offering insight into Hori sleep onset stages (Hori, Hayashi, & Morikawa, 1994; Tanaka, Hayashi, & Hori, 1999). Passive behavioral measures have been shown to be unobtrusive sleep onset trackers that offer information that can supplement physiological measures (Ogilvie, 2001; Mavromatis and University of Brunel 1983; Casagrande, De Gennaro, Violani, Braibanti, & Bertini, 1997; Prerau et al., 2014). Each of these signals are normalized over a calibration period each time a user starts a Dormio session and are used to identify subsequent Dormio-defined sleep onsets. While the use of serial awakenings may sound strenuous, participants have reported such serial awakenings at sleep onset as positive and relaxing (Hayashi, Motoyoshi, & Hori, 2005; Horowitz, Grover, Reynolds-Cuéllar, Breazeal, & Maes, 2018).

2.2. Dormio sleep-onset detection algorithm

One of the main challenges and contributions of the Dormio system is enabling interaction with hypnagogia without the need for polysomnographic (PSG) sensors. Hori and colleagues have defined nine substages of sleep onset (Hori et al., 1994) based on electroencephalographic (EEG) changes, leaving the line between wake and sleep blurry. The current version of Dormio aims simply to detect the sleep onset period (SOP), without making claims of identifying specific Hori stages or the exact moment of sleep onset.

The Dormio system aggregates data from three measures to predict sleep onset. First, after users gently close their hand when they lie down to sleep, a flex nnnnsensor monitors the slow opening of the hand, with its parallel loss of muscle tone. This passive behavioral measure of flexor digitorum profundus activity has been used in the past for reliable SOP detection (Kelly, Strecker, & Bianchi, 2012; Prerau et al., 2014) and is temporally tied to the onset of hypnagogic imagery (Ogilvie, 2001; Noreika et al., 2015; Prerau et al., 2014). Drops in heart rate and shifts in electrodermal activity (EDA) coincide with this loss of muscle tone and provide further indications of descent into hypnagogic sleep (Penzel, 2003; Penzel & Kesper, 2006; Herlan, Ottenbacher, Schneider, Riemann, & Feige, 2019; Ogilvie, 2001; Carskadon & Dement, 2011). Each of the three Dormio sensors is sampled at 100 Hz. The user's heart rate is monitored by means of the Adafruit's Pulse Sensor Amped on their middle finger, muscle tone is tracked using a voltage divider composed of a resistor and a 4.5″ Sparkfun flex sensor wrapped around the middle finger, and EDA is monitored using a constant voltage source, a voltage divider and a low-pass filter to measure conductance between two electrodes placed on the bottom of the wrist (Murphy and Gitman, 2011; Symbol (2014); Boucsein et al., 2012). These three measures are averaged over the first 120 s when the subject initially lies down, and predefined deviations from these mean values are interpreted as Dormio-defined sleep onset. Threshold deviations for each metric, which were taken to indicate sleep onset, were based on pilot data from 5 participants with repeated descent into sleep followed by awakenings and subjective reports of the sleep state (asleep, half-awake or awake) they achieved (Rowley, Stickgold, & Hobson, 1998; Ogilvie, 2001). Based on this pilot data, Heart Rate (BPM) deltas of $>$ 5 BPM, Electrodermal Activity sensor deltas $>$ 4 µSemen or flexor muscle sensor deltas $>$ 8 KΩ were taken as indications of sleep onset. Awakenings were performed whenever one of these thresholds was passed.

2.3. Procedures

We enrolled 50 participants (mean age = 26.71 ± S.D. 7.86 yrs, females = 24) to participate in a daytime napping study. Half of the participants were assigned to each of two groups, the Sleep group and the Awake group. Participants arrived at the laboratory in the afternoon between the hours of 12:00 pm and 4:00 pm. Participants were given a consent form to read and sign. Consent form and experimental procedures were approved by the MIT Institutional Review Board, The Committee on the Use of Humans as Experimental Subjects. One subject in the wake condition failed to obey experimenter instructions and was eliminated from analysis, leaving a total n = 49.

Participants were told the experiment investigated the relationship between rest and cognitive flexibility, that they would engage in active rest or a sleep, and were offered a sleep mask as compensation for participation in the study. After consenting, participants completed questionnaires on creative self-efficacy, demographic information, and sleep quality. All participants wore the Dormio system, regardless of condition. Experimenters remained in the room with participants, out of sight as participants had eyes closed in awake conditions and wore an eye mask in sleeping conditions.

Participants in the Sleep group were given a 45-min sleep opportunity. Mentation reports were collected throughout this period, after each qualifying sleep onset and instrumental awakening. Participants in the Wake group were asked for 4–5 mentation reports, depending on timing of sensor setup and length of mentation reports taking up experimental time.

2.4. Instructions

The wording of instructions given to participants in administering sleep and dream studies is crucial, especially given that participants are in periods of semi-wake when executive control is transient, metacognitive ability is declining, and dream amnesia after waking is common. As an example, when REM sleep was initially distinguished from NREM sleep in the 1950's, it was reported that 74–80% of REM sleep awakenings produced vivid dream recall, compared to only 7–9% of NREM awakenings (Dement and Kleitman, 1957). But by just changing the wording of the question from "tell me if you had a dream" to "tell me anything that was going through your mind just before you woke up," reports of conscious experiences in NREM sleep jump up to between 23% and 74% (Rechtschaffen, 1994). Because of the importance of word choice here, each condition is described in detail below and the exact instructions read to participants can be found in *Appendix A*. Experimental instructions were delivered by an experimenter, while audio prompts from the Dormio were delivered via pre-recorded human voice:

Condition 1: Sleep + Tree. A prompted awakening from hypnagogic sleep, using Dormio to incubate the dream theme 'Tree'. Upon lying down, the Dormio web app instructed these participants to "*Think of a tree*". Once entry into hypnagogia was determined by Dormio, a variable timer was triggered. This timer instigated wakeups from 1:00 to 5:00 min after Dormio-detected sleep onset, to allow participants to experience different depths of sleep. At the end of this time, the computer alerted participants, "*You're falling asleep,*" and asked them to verbally report, "*Please tell me, what's going through your mind*", and recorded their verbal response. Once participants finished speaking, Dormio asked about their sleep state ("*And were you asleep?*"), to which participants could respond 'Awake', 'Halfway' or 'Asleep'. Dormio then instructed them, "*Remember to think of a tree*" and "*You can fall back asleep now*". This loop of events was repeated for 45 min, enabling the collection of multiple hypnagogic reports. At the end of the last loop, the experimenter instructed the participant to wake up fully.

Condition 2: Sleep-Tree. Unprompted hypnagogic sleeps. Dormio functioned as it did in Condition 1, except *"Remember to think of a Tree"* was replaced with *"Remember to observe your thoughts"*.

Condition 3: Wake + Tree. Prompted periods of time-matched wake. Participants sat upright with head unsupported (so the experimenter could survey for muscle tone loss, which would indicate sleep onset), eyes closed, and were instructed to stay awake. The Dormio web app instructed these participants to *"think of a Tree"*. Once 7 min had passed, approximating sleep onset time, a variable timer was triggered from 1 to 5 min later. At the end of this time, Dormio alerted participants and asked them to *"Please tell me what's going through your mind"* and recorded their responses. Once participants finish speaking, Dormio instructed them, *("Remember to think of a tree")*, and repeated the process.

Condition 4: Wake-Tree. Involved an unprompted period of time-matched wake. Participants sat upright with eyes closed. Dormio functioned as it did in Condition 3, except replaced *"Remember to think of a Tree"* with *"Remember to observe your thoughts"*.

2.5. Data analysis

2.5.1. Kruskal Wallis H test

The Kruskal Wallis H rank-order was used to test for differences between groups, followed by *post-hoc* Mann-Whitney *U* Test without Bonferroni corrections (Conover 1971; Hsu 1996; 2004; Daniel 1990). For comparisons of frequency of "Tree" incorporation into reports, the percent of reports with "Tree" references were calculated for each subject, and the calculated values compared across conditions. We did a multiple comparison analysis regardless of the result of Kruskal Wallis H Statistic Test, and have noted throughout the results where Kruskal Wallis justified the multiple comparison and where it did not. We include both Kruskal Wallis justified and unjustified multiple comparisons to minimize Type Two error (Hsu, 1996).

Table 1
Incorporation of tree references into mentation reports.

Condition	Reports	Rpts w/ content	% with content	Num. w/ tree ref	% w/ tree ref	Tree refs	Direct refs	Indirect refs
Sleep + Tree	67	66	99%	45	67%	91	77	14
Sleep-Tree	69	64	93%	2	3%	2	1	1
Wake + Tree	56	55	98%	29	52%	71	51	19
Wake-Tree	48	46	96%	0	0%	0	0	0

3. Results

3.1. Dream incubation rates

We performed serial awakenings of 25 sleep participants, collecting 136 dream reports, 67 from the Sleep + Tree condition and 69 from the Sleep, No Incubation condition. All sleeping participants (25/25) were able to recall at least 1 hypnagogic dream. One subject reported difficulty speaking while in hypnagogia, but uttered short phrases and elaborated on each after their final awakening. We collected a total of 104 wake reports from awake participants, 56 from the Wake + Tree condition and 48 from the Wake-Tree. All awake participants (24/24) gave at least 3 mentation reports from 4 to 5 requests (Table 1).

All dream reports were collected via audio, transcribed into typed text, and were not edited prior to scoring. For the purpose of assessing rates of dream incubation, a direct reference to 'Tree' is defined as an instance of use of the word "tree" or the parts of a tree in a dream mentation report, including "branch", "leaf", or "root". An indirect reference to 'Tree' is defined as use of words indicating themes related to but not directly referencing the object of a literal tree, including "paper", "plant", or "wood". One condition-blind rater counted instances of these specific words used in dream reports. Methods adapted from the Wamsley (2010) Alpine Racer study, which assessed "direct" and "indirect" incorporation of the theme of skiing into dreams.

Condition 1—Sleep + Tree: Out of 67 total verbal dream reports, 45 (67%) contained a total of 91 references to 'Tree' (2.0 per report with tree reference), including 77 direct references and 14 indirect references (Table 1 and Fig. 3).

Condition 2—Sleep-Tree: Out of 69 total verbal dream reports, 2 (3%) contained one reference each, one a direct reference to 'Tree' the other an indirect reference.

Condition 3—Wake + Tree: Out of 56 total verbal waking reports, 29 (52%) contained direct references to 'Tree'. Across these 56 reports, there were 70 references to 'Tree', 51 direct and 19 indirect.

Condition 4—Wake, No Incubation: Out of 48 total verbal waking reports, there were no direct or indirect references to 'Tree'.

The percent of direct "tree" references varied significantly by group (Kruskal Wallis H test; $H = 29.69$, $p < .001$). A Mann-Whitney U test indicated that the inclusion of direct references to 'Tree' in reports was significantly greater in the + Tree vs. -Tree conditions (+Tree = 62 ± 35%, -Tree = 1 ± 3%, $U = 527.0$, $p < .001$). Additionally, direct references to 'Tree' in reports was

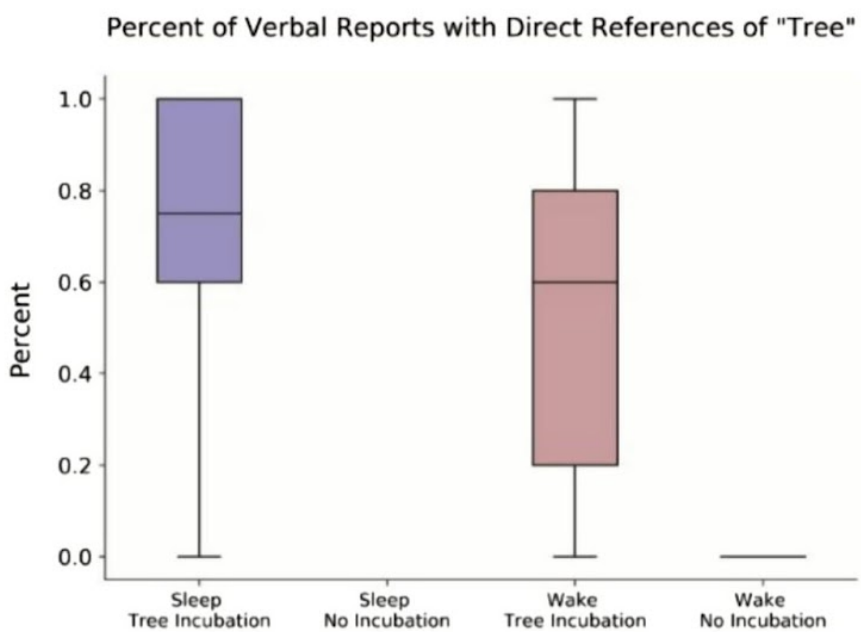

Fig. 3. The percent of direct references to 'Tree' in verbal reports, averaged across participants.

Table 2
Sleep Tree Incubation dream report examples.

	Time of Dream Report	Dream Content
Subject 11	Verbal report given after awakening	*"My dream was pleasant and mysterious. I never knew what the next part of my dream was going to be. My dream did involve a tree. I was following the roots with someone and the roots were transporting me to different locations. At each location I was trying to find a switch. It was unclear why I had to turn on the switch, but at the final location a window with a bright light was revealed. I saw a familiar face, but I couldn't place where I'd seen them. In the background, the moon was shining bright and illuminating the face. I was dreaming this while awake and not fully asleep…I could hear myself talking to someone about finding a switch. I could hear my breathing, my footsteps, the wind, and an air conditioner. When I bumped into objects, I can hear the noise of the collisions. I could hear the roots of the tree pulsating with energy as if they were leading me to some location."*
Subject 3	Post-study debriefing	*"I think it's really, really useful for creativity…at the beginning of my dreaming experience I was seeing scenes that were the same size and functionality of real trees, but then the second time I was much bigger than the trees and I could eat them like finger food. You wouldn't come up with that idea at the beginning, but this time I had hundreds of them. The hope is to break out of the banal stories. Which is why I liked this experiment. I'm afraid when I walk out that I will see everything changing like fantasies. But yeah why not. Who says that I must live in the world that everyone is living in? I could write it as if I'm living in a novel."*
Subject 6	Post-study debriefing	*"I particularly remember feeling that my consciousness was almost entirely untethered when I thought about the subject of my post-sleep story about a tree - when a person began exploring the freedom of space through tree imitation, before collapsing in a twisted heap and fully becoming a tree. Then, they proceeded to explore four dimensions - which was thoroughly confusing but a lot of uninhibited fun."*
Subject 12	Verbal report given after awakening	*"I'd start with a tree, I'm like thinking of a tree, for the first few minutes I didn't really go anywhere with the tree, I was just looking at it, it was like really colorful, but each time it woke me up, the path and depth in terms of how much it became a story went deeper. I started to go down a story path every time the word tree was mentioned, and when I was told that I was sleeping and to think of a tree again I switched back to the tree and took a different path. Very interesting, relaxing, and really made me think…I felt much more creative than usual. I never really think of myself as a creative person but it felt easier to think of abstract things and stories, like it just came to me."*

significantly greater in the Sleep + Tree condition than the Sleep-Tree condition (Sleep + Tree = 67 ± 35%, Sleep-Tree = 1 ± 5%; U = 131.0, p = 0.001) and in the Wake + Tree condition than the Wake-Tree condition (Wake + Tree = 52 ± 36%, Wake-Tree = 0 ± 0%; U = 132.0, $p < .001$). References to 'Tree' did not differ between the Sleep + Tree and Wake + Tree conditions (Sleep + Tree = 67 ± 35%, Wake + Tree = 52 ± 36%; U = 57.0, p = 0.129).

3.2. Dream phenomenology

3.2.1. Sleep + Tree reports

Hypnagogic mentation in the Sleep + Tree group revealed inclusion of the 'Tree' theme into 67% of dream reports that included episodic memories, current concerns, and dream narratives (Table 2). Dream reports increased in bizarreness and immersion with each awakening, but consensual rating of bizarreness was not performed. An example is given below:

Awakening 1: Trees, many different kinds, pines, oaks
Awakening 2: Who I'm going to have over for dinner on Saturday, and occasionally trees, and how I'm not falling asleep
Awakening 3: A tree from my childhood, from my backyard. It never asked for anything.
Awakening 4: Trees splitting into infinite pieces
Awakening 5: I'm in the desert, there is a shaman, sitting under the tree with me, he tells me to go to South America, and then the tree…"

3.2.2. Sleep-tree reports

Hypnagogic mentation in the absence of priming revealed a range from flashing imagery to fully immersive narrative scenes. Reports often reflected low cognitive control, disinhibition, labile personal agency, acceptance of implausibility, as well as temporal, spatial and proprioceptive distortion (Table 3). An example of a series of reports from one subject is given below:

Awakening 1: The desert
Awakening 2: I was thinking about how someone else would have to fall
asleep here
Awakening 3: the sea, sharks, lots of movement
Awakening 4: clouds and movement
Awakening 5: the mothering feeling…in the middle…safe
Awakening 6: I lost it! I wasn't thinking of anything.

3.2.3. Wake reports

Reports from the Wake + Tree group revealed a range of imagery with low immersion. Reports often pulled from episodic memories or involved prospective planning, and revolved around current concerns or cultural references where trees played a central

Table 3
Sleep No Incubation dream report examples.

	Time of Dream Report	Dream Content
Subject 37	Post-study debriefing	*"I feel like my story was far more open and interesting than it would have been regularly, and that the thoughts I had flowed into each other much more easily than what otherwise might have been."*
Subject 28	Post-study debriefing	*"I think it would be good to think about ideas for art in this state because everything feels looser and your mind goes places it might not go otherwise. Even reflecting on your day feels good because the thoughts don't seem permanent…my thoughts kept jumping around so I didn't really have a normal sense of time. I don't think I really had any sense of time. It felt shorter than 45* min *when the experiment ended…I let myself think about anything I wanted to and my mind felt very relaxed because I was sort of asleep. It definitely felt different from my normal cognitive state. I think I could see my whole self at some points, so kind of like an out of body experience."*
Subject 29	Post-study debriefing	*"I feel more at ease. And as compared to earlier today - when I couldn't even read more than a few pages without feeling distracted - I feel calm. I feel creative. The writing activity especially was very calming, and makes me feel like that sort of random thought exercise can be a source of inspiration for me moving forward. I just feel more in tune with my experiences and memories - and feel like I want to be more artful… I definitely didn't feel like I had been asleep for 45 min. I felt it was more likely around 10–15 min. So in that sense, dreams felt a lot slower to me. I didn't really imagine my body. At some points it felt like I wasn't even there, and I was just a pair of eyes observing the memories and world around me - without necessarily physically being there. It's like I was just a visitor, looking at my life as if it were in an enclosure. Life is very beautiful, but sometimes when we get lost in the minutia of daily activities - we forget that. I felt like I was seeing a highlight reel of peculiar memories, and it really made me want to be more reflective about my life and really decide what I do on an everyday basis with intention and purpose. I just felt much more relaxed during the experience. I didn't feel inhibited by any of the constraints I feel when I have to convey experiences with actual words - it felt like I could communicate without any sort of language (verbal or otherwise)—I just understood everything around me for what it was."*
Subject 33	Post-study debriefing	*"I went from imagining something that I thought might induce a dream, to beginning to dream about that imagined thing. Then, there would be a transition from imagined experience to dream, sometimes that was continuous, and sometimes not continuous at all. When not continuous, my mind would jump from what I had been imagining to something entirely different, and this lack of control indicated to me that I was dreaming. I never lost full awareness of where I was, such that when I was woken I was not surprised to find myself in this reality…However, I seemed to have some kind of creative inspiration while I wrote that seemed somewhat self directed similar to how dreams are. Certainly, I thought of some strange things that I would never have thought about were I not somewhat asleep. I had a dream that I was hovering through the air, and throwing what were like miniature bombs to the ground that would explode into literal mushrooms, not mushroom clouds. I consider ideas like these to be creative."*
Subject 35	Verbal report given after awakening	*"I had a lot of strong images and some narrative stuff—didn't experience any big hypnic jerk but I guess some little ones. My mind wandered a fair amount from physical locations that were made up to ones that resembled ones I knew. I remember a rather horrifying story from the experience of a train with a pig's face and a piglet who was talking to me and saying I didn't understand what it was like for my mother to be taken away. There was a period of time in which there was narration that sounded a lot like an oliver sacks book and like his voice and i had some v mild hallucination type things of colors fluctuating in a thermal-imagey type way. I daydreamed about things I wanted to do in the coming weeks. I saw myself turn around, wearing a veil. I saw maxwelton and bone caves with swingsets at the entrances, and my friends who I just went on a caving trip with sitting in them. I imagined several strange and implausible things and honestly can't remember 90% of them just bc the images went by so quickly"*

role.

Awakening 1: I'm thinking about an X Files episode where a creature ties people to trees
Awakening 2: I'm thinking about climbing a tree and reading at the top of it
Awakening 3: I'm thinking about walking through orange and almond groves
Awakening 4: the adventure I'm going to have this weekend
Awakening 5: I'm thinking about the tree that the peach grew on in "James and the Giant Peach"

Reports from the Wake-Tree group revealed low imagery, low immersion, high cognitive control, high reference to current concerns and future planning, and numerous references to the ongoing study and lab environment (see Table 4). A series from one subject is given below:

Awakening 1: Oh I'm just awake.
Awakening 2: Thinking about what I have to do tonight
Awakening 3: I was thinking about the election
Awakening 4: I was thinking about the itch on my ear
Awakening 5: I was thinking about thinking about what I should be thinking about

3.3. *Sleep physiology*

One goal of this study was to optimize the physiological thresholds for Dormio-defined sleep onset. Biosignals collected from participants have been used previously to characterize sleep onset (Ogilvie, 2001). The measures of interest were the changes in HR,

Table 4
Wake Tree Incubation and Wake No Incubation report examples.

	Wake Condition	Dream Content
Subject 23	Wake Tree Incubation, Post-study debriefing	*"I had a mostly pleasant experience. During the first portion, I found my mind mostly wandering between the task at hand (thinking about trees) and thinking about the study overall and thinking about my heartbeat/breathing…I thought about the word t-r-e-e and I would recall past experiences when I was around trees. It was interesting how I often think of trees as secondary items that are in the environment around me but not really primary. I can't say the thoughts I had were creative."*
Subject 17	Wake Tree Incubation, Post-study debriefing	*"I did get quite bored during the experiment but forced myself to think about things instead of going completely blank, which would cause me to fall asleep. At first I tried to think about the tree right when the voice directed me to. Each time I would think about the trees along the street of my childhood home and how the leaves would change colors in autumn. However, soon after I thought about that my mind would get distracted and I would think about what was really going on in my mind such as, what I had eaten for lunch, who I saw, what music I was listening too. I would also think about my day so far, and my plans for the rest of the day. I felt less inhibited when my mind wandered from thinking about the tree. I would say I only thought about the tree for 30 seconds or less after the voice would direct me to think about it. "*
Subject 42	Wake No Incubation, Post-study debriefing	*"My thoughts were about recent events including the experiment itself. I thought about what I should think about and tried to guess what would trigger the device. I also felt a sense of tightness in my stomach and wondered if it's because I was overly concentrated on my thoughts. I wasn't really trying to be creative. I felt more of what my body is feeling than if I had my eyes open."*
Subject 40	Wake No Incubation, Post-study debriefing	*"It was very relaxing and allowed me to calm down after a long day of work. I was able to let my mind relax and think more calmly. My thoughts were based on things I was doing or had to do. None of these included a tree. I just kind of let my mind wander without any logic".*

EDA and Flexion from the onset of the experimental session (the moment the a participant lay down, when physiological data collection began) and the first subjective report of 'Sleep' or "Halfway sleep" obtained after each Dormio-iniated arousal, following the participant's mentation report. These changes are compared to the changes seen between the onset of the experiment and the first subjective report of 'Wake' following a Dormio-initiated arousal. Across all participants, sleep onset averaged 10.3 ± 6.4 (S.D.) minutes. Changes in HR, EDA and Flexion were more positive (HR, EDA) or less negative (flexion) for reported 'Wake' than for reported 'Sleep' and in the direction of greater arousal for all three (Fig. 4). To identify potential sleep onset threshold values for each parameter, we calculated the 80th percentile of 'Sleep' values, above which subjects would be likely to report being awake, and the 20th percentile for 'Awake' values, below which subjects would likely report being asleep.

The mean change in HR between experiment onset and first verbal report of 'Sleep': -+2.9 ± 22.9 bpm vs 'Wake': +10.0 ± 18.7. Eighty percent of 'Sleep' reports occurred with changes in HR < 6 bpm, while 80% of 'Wake' reports had ΔHR > -2 bpm. Mean muscle flexion change between experiment onset and first report of 'Sleep': was −6.7 ± 9.0 KΩ vs + 3.4 ± 6.3 KΩ for 'Wake'. Eighty percent of 'Sleep' reports were obtained with changes < -4 KΩ, 80% and 80% of 'Wake' reports were > -6.0 KΩ. Finally the mean change in EDA was −4.0 ± 13.4 μSemen for 'Sleep' reports and + 3.4 ± 8.6% for 'Wake'reports. Eighty percent of 'Sleep' reports showed changes in EDA < 5 μSemen, while 80% of 'Wake' reports were > -1 μSemen.

Physiological Measure	Provisional sleep onset threshold	80th percentile Sleep	20th percentile Wake
ΔHeart rate	> 5 BPM	6 BPM	−2 BPM
ΔFlexion	> 8 KΩ	−4 KΩ	−6 KΩ
ΔElcetrodermal activity	> 5 μSemen	5 μSemen	−1 μSemen

Future studies will look at the predictive power of system thresholds combining these presumptive values.

4. Discussion

4.1. Dormio: The dream incubation device

The Targeted Dream Incubation (TDI) protocol is designed for controlled generation of specific dream content at sleep onset, enabling experiments which probe the causal role of dream content in post-sleep performance. This protocol is available to anyone with an array of sensors that can track sleep onset, as well as deliver and record audio. Dormio is designed to enact this protocol automatically, making the TDI protocol mobile and cheap in comparison to techniques that require PSG. Though the choosing not to use PSG for TDI will likely lead to less specificity in staging sleep onset, given the extensive evidence that sleep onset imagery occurs from early drowsiness into the early minutes of stage 2 NREM sleep (Rowley et al., 1998; Nielsen, 2017), Dormio has a large margin of error for which sleep onset detection can be tolerated without sacrificing the hypnagogic dream incubation goal. This paper presents results suggesting that the Dormio device can track sleep onset with enough specificity and collect dream reports with sufficient reliability to enact TDI, incubating and capturing experimenter-chosen themes in hypnagogic dreams. Results suggest Dormio is an effective dream incubation device, with 67% of Sleep + Tree awakenings yielding dream reports that incorporate the auditory prime, 'Tree', automatically captured by Dormio's audio recording system.

There are significant limitations to keep in mind when interpreting this experiment. The age range of participants is limited, and

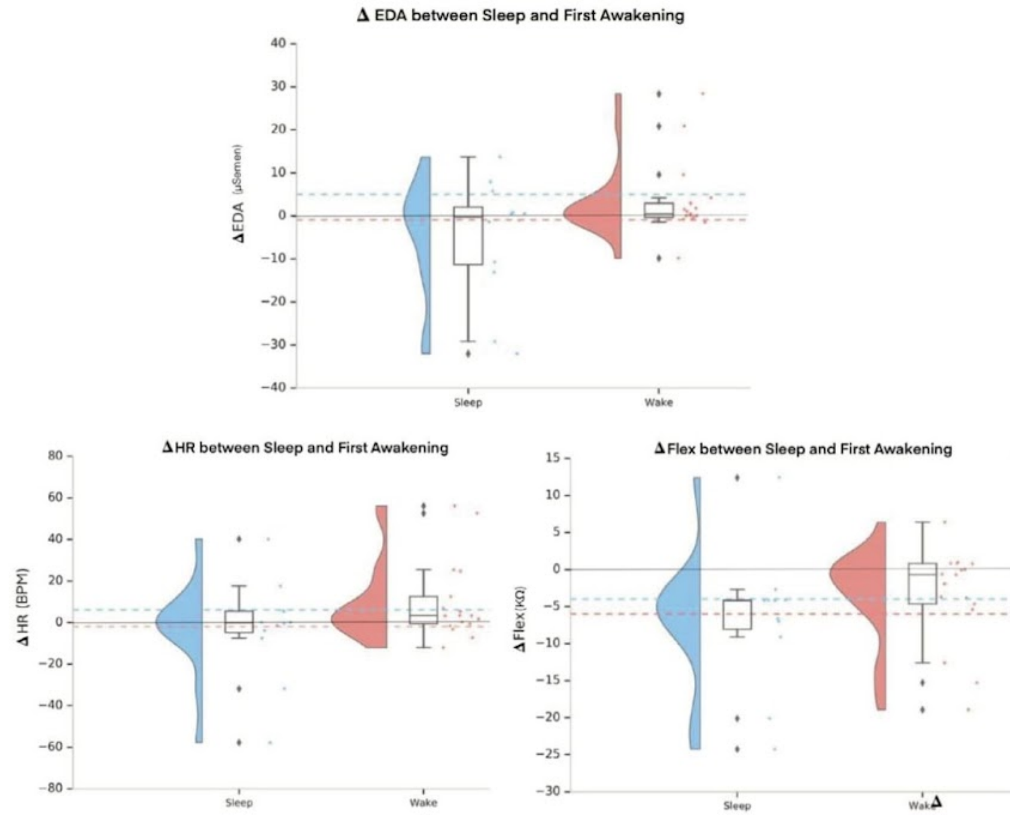

Fig. 4. Distributions in absolute change in HR, Flex and EDA. Measurements are from prior to beginning to try to sleep and first automated "awaken" with a subjective report of having in fact been asleep (left, blue) and the first with a report of actually having been awake (right, red). Blue dotted lines denote the 80th percentile of 'Sleep' awakenings, and hence above which 'Awake' is a likely report. Red dotted lines denote the 20th percentile of 'Sleep' awakenings, above which participants are likely to report having been 'Asleep'. (a) Change in heart rate between Dormio-defined sleep onset and first awakening. HR Mean Sleep: -2.89 ± 22.94. HR Mean Wake: 10.01 ± 18.7. 80% of Sleep reports below 6, 80% of Wake reports above -2. (b) Delta in FDP muscle flexion between Dormio-defined sleep onset and first awakening. Flex Mean Sleep: -6.74 ± 9.05. Flex Mean Wake: -3.42 ± 6.32. 80% of Sleep reports below -4, 80% of Wake reports above -6. (c). Delta in electrodermal activity between Dormio-defined sleep onset and first awakening. EDA Mean Sleep: -4.88 ± 13.44. EDA Mean Wake: 3.36 ± 8.64. 80% of Sleep reports below 5, 80% of Wake reports above -1.

all are university-affiliated, yielding a somewhat homogenous population. This study, designed to investigate efficacy of TDI using only Dormio, did not have PSG measurements. This leaves us with little information as to where participants were awoken within the range of the sleep-onset process, and means experimenters must trust verbal reports with regards to sleep onset, which can be unreliable. Further, there is a methodological issue with trusting dream reports, as dreams can be forgotten or fabricated due to demand characteristics. We are aware of these issues in the TDI protocol, and look forward to future techniques which allow for direct capture of dream reports via neurophysiology as opposed to subjective report. Future studies on TDI should use multiple incubation themes, as opposed to our single theme 'Tree', as semantic or syntactic characteristic of auditory primes may influence incubation rates. Regardless of these limitations we think the Dormio device and TDI protocol warrant future study, and enable researchers to ask new questions about dream-related cognitive enhancement.

The potential utility for a device like Dormio to specifically enhance performance on a task pre-determined by the user is tantalizing. Significant correlations between dream content and sleep-dependent memory processing have been reported in several studies, which used a variety of learning tasks, including learning a story (Barrett, 1993; Nielsen & Stenstrom, 2005), a foreign language (De Koninck et al., 1990), word-picture associations (Schoch, Cordi, Schredl, & Rasch, 2019), a visual maze (Wamsley & Tucker, 2010; Wamsley & Stickgold, 2019), and explicit visuospatial memories (Plailly, Villalba, Vallat, Nicolas, & Ruby, 2019), although others have failed to find significant correlations (see Plailly et al., 2019 for summary). Taken as a whole, these studies provide substantial support for the existence of such correlations, although not necessarily for all forms of memory encoding. While correlations have been found, no studies have attempted to show a causal relationship between dream incorporation, and memory consolidation.

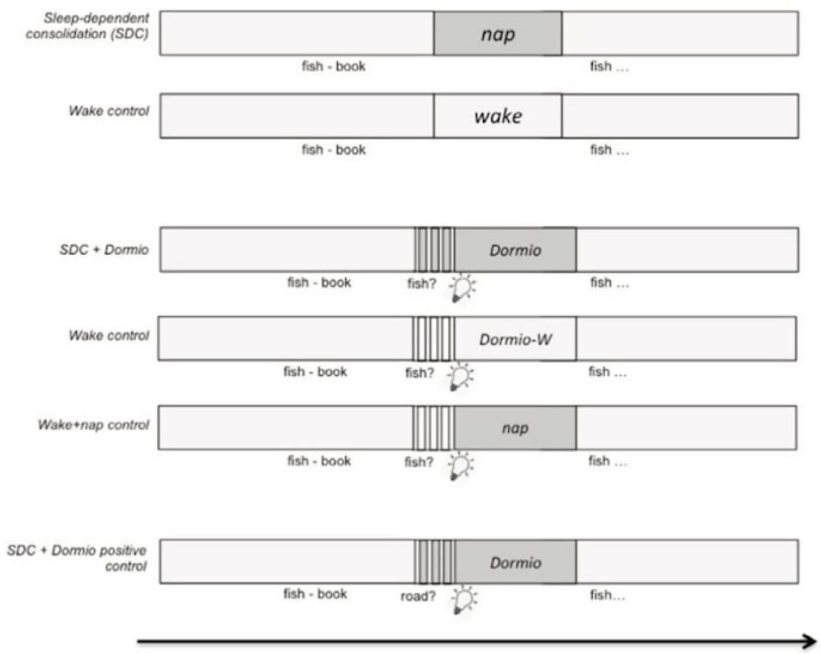

Fig. 5. Experimental design of future study of TDI and sleep-dependent memory consolidation (SDC).

4.2. Uses of targeted dream incubation (TDI)

Establishing a causal link between dream incorporation and sleep-dependent memory processing requires the experimental manipulation of dream content through targeted dream incubation. The design of one such experiment is shown in Fig. 5. This design tests the hypothesis that inducing dreams about the cue in a word pair enhances recall of the associated target word. Comparisons between the dream incubation condition and control conditions could confirm the specific contribution of dreaming about the cue word to subsequent, post-sleep memory enhancement. A similar design could test the hypothesis that inducing dreams about a topic increases creative thinking about the topic: where tests of creative uses of a target item (e.g. "bricks") are conducted in the post-sleep period.

Considerable anecdotal evidence supports the effectiveness of creativity augmentation using sleep onset dream incubation. Reports by both Thomas Edison and Salvador Dali document its consistently successful applications to the design of inventions and works of art, respectively (Stickgold, 2019). In both of these cases, sleep onset dreams contained explicit images or thoughts that contributed to the creative resolution of complex problems. Similar to the experiences of Edison and Dali, the Dormio device could take advantage of the sleep onset period to incubate specific problems and generate specific solutions. Dream reports collected within seconds to minutes of sleep onset could deliver creative benefits immediately on awakening.

But TDI may also contribute to sleep-dependent memory processing by identifying and tagging memories for further processing later in the sleep period. Evidence for such tagging is found in TMR studies, where memory reactivation during deep NREM sleep (N3) led to enhanced integration of new memories into existing memory networks that was correlated with subsequent time spent in REM sleep, suggesting that TMR during N3 tagged the reactivated memories for subsequent processing during REM sleep (Tamminen, Lambon, & Lewis, 2017). TDI has not yet been explored for the enhancement of declarative memory or other purposes, but TDI at sleep onset might well tag the dream content for processing during subsequent N3 or REM sleep.

4.3. Researching Dreams: "The hard problem"

Correlational studies linking dream incorporation and memory consolidation leave two important questions unanswered. The first of these is whether there is a causal link between the two. For example, Wamsley et al's study demonstrating a correlation between dream incorporation and improvement on a maze-learning task also reported that those who reported task-related dreams were among the most poorly performing participants at training (Wamsley, Tucker, Payne, Benavides, & Stickgold, 2010). Although the correlation between dream incorporation and task improvement remained significant even after initial performance was added as a covariate, this finding raises the possibility that the correlation is driven largely by factors that separately caused increases in dream incorporation and in task performance. TDI could resolve this issue by demonstrating that the experimental induction of task-related dreaming at the moment of sleep onset enhances sleep-dependent memory consolidation.

The second unanswered question, however, cannot be so easily resolved. In their 2010 paper, Wamsley and colleagues concluded, "it is not our contention that dream experiences cause memory consolidation during sleep. Instead, … dreaming may be a reflection of the brain processes supporting sleep-dependent memory processing" (Wamsley et al., 2010). While TDI may resolve the tightness of this link, it cannot help us know whether dreaming per se, that is the experiential phenomenon of dreaming as a mental event, is critical to this memory processing or simply a functionless epiphenomenon. But despite this remaining ambiguity, the Dormio data described here demonstrates that this device can be used to test whether TDI—targeted dream incubation—can significantly enhance creativity, learning, and memory performance, opening a door to a new era of dream research.

CRediT authorship contribution statement

Adam Haar Horowitz: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Resources, Software, Validation, Visualization, Writing - original draft, Writing - review & editing. **Tony J. Cunningham:** Writing - original draft, Writing - review & editing. **Pattie Maes:** Conceptualization, Funding acquisition, Resources, Supervision. **Robert Stickgold:** Conceptualization, Supervision, Validation, Visualization, Writing - original draft, Writing - review & editing.

Declaration of Competing Interest

The authors report no conflicts of interest

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Appendix A:

Below are the specific instructions given to the users in each condition. As the instructions are critical to correctly initiate dream incubation and hypnagogic imagery, attempts at replication should closely mirror the instructions below:

Instructions for Condition 1 (Sleep Tree Incubation): *"This experiment is investigating the relationship between mental rest and cognitive flexibility. Varied imagery, memories, words, or bodily feelings may come up throughout the experiment. The aim of this exercise is to observe them, stay with them, follow them lightly and see where they go. One thing not to worry about is questioning whether you are asleep. This period in between sleep and wake feels to some people like sleep, to others just like relaxation or mind wandering. All are completely fine, just watch your mind and relax. Sleep cannot be forced, just allowed. Head towards sleep, but don't worry at all where you are in it, just relax.*

After you lie down, you will be asked to think of a theme. Relax, hold that theme in your mind. A few times, you will be told you are falling asleep and reminded of the dream theme. These prompts are not to wake you up fully, just to make sure you do not descend into deep sleep, and to keep you aware so that you can keep observing your mind. Just stay still when the prompts come. Again, we're interested in your thinking in this semi-lucid period. Whenever you are prompted to report, please just vocally report what was going through your mind, and report whether you think you were asleep, by either saying awake, halfway or asleep. Then relax and drift towards sleep again."

Instructions for Condition 2 (Sleep No Incubation): *Same until: "After you lie down, you will be asked to observe your thoughts. Relax, and see where your thoughts go. A few times, you will be told you are falling asleep and reminded to observe your thoughts. These prompts are not to wake you up fully, just to make sure you do not descend into deep sleep, and to keep you aware so that you can keep observing your mind. Just stay still when the prompts come. Again, we're interested in your thinking in this semi-lucid period. Whenever you are prompted to report, please just vocally report what was going through your mind, and report whether you think you were asleep, by either saying awake, halfway or asleep. Then relax and drift towards sleep again."*

Instructions for Condition 3 (Wake Tree Incubation): *"This experiment is investigating the relationship between mental rest and cognitive flexibility. Varied imagery, memories, words, or bodily feelings may come up throughout the experiment. The aim of this exercise is to observe them, stay with them, follow them lightly and see where they go. One thing not to worry about is questioning whether you are mind wandering or focused. All are completely fine, just watch your mind and relax. After you close your eyes, you will be asked to think of a theme. Relax, hold that theme in your mind. A few times, you will be told to observe your thoughts and reminded of the theme. These prompts are just to keep you aware so that you can keep observing your mind. Just stay still when the prompts come. Again, we're interested in your thinking in this period of mental rest. Whenever you are prompted to report, please just vocally report what was going through your mind. Then relax and let your mind drift again."*

Instructions for Condition 4 (Wake No Incubation): *Same until: "After you close your eyes, you will be you will be asked to observe your thoughts. These prompts are just to keep you aware so that you can keep observing your mind. Just stay still when the prompts come. Again, we're interested in your thinking in this period of mental rest. Whenever you are prompted to report, please just vocally report what was going through your mind. Then relax and let your mind drift again."*

Appendix B. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.concog.2020.102938.

References

Ajilore, O., Stickgold, R., Rittenhouse, C. D., & Allan Hobson, J. (1995). Nightcap: Laboratory and Home-Based Evaluation of a Portable Sleep Monitor. *Psychophysiology*. https://doi.org/10.1111/j.1469-8986.1995.tb03410.x.

Antrobus, J. S., & Wamsley, E. J. (2017). Sleep Mentation in REM and NREM: A Cognitive Neuroscience Perspective☆. *Reference Module in Neuroscience and Biobehavioral Psychology*. https://doi.org/10.1016/b978-0-12-809324-5.02859-5.

Arzi, A., Holtzman, Y., Samnon, P., Eshel, N., Harel, E., & Sobel, N. (2014). Olfactory Aversive Conditioning during Sleep Reduces Cigarette-Smoking Behavior. *The Journal of Neuroscience: The Official Journal of the Society for Neuroscience, 34*(46), 15382–15393.

Arzi, A., L. Shedletsky, M. Ben-Shaul1, K. Nasser, A. Oksenberg, I. S. Hairston, and N. Sobel, "Humans Can Learn New Information During Sleep," Nature Neuroscience, 15 (2012): 1460-1465.

Barrett, D. (1993). The 'Committee of Sleep': A Study of Dream Incubation for Problem Solving. *Dreaming*. https://doi.org/10.1037/h0094375.

Baylor, G. W., & Cavallero, C. (2001). Memory Sources Associated with REM and NREM Dream Reports throughout the Night: A New Look at the Data. *Sleep, 24*(2), 165–170.

Boucsein, W., Fowles, D. C., Grimnes, S., Ben-Shakhar, G., Roth, W. T., ... Filion, D. L. (2012). Publication recommendations for electrodermal measurements. *Psychophysiology, 49*(8), 1017–1034.

Carr, M., & Nielsen, T. (2015). Morning Rapid Eye Movement Sleep Naps Facilitate Broad Access to Emotional Semantic Networks. *Sleep, 38*(3), 433–443.

Carskadon, M. A., & Dement, W. C. (2011). Normal Human Sleep. *Principles and Practice of Sleep Medicine*. https://doi.org/10.1016/b978-1-4160-6645-3.00002-5.

Casagrande, M., De Gennaro, L., Violani, C., Braibanti, P., & Bertini, M. (1997). A Finger-Tapping Task and a Reaction Time Task as Behavioral Measures of the Transition from Wakefulness to Sleep: Which Task Interferes Less with the Sleep Onset Process. *Sleep, 20*(4), 301–312.

De Koninck, J., Christ, G., Hébert, G., & Rinfret, N. (1990). Language Learning Efficiency, Dreams and REM Sleep. *Psychiatric Journal of the University of Ottawa: Revue de Psychiatrie de l'Universite d'Ottawa, 15*(2), 91–92.

Fogel, S. M., Ray, L. B., Sergeeva, V., De Koninck, J., & Owen, A. M. (2018). A Novel Approach to Dream Content Analysis Reveals Links Between Learning-Related Dream Incorporation and Cognitive Abilities. *Frontiers in Psychology, 9*(August), 1398.

Freud, S. (1910). *The interpretation of dreams (Strachey transl.)*. (New York: Basic Books.

Hauner, K. K., Howard, J. D., Zelano, C., & Gottfried, J. A. (2013). Stimulus-Specific Enhancement of Fear Extinction during Slow-Wave Sleep. *Nature Neuroscience, 16*(11), 1553–1555.

Hayashi, M., Motoyoshi, N., & Hori, T. (2005). Recuperative Power of a Short Daytime Nap with or without Stage 2 Sleep. *Sleep, 28*(7), 829–836.

Herlan, A., Ottenbacher, Jörg, Schneider, J., Riemann, D., & Feige, B. (2019). Electrodermal Activity Patterns in Sleep Stages and Their Utility for Sleep versus Wake Classification. *Journal of Sleep Research, 28*(2), e12694.

Hori, Tadao, Mitsuo Hayashi, and Toshio Morikawa. 1994. "Topographical EEG Changes and the Hypnagogic Experience." Sleep Onset: Normal and Abnormal Processes. https://doi.org/10.1037/10166-014.

Horowitz, Adam Haar, Ishaan Grover, Pedro Reynolds-Cuéllar, Cynthia Breazeal, and Pattie Maes. 2018. "Dormio." Extended Abstracts of the 2018 CHI Conference on Human Factors in Computing Systems - CHI '18. https://doi.org/10.1145/3170427.3188403.

Kelly, J. M., Strecker, R. E., & Bianchi, M. T. (2012). Recent Developments in Home Sleep-Monitoring Devices. *ISRN Neurology, 2012*(October), 768794.

Klepel, F., & Schredl, M. (2019). Correlation of task-related dream content with memory performance of a film task – A pilot study. *International Journal of Dream Research, 12*, 112–118.

Leslie, K., & Ogilvie, R. (1996). Vestibular dreams: The effect of rocking on dream mentation. *Dreaming, 16*, 1–16.

Mavromatis, A., and University of Brunel. 1983. Hypnagogia: The Nature and Function of the Hypnagogic State.

Murphy, J., & Gitman, Y. (2011). Pulse sensor amped. Retrieved from the website: https://pulsesensor. com/products/pulse-sensor-amped.

Nielsen, Tore. 2017. "Microdream Neurophenomenology." Neuroscience of Consciousness 2017 (1): nix001.

Nielsen, Tore A., and Philippe Stenstrom. 2005. "What Are the Memory Sources of Dreaming?" Nature 437 (7063): 1286–89.

Nir, Y., & Tononi, G. (2010). Dreaming and the Brain: From Phenomenology to Neurophysiology. *Trends in Cognitive Sciences, 14*(2), 88–100.

Noreika, V., Canales-Johnson, A., Koh, J., Taylor, M., Massey, I., & Bekinschtein, T. A. (2015). Intrusions of a Drowsy Mind: Neural Markers of Phenomenological Unpredictability. *Frontiers in Psychology, 6*(March), 202.

Noreika, V., Valli, K., Lahtela, H., & Revonsuo, A. (2009). Early-Night Serial Awakenings as a New Paradigm for Studies on NREM Dreaming. *International Journal of Psychophysiology: Official Journal of the International Organization of Psychophysiology, 74*(1), 14–18.

Ogilvie, R. D. (2001). The Process of Falling Asleep. *Sleep Medicine Reviews, 5*(3), 247–270.

Oudiette, D., Antony, J. W., Creery, J. D., & Paller, K. A. (2013). The Role of Memory Reactivation during Wakefulness and Sleep in Determining Which Memories Endure. *The Journal of Neuroscience: The Official Journal of the Society for Neuroscience, 33*(15), 6672–6678.

Oudiette, D., & Paller, K. A. (2013). Upgrading the sleeping brain with targeted memory reactivation. *Trends in Cognitive Sciences, 17*, 142–149.

Pagel, J. F., Blagrove, M., Levin, R., States, B., Stickgold, R., & White, S. (2001). Definitions of Dream: A paradigm for comparing field descriptive specific studies of dream. *Dreaming, 11*, 195–202.

Pagel, J. F. (2003). Non-dreamers. *Sleep Med, 4*, 235–241.

Penzel, T. 2003. "Is Heart Rate Variability the Simple Solution to Diagnose Sleep Apnoea?" The European Respiratory Journal: Official Journal of the European Society for Clinical Respiratory Physiology.

Penzel, Thomas, and Karl Kesper. 2006. "Physiology of Sleep and Dreaming." Sleep Apnea. https://doi.org/10.1159/000093138.

Plailly, J., Villalba, M., Vallat, R., Nicolas, A., & Ruby, P. (2019). Incorporation of Fragmented Visuo-Olfactory Episodic Memory into Dreams and Its Association with Memory Performance. *Scientific Reports, 9*(1), 15687.

Prerau, M. J., Hartnack, K. E., Obregon-Henao, G., Sampson, A., Merlino, M., Gannon, K., ... Purdon, P. L. (2014). Tracking the Sleep Onset Process: An Empirical Model of Behavioral and Physiological Dynamics. *PLoS Computational Biology, 10*(10), e1003866.

Rasch, B., Buchel, C., Gais, S., & Born, J. (2007). Odor cues during slow-wave sleep prompt declarative memory consolidation. *Science, 315*, 1426–1429.

Rechtschaffen, Allan. 1994. "Sleep Onset: Conceptual Issues." Sleep Onset: Normal and Abnormal Processes. https://doi.org/10.1037/10166-001.

Rowley, J. T., Stickgold, R., & Hobson, J. A. (1998). Eyelid Movements and Mental Activity at Sleep Onset. *Consciousness and Cognition, 7*(1), 67–84.

Rudoy, J. D., Voss, J. L., Westerberg, C. E., & Paller, K. A. (2009). Strengthening individual memories by reactivating them during sleep. *Science, 326*, 1079.

Schoch, S. F., Cordi, M. J., Schredl, M., & Rasch, B. (2019). The Effect of Dream Report Collection and Dream Incorporation on Memory Consolidation during Sleep. *Journal of Sleep Research, 28*(1), e12754.

Schredl, M., Hoffmann, L., Sommer, J. U., & Struck, B. A. (2014). Olfactory stimulation during sleep can reactivate odor-associated images. *Chemical Perception, 7*, 140–146.

Schredl, M. "Is Dreaming Related to Sleep-Dependent Memory Consolidation?" In N. Axmacher & B. Rasch (Eds.), Cognitive Neuroscience of Memory Consolidation (2017). Cham: Springer International Publishing. pp. 173-182.

Shimizu, R. E., Connolly, P. M., Cellini, N., Armstrong, D. M., Hernandez, L. T., Estrada, R., ... Simons, S. B. (2018). Closed-Loop Targeted Memory Reactivation during Sleep Improves Spatial Navigation. *Frontiers in Human Neuroscience, 12*(February), 28.

Smith, C. T., Nixon, M. R., & Nader, R. S. (2004). Posttraining Increases in REM Sleep Intensity Implicate REM Sleep in Memory Processing and Provide a Biological Marker of Learning Potential. *Learning & Memory, 11*(6), 714–719.

Stickgold, R., Malia, A., Maguire, D., Roddenberry, D., & O'Connor, M. (2000). Replaying the Game: Hypnagogic Images in Normals and Amnesics. *Science, 290*(5490), 350–353.

Stickgold, R. (2019). Creativity of the Dream and Sleep State. *Secrets of Creativity*. https://doi.org/10.1093/oso/9780190462321.003.0007.

Stickgold, R., & Wamsley, E. J. (2011). Why We Dream. *Principles and Practice of Sleep Medicine*. https://doi.org/10.1016/b978-1-4160-6645-3.00055-4.

Stickgold, R., Scott, L., Rittenhouse, C., & Hobson, J. A. (1999). Sleep-Induced Changes in Associative Memory. *Journal of Cognitive Neuroscience, 11*(2), 182–193.

Symbol, S. Spectra Symbol Flex Sensor. URL: https://www. sparkfun. com/datasheets/Sensors/Flex/FLEXSENSOR (REVA1). pdf (visited on 04/17/2014).
Tanaka, H., Hayashi, M., & Hori, T. (1999). Topographic Mapping of EEG Spectral Power and Coherence in Delta Activity during the Transition from Wakefulness to Sleep. *Psychiatry and Clinical Neurosciences, 53*(2), 155–157.
Tassi, P., & Muzet, A. (2000). Sleep Inertia. *Sleep Medicine Reviews, 4*(4), 341–353.
Vargas, I. M., Schechtman, E., & Paller, K. A. (2019). Targeted Memory Reactivation during Sleep to Strengthen Memory for Arbitrary Pairings. *Neuropsychologia, 124*(February), 144–150.
Wamsley, E. J. (2014). Dreaming and Offline Memory Consolidation. *Current Neurology and Neuroscience Reports*. https://doi.org/10.1007/s11910-013-0433-5.
Wamsley, E. J., & Stickgold, R. (2011). Memory, Sleep and Dreaming: Experiencing Consolidation. *Sleep Medicine Clinics, 6*(1), 97–108.
Wamsley, E. J., & Stickgold, R. (2019). Dreaming of a Learning Task Is Associated with Enhanced Memory Consolidation: Replication in an Overnight Sleep Study. *Journal of Sleep Research, 28*(1), e12749.
Wamsley, E. J., Tucker, M., Payne, J. D., Benavides, J. A., & Stickgold, R. (2010). Dreaming of a Learning Task Is Associated with Enhanced Sleep-Dependent Memory Consolidation. *Current Biology: CB, 20*(9), 850–855.
Weitzman, E. D., & Kremen, H. (1965). AUDITORY EVOKED RESPONSES DURING DIFFERENT STAGES OF SLEEP IN MAN. *Electroencephalography and Clinical Neurophysiology, 18*(January), 65–70.
Wixted, J. T. (2013). Sleep Aromatherapy Curbs Conditioned Fear. *Nature Neuroscience*.

Creativity Paper 2: Targeted dream incubation increases post-sleep creative performance

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Highlights:

- We present a serial auditory incubation protocol for targeted dream incubation (TDI)
- We utilize a wearable device, Dormio, to enable TDI at sleep onset
- We demonstrate that TDI increases post-sleep creative performance
- We discuss how our TDI protocol enables future research on the causal effects of dream content

Summary

The link between dreams and creativity has been a topic of intense speculation, given their commonly hyper-associative structure and specific anecdotal reports of artistic and scientific discoveries made while dreaming by the likes of Edison, Mendeleev, Dalí, and Proust. Dream-mediated creativity can be understood within a framework of cognitive flexibility. Creative solutions can result from identifying and strengthening remote associations between existing memories. Dreaming is thought to reflect a brain state that favors spreading activation among memory traces within cortical networks. However, the scientific literature linking dreams and creativity remains sparse, mostly correlating sleep physiology with waking creative traits. While research has shown that periods of sleep contribute to post-sleep enhancement of creativity, few experiments have collected relevant data on the specific contribution of phenomenological content, *i.e.* dreams. We present a protocol that uses serial auditory incubation of dream content at sleep onset, wherein repeated exposure to specific auditory stimuli is given during the hypnagogic period, enabling targeted dream incubation (TDI). We use Dormio, a wearable electronic device that tracks sleep state and executes TDI automatically. We present an experiment (N=49) using the Dormio device to incubate a target word ("tree") and show direct incorporation of the target word into dream content. We further present evidence that incubation of dream content confers a creative benefit on tasks related to the incubated theme of "tree," including the Alternative Uses Task, Verb Generation Task and Creative Storytelling Task. These benefits are significant, as evaluated by both subjective and computationally objective measures. We present evidence that dream incubation can also increase creative self-efficacy, *i.e.*, one's self-assessed creativity. To our knowledge, this is the first controlled study demonstrating a causal role for dream incubation in the enhancement of creative performance. We propose that the Dormio device, and the TDI protocol at sleep onset more broadly, can serve as a tool for controlled experimentation on dream content related to creativity.

Keywords: Dreams, memory, wearables, electronics, devices, creativity, incubation

1. Introduction

1.1 Sleep "Hacking"

The field of sleep science is moving from a passive to an active view of sleep, firstly in acknowledging that specific aspects of sleep physiology enable the cognitive benefits produced by sleep, rather than passive benefits coming simply from lack of sensory interference overnight, and secondly by actively shaping sleep rather than passively letting it run its course. Sensory processing of sound, scent, and somatosensory input continues during sleep, opening an avenue for direct sensory modulation of brain activity in sleep.[257] These interventions can work at the sensory level via direct entrainment of cortical oscillations or at the symbolic level via reactivation of previously learned associations.

The most heavily researched sensory-level intervention to "hack" sleep mechanisms at the cognitive level is Targeted Memory Reactivation (TMR).[243] In TMR, a cue that was previously linked to a learning task during wake is re-presented during sleep to drive specific reactivation of memories associated with the cue. TMR has been shown to improve post-sleep performance on tests of declarative memory, skill learning, and spatial navigation.[258,259,260]

1.2 Sleep As A Source of Creative Insight

Targeted reactivation of task-related memories can improve post-sleep creativity. Ritter (2012) found higher creativity following the presentation of task-related odors during overnight sleep compared to different-odor and no-odor control conditions. Odors presumably reactivated aspects of the creativity task, prompting creative ideation. However, this study did not report any data about the dreams which accompanied, and perhaps drove, this creative processing.[261]

Studies have suggested that periods of sleep present an optimal brain environment to engage in creative ideation. Periods of sleep are known to foster insight over and above time-matched periods of wake.[213,262,263] Neuroimaging data suggest that functional connectivity of higher order associative areas of the brain during REM sleep favors associations between distant memories[264] and semantically distant concepts.[265] A recent paper[195] suggests that sleep-onset NREM1 (referred to as N1 or hypnagogia) sleep is a creative sweet spot, engaging precise brain networks instrumental to creativity. Their study shows that spending as little as 15 seconds in N1 during a resting period tripled the chance of subjects subsequently having a moment of creative insight on a mathematical task compared to subjects who remained awake. They found that 34% of subjects reported spontaneously having task-related dreams, but did not find a correlation between these dreams and performance. However, it should be noted that the study excluded 36% of the mental reports collected, deeming them not true hypnagogic reports because they lacked "fleeting, involuntary, spontaneous, perceptual, and bizarre mental content."[195] Additionally, the study design did not include a mechanism to vary dream content across groups in a controlled manner. As such, this study could not draw causal conclusions about possible effects of dream content on creativity.

Apart from extensive anecdotal evidence supporting an association between N1 and creativity, this N1 sweet spot makes sense within a mechanistic framework of the brain basis of creativity. As originally suggested by Guilford, creative talent or creative ability can be assessed by a number of variables such as ideational fluency (i.e., number of ideas), the degree of novelty (or uniqueness/originality) of ideas, or the flexibility of the mind (i.e., the ability to produce different types of ideas, as opposed to rigidity).[266] A brain state which enables this kind of flexibility would both broaden the representational search space to encounter novel ideas and allow for some degree of cognitive control for identification of the best ideas for the task at hand. The N1 sleep state is characterized by less constrained cognitive control than wake while preserving enough executive control for recognition and capture of task-relevant sleep mentation.[195] Together, these elements potentiate cognitive flexibility and the exploration of distant semantic associations. Thus we hypothesize beneficial effects of N1 on any tasks which require semantic divergence (such as the Alternative Use Task, Creative Storytelling Task and Verb Generation Task described in Section 2.3).

1.3 Dream Content Correlates With Post-Sleep Performance

Several studies have found that task-related dream content predicts enhanced post-sleep task performance across a range of tasks. Novel learning experiences are incorporated into the content of NREM dreams, which is thought to reflect the processing of the newly learned material.[55,267] Incorporation of a currently studied language into dream content earlier in the semester predicts faster language learning.[268] Morning recall of short stories encoded the night before is correlated with story-related words in dream reports collected during the intervening night.[179,269] Improved coordination on a tennis video game task is correlated with gameplay incorporation into hypnagogic dreams, but not daydreams.[178] Reporting a dream about an exam on the pre-exam night is associated with better performance on the exam, and the frequency of dreams concerning the exam during a school term correlates with exam performance.[270] Participants trained on a 3D virtual maze task who refer to the maze task in their hypnagogic dream reports improve ten-fold at retest compared to sleep group participants who give no task-related dream reports; thinking of the maze while awake, importantly, is not associated with any significant performance benefit.[177,181] Dream experiences here are clear reflections of learning-induced reactivation of memory networks during sleep, and the experiencing of this reactivation in dreams correlates with dramatically enhanced memory performance.

1.4 Dreams as Source of Creative Insight

Dream recall frequency[193,271,272] and complexity[273] have been correlated with higher creativity. Subjects with narcolepsy demonstrate improved performance on tests of creativity, and their time spent in N1 dreams is a key modulator of creativity.[4] Although popular culture abounds with references to dream-induced creativity, the scientific literature linking dreams and creativity is surprisingly sparse.[195] In one study, participants asked to “incubate” a problem of their choosing in their dreams frequently reported dreaming of a useful solution.[274,275] However, the study did not control for the types of problems (emotional versus academic, for example), there was no control group in which dreams were not incubated, and there was no independent assessment of the usefulness of the dreamt solutions.[275]

1.5 Dreams as Correlates

Previous studies linking dream content with waking performance face one key challenge: dream content is difficult to control, and controlled experiments are not possible without independently varying conditions.[276] Studies have typically presented a task pre-sleep to all participants and then identified participants who had task-related dreams, allowing post-hoc analysis of correlations between dream content and post-sleep performance. These studies are limited to correlative claims because without methods for effective dream incubation they cannot utilize random group assignment based on an independent variable of dream incubation and test *a priori* hypotheses relating incubation and performance. This methodological challenge is compounded by a widespread "perception that, when occurring during sleep, cognition is not a legitimate area of scientific inquiry."[179] TMR studies, for instance, rarely even collect dream reports associated with cue presentation, though they explicitly aim to reactivate memories and potentially reactivate the accompanying experiences of these memories in dreams, as well. Sleep-mediated learning effects are explained in behaviorist terms, essentially ignoring any experiential contribution.

Our study addresses this core methodological challenge by experimentally incubating specific dream content, using the Dormio device and Targeted Dream Incubation (TDI) protocol, and then presenting tasks post-sleep. Because we can incubate task-related dreams using TDI,[225,277] rather than using the actual task as a dream incubation stimulus and relying on spontaneous task-related dreams, we can experimentally vary dream content across independent groups. This allows us to investigate the relationship between incubation of dreams and post-sleep performance. This study thus offers the first controlled experimental evidence supporting the causal effect of TDI on creative performance. The results suggest creative boosts are specifically caused by TDI in proportion to the successful incubation of theme-related dreams.

2. Methods

2.1 The Dormio Device

The Dormio system consists of a hand-worn sleep tracker and associated app, which is used to communicate with users and record dream reports via laptop or smartphone (Figure S1).[14,225,277–279] Dormio uses audio cues to suggest a dream theme to subjects during each of a series of awakenings, creating a serial dream incubation paradigm.[263,276] Dream incubations are followed by awakenings and requests for dream reports in an adapted, automated version of the serial awakenings paradigm previously used to collect hypnagogic dream reports.[249,280] Based on pilot data,[278] heart rate (BPM) changes of > 5 BPM, electrodermal activity sensor changes > 4 μSiemen or flexor muscle sensor changes > 8 KΩ were taken as indications of sleep onset. Further polysomnographic pilot data during a Dormio dream incubation session indicated that these wakeup thresholds correspond well to entry into N1 sleep and effectively limit subjects' entry into N2 (Figure S1). For a detailed description of physiological indicators of Dormio-defined sleep onset see (Horowitz, 2019; Haar Horowitz, 2020).[225,277]

2.2 Sleep and Dream Study Procedures

We enrolled 50 subjects (mean age = 26.71 ± S.D. 7.86 yrs, females = 24) to participate in a daytime napping study. Subjects were assigned to one of two states, Sleep (S) or Wake (W), and one of two conditions, Tree-Incubation (I) or No-Incubation (N), generating four experimental groups (SI, SN, WI, WN).

Subjects arrived at the laboratory in the afternoon between the hours of 12:00 pm and 4:00 pm, optimizing for the postprandial increase in sleepiness. Subjects were given a consent form to read and sign. The consent form and experimental procedures were approved by the MIT Institutional Review Board and the Committee on the Use of Humans as Experimental Subjects. One subject assigned to a sleep group was unable to sleep and was eliminated from analysis, leaving a total N=49. Subjects were told the experiment investigated the relationship between rest and cognitive flexibility and that they would engage in active rest or a nap. They were offered a sleep mask as compensation for participation in the study. After the consent process, subjects completed a series of questionnaires including creative self-efficacy, sleep quality, and demographic information. During the experimental period of sleep or wake, all subjects wore the Dormio system, regardless of their assigned experimental group. Experimenters remained in the room with subjects, out of sight as subjects had eyes closed in awake conditions and wore an eye mask in sleeping conditions. Following the period of sleep or wake, subjects completed a set of three creativity tasks followed by another creative self-efficacy questionnaire.

In administering sleep and dream studies, the wording of instructions given to subjects is crucial. Since we worked with subjects in periods of semi-lucidity where executive control is transient, metacognitive ability is reduced, and dream amnesia is common upon awakening, we attempted to design an interaction that would optimize the likelihood of dream recall. The precise wording of both the instructions read to subjects and the prompts for incubation and reports for each condition can be found in the Supplementary Materials (Sections 5.3.2 and 5.3.3) and are summarized here (Figure 1). Experimental instructions were delivered by an experimenter, while pre-recorded human voice prompts for incubation and reports were delivered by Dormio.

For the Sleep Tree-Incubation group, a variable timer initiated wakeups 1 to 5 minutes after Dormio detected N1 sleep. During each wakeup, a computer with pre-recorded audio prompts requested and then recorded a verbal dream report from the subject and then instructed them to “remember to think of a tree” and go back to sleep. The Sleep No-Incubation group followed a similar protocol, except that they were instructed to observe their thoughts (“remember to observe your thoughts”) rather than think of a tree. In the Wake Tree-Incubation group, subjects were left to mind-wander for periods of 7 minutes (mirroring average time needed for sleep onset in the sleep groups) plus a variable period of 1 to 5 minutes. Following each period, the computer requested and recorded a verbal report from the subject about their thoughts and then instructed them to continue thinking about a tree. The Wake No-Incubation group followed a similar protocol, except that they were instructed to observe their thoughts rather than to think of a tree.

Note that throughout this study, “incubation” refers to the process of providing stimuli to direct mentation towards a specific theme, as in “incubating” a specific dream topic. This usage is distinct from the traditional creativity neuroscience literature, wherein “incubation” refers to a period after a subject has received a task, typically during which attention is diverted from the task.

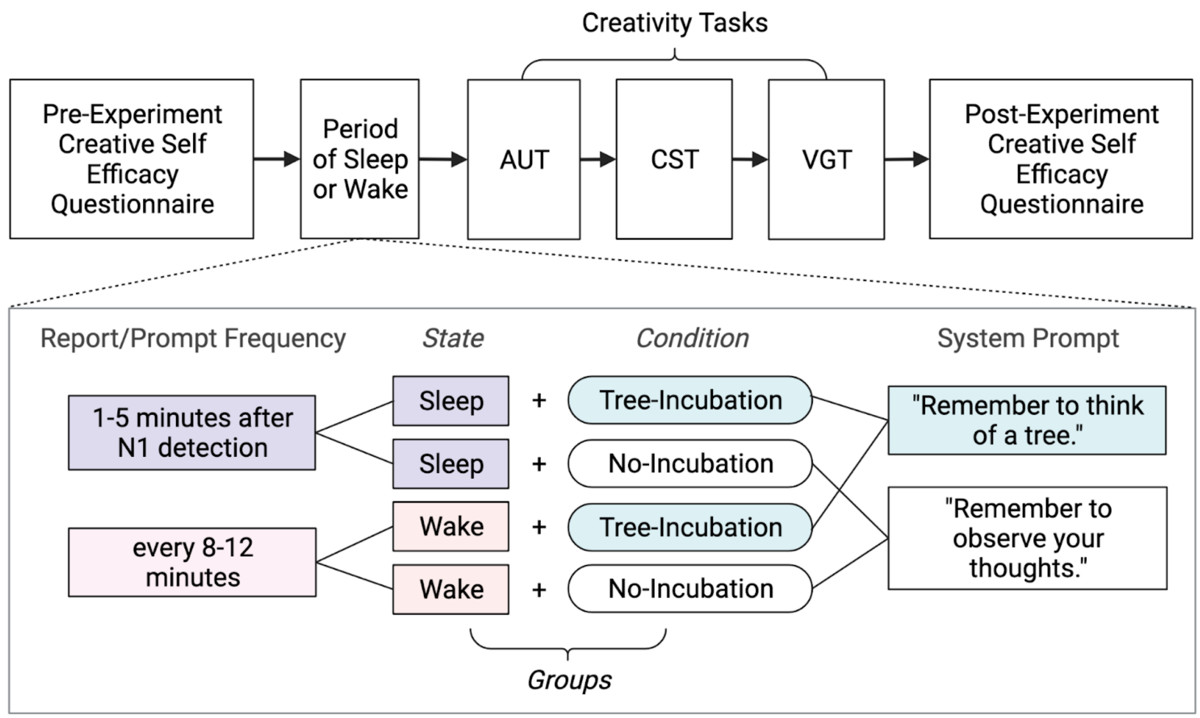

Figure 1. Experimental protocol. The flowchart indicates the order of events in the experimental protocol. The period of sleep or wake was 45 minutes in length. AUT: Alternative Uses Task; CST: Creative Storytelling Task; VGT: Verb Generation Task.

2.3 Creativity Assessment Procedures

Before the periods of nap or wake, subjects filled out a self-assessment of creative and flexible thinking.[281] After the 45-minute experimental period, they completed the Creative Storytelling Task,[282,283] Alternative Uses Task,[284,285] and Verb Generation Task,[286] in that order. After completing these tasks, subjects completed a written description of their dream experiences and filled out another self-assessment of creative and flexible thinking.

The Alternative Uses Task (AUT) has been widely validated as a measure of creativity which specifically indexes divergent thinking abilities, namely the ability to broaden representational search space and produce wide ranging responses to queries. Furthermore, task performance is correlated with and predictive of real-world creative achievements.[285,287] For this task, subjects were prompted to“list all the creative, alternative uses you can think of for a tree” and given three minutes to provide handwritten responses. Subjects were explicitly told to be creative, as noted in the prompt. Explicit instructions to be creative have been consistently shown to influence creativity across a wide variety of tasks, including divergent thinking.[288]

The Creative Storytelling Task (CST) has been used for decades to assess the neural correlates of creativity, specifically assessing creative effort, semantic divergence, and the ability to make new combinations of mental elements that form the basis of a meaningful product. Furthermore, the CST has been shown to engage brain areas core to creativity.[282,283] Importantly, the CST assesses task performance which is real-world relevant to individuals writing creatively in their professional or personal life. Moreover, computational linguistic assessments of the CST correlate well with subjective analyses, suggesting creative writing can be evaluated reliably and objectively.[289] In this task, all subjects were instructed to write a creative story including the word "tree." Subjects were instructed to use their imagination and to be creative. Subjects wrote responses by hand, and were told writing was necessary but drawing was additionally allowed. Subjects were told no time limit was given, but every 5 minutes that passed was announced so subjects could have a sense of time, and total writing time was recorded.

The Verb Generation Task (VGT), a classic cognitive neuroscience measure of language production and semantic processing abilities, has been used to quantify the contribution of semantic divergence to creativity.[288] Performance on the task can be automatically computationally assessed, and these objective assessments have been shown to correlate well with subjective assessments by raters.[290] For this task, a list of 31 nouns was presented and the subject was instructed to respond in writing with the first verb that came to mind for each noun. Subjects were instructed explicitly to generate creative verb associations, adapting methods from Heinen (2018).[286] Nouns given were all semantically related to "tree" (leaf, sunshine, bird, plant, shadow, tree, frog, swing, forest, wind, mountain, rope, tea, pot, roots, squirrel, book, seed, apple, grass, branch, water, shovel, stick, nest, flower, river, hole, dirt, syrup, chair). Semantic distance values measuring distance between noun-verb pairs in the VGT serve as an objective measure, independent of potentially shared biases of raters, and index the unusualness of the verb in the context of the given noun.

2.4 Creativity Evaluation

Prior to any evaluation of creativity task responses, we first applied data pre-processing. Firstly, we used a spell-check function to correct instances of misspelling. Secondly, a few acronyms (such as "ASMR") were expanded into their component words ("autonomous sensory meridian response"). Thirdly, any numbers written as digits (such as "2") were changed into the corresponding word (such as "two").

2.4.1 Alternative Uses Task

AUT Subjective Ratings

Subjective ratings of AUT responses were performed by three trained and condition-blind raters. Raters provided both (1) a "Snapshot" rating in which all of a subject's alternate uses were rated as a group and (2) an "Individual Use" rating in which each alternative use was rated on its individual creativity. Creativity was defined for AUT raters as a combination of Originality, Flexibility, and Fluency, with definitions for each of these constructs taken directly from the Torrance Tests of Creative Thinking.[291] In the Snapshot rating, raters evaluated the subject's list of alternative uses on the basis of overall Originality, Flexibility, and Fluency by assigning a value of 1 (low creativity) to 5 (high creativity). In the Individual rating, responses were scrambled across subjects and raters focused on Originality in assigning a value of 1 to 5 to each individual alternative use. After ratings were assigned, the Consensual Assessment Technique[292] was used to address any discrepancy of >= 3 between any of the three raters to find a consensus discrepancy of < 3.

AUT Computational Ratings

We computationally evaluated both semantic distance and fluency of AUT responses. Semantic distance was evaluated by taking the cosine distance between the GloVe embeddings of the prompt word "tree" and each use case reported by a subject (see Methods Section 2.5 for details on GloVe embeddings). For use cases given as a multiple-word response (such as "clothes hanger"), the semantic distance was calculated by taking the mean of the semantic distances between each component word in the response and the word "tree." We produced a single score for each subject by taking the mean of the semantic distance values for the set of alternative uses the subject produced. AUT fluency was quantified as the number of uses generated by each subject.[49]

2.4.2 Creative Storytelling Task

CST Subjective Ratings

Raters were provided stories in two formats: typed text and scans of the page containing subjects' original handwritten words and accompanying imagery. Three condition-blind raters assessed subjects' stories on the following eight dimensions, adapted from Prabhakaran (2014): Overall Creativity, Narrative Cohesion/Plot Continuity, Fantasy, Imagery, Descriptiveness, Semantic Flexibility, Emotiveness and Humor. Definitions for each dimension, taken directly from Prabhakaran (2014) and listed below, were given to raters.

1. **Overall Creativity:** the extent to which the subject told a unique story that "came alive"; story does not need to be cohesive or have a plot
2. **Narrative Cohesion/Plot Continuity:** the extent to which the story has a continuous plot
3. **Fantasy:** the extent to which the story transports you to a world which is not our own, using things like imagination, visualization, etc.
4. **Descriptiveness:** the extent to which the subject added additional details
5. **Semantic Flexibility:** uniqueness of incorporation of the topic "tree" into the story
6. **Emotiveness:** the extent to which the subject used words that convey emotion and shifts of emotion
7. **Humor:** the extent to which the subject incorporated clever, witty, and/or amusing elements into the story
8. **Imagery:** the extent to which the image contributes to the creativity of the story

Raters were instructed to rate each of these dimensions on a 7-point Likert scale (1–7), with 1 reflecting a low rating and 7 reflecting a high rating. After each rater finished, ratings were assessed for discrepancies of $\geq$ 3 points. In line with the Consensual Assessment Technique,[292,293] raters then discussed differences until a $\leq$ 2 consensus was reached. Then, a mean across the three raters was taken for each subject for each rating dimension. Imagery ratings were only assigned to subjects who chose to draw in their story response, and these were assessed for creativity. Further analyses were done comparing imagery frequency across groups (Table S2).

CST Computational Ratings

To complement subjective story ratings with a computationally objective rating of creativity, we used a separate computational linguistic analysis tool called Coh-Metrix. This tool indexes aspects of text cohesion and readability and was specifically developed to analyze the creativity of short stories. Coh-Metrix has been shown to predict human ratings of creativity to a significant degree.[289] We analyzed stories using two Coh-Metrix linguistic features studied in Zedelius et al. (2019), narrativity and referential cohesion.

1. **Narrativity** reflects how well the text aligns with the narrative genre by conveying a story, as texts higher in narrativity are more conversational and more "story-like" (this is distinct from the CST subjective rating dimension called Narrative Cohesion).

2. **Referential cohesion** reflects how well content words and ideas are connected to each other across the entire text. Texts higher in referential cohesion have greater overlap between sentences throughout the story with regard to explicit content words and noun phrases.

In Zedelius et al. (2019), lower levels of referential cohesion were the most consistent predictor of higher subjective scores of creativity. Because of this inverse relationship, we apply reverse scoring to Coh-Metrix output for narrativity and referential cohesion percentiles.

2.4.3 Verb Generation Task

VGT Subjective Ratings

Subjective ratings of VGT responses were performed by 39 Masters workers recruited on the Amazon Mechanical Turk platform. We first extracted the set of unique pairings of noun prompts and verb responses across all 49 subjects VGT responses, resulting in a total of 1219 noun-verb pairings. We then obtained 5 human ratings for each noun-verb pairing (resulting in a total of 6,095 data points), with an average of 156.3 ratings provided per rater. Raters were presented with one noun-verb pair and asked to assign a score of 1 (“Not creative at all”), 2 (“A little creative”), 3 (“Somewhat creative”), 4 (“Creative”), or 5 (“Very Creative”) to the verb with respect to the noun. We then took a mean across the 5 ratings per noun-verb pairing to assign a score to each pairing. Finally, we obtained a “VGT Subjective Score” for each subject by calculating the mean score across their 31 noun-verb responses.

VGT Computational Ratings

We computationally evaluated VGT responses by measuring semantic distance and elaboration. Semantic distance in creative cued VGT has a demonstrated strong relationship to a creativity factor derived from verbal, nonverbal, and achievement-based creativity measures.[286] Semantic distance was computed by calculating the cosine distance between the GloVe embeddings of the noun prompt and verb response. For verb responses given as multiple words (for example, “launching into space” as a response to the noun prompt “swing”), the semantic distance was calculated by taking the mean of the semantic distances between each component word in the response and the noun prompt. Before calculating the semantic distance, verb responses were processed in three steps for consistency: (1) verbs were edited to take the “-ing” form of the verb (for example, “run” was changed to “running”), (2) stop words (e.g. a, at, is, the, which, and on) were removed, and (3) for instances where the prompt noun was repeated in the verb response, the repeated noun was removed from the response as they would introduce a confounding semantic distance value of 0 when taking a mean of component words. For example, using these processing steps, the verb response of “eating a leaf” in response to the noun prompt “leaf” was changed to just “eating”). We produced a single score for each subject by taking the mean of the semantic distance values for the set of noun prompt and verb response pairs the subject produced, adapting methods from Prabhakaran et al (2014). VGT elaboration was quantified as the word count for a given verb response. Out of 1519 VGT responses, there were 132 multi-word responses (length of verb response > 1 word). Out of 49 subjects, 20 elaborated at least one multi-word response.

2.5 Global Vectors for Word Representation (GloVe)

Global Vectors for Word Representation (GloVe) is an unsupervised learning algorithm for obtaining vector representations of words.[294] GloVe is trained based on a co-occurrence matrix and outputs word vectors that capture meaning in vector space. Using GloVe, we can predict co-occurrence ratios of words and thus quantify the semantic similarity or distance between two words. GloVe outperforms other similar methods for quantifying semantic similarity, including the commonly used word2vec, on several word similarity tasks.[294] We used a 300-dimensional word vector space from a GloVe model trained on 42 billion tokens and their aggregated global word-word co-occurrence statistics. We calculated the cosine distance between word vectors to calculate semantic distance.

2.6 Assessing Incubation

For the purposes of assessing incubation, a direct reference to “tree” is defined as an unambiguous mention of “tree” or part of a tree (including tree, forest, branch, or root) while indirect references are sensations, objects, locations, or themes related to “tree” (such as plant or paper), adapting methods from Wamsley (2010).[280] These results focus on sleep phenomenology data from our subjects. For a detailed report on sleep physiology from these subjects see Horowitz (2019).[225]

2.7 Statistical Analyses

We follow the primary and secondary endpoint framework for our statistical analysis**.** [295] Our primary endpoint is the “Creativity Index,” a composite measure we construct by taking a weighted mean z-score across 15 of the 17 measured creativity dimensions.[296,297] The two dimensions we excluded from the Creativity Index were those without data points for all subjects, namely the CST Imagery rating (since only subjects who included imagery in their story response received imagery ratings) and the AUT Individual Use rating (since these ratings applied to individual uses, delinked from individual subjects). To construct the Creativity Index, each creativity dimension was z-scored and weighted such that each of the three creativity assessments (AUT, CST, VGT) was equally represented as one-third of the composite measure.[296,297] More specifically, each of the three included AUT dimensions received a weight of 1/9, each of the nine included CST dimensions received a weight of 1/27, and each of the three VGT dimensions received a weight of 1/9 (the weights for each assessment sum to 1/3; the weights across all the dimensions sum to 1).

Our secondary endpoints, provided to supplement the interpretation of the primary endpoint, include all 17 individual measured dimensions of creative performance and one composite measure. For our secondary endpoint analysis, we interpret each result individually, providing uncorrected p-values**.**[298] In addition to all 17 individual creativity dimensions, we include a secondary endpoint called the “Semantic Flexibility Index,” a composite measure constructed by taking a mean z-score across the three creativity dimensions concerning semantic flexibility– (1) the computationally evaluated AUT Semantic Distance measure, (2) the human-rated CST Semantic Flexibility measure, and (3) the computationally evaluated VGT Semantic Distance measure — for each subject. We generate the Semantic Flexibility Index to investigate subjects’ ability to form distant semantic associations across the three tasks and across both human-rated and computationally generated measures of semantic association.

Statistical analysis of main effects and interactions were conducted using the nonparametric Aligned Rank Transform ANOVA test (ART ANOVA).[299] Post-hoc pairwise comparison analyses were conducted using nonparametric Aligned Rank Transform multifactor contrast tests (ART-C).[300] We include post-hoc comparison results regardless of omnibus (ART ANOVA) based on past work by Hsu (1996): “An unfortunate common practice is to pursue multiple comparisons only when the null hypothesis of homogeneity is rejected.”[301]

Additional statistical analyses included bivariate ordinary least squares regression (with heteroskedasticity robust estimators) to test within each state the predictive relationship between the degree of stimulus incubation achieved during the experimental period and creative performance. We represent the degree of stimulus incubation as the number of verbal reports containing a direct reference to “tree,” which we call “Tree” Dream Reports in the sleep state and “Tree” Wake Reports in the wake state. We use the fitted regression model $Y = \alpha + \beta_1 \times$ “Tree” Reports. Note that subject 28 (from the Sleep No-Incubation group) was excluded from regression analyses as they issued inaudible verbal reports during the experiment, only describing their dream after a final awakening.

3. Results

We present results for 49 subjects split across two states, Sleep (S) and Wake (W), and two conditions, Tree-Incubation (I) and No-Incubation (N), to form four groups (SI, SN, WI, WN).

3.1 Dream Incubation

We performed serial awakenings on 25 sleep subjects from whom we collected 136 dream reports (67 from the Sleep Tree-Incubation group and 69 from the Sleep No-Incubation group). All 25 sleep subjects recalled at least 1 hypnagogic dream. One subject (subject 28) reported difficulty speaking while in hypnagogia, but uttered short inaudible phrases and elaborated on each at the end of the 45-minute experimental period. We also gathered 104 reports from awake subjects (56 from the Wake Tree-Incubation group and 48 from the Wake No-Incubation group). All 24 awake subjects produced at least 1 report. Characteristics of these reports are presented in Table 1. For a detailed description of dream phenomenology and example reports from each condition refer to Supplementary Materials (Tables S3 and S4).

We investigate group differences in the percent of direct “tree” references produced by each subject using the Aligned Rank Transform ANOVA and post-hoc Aligned Rank Transform multifactor contrast tests. We find that the percent of direct “tree” references varied significantly by state ($S = 37.2 \pm 42.2$, $W = 26.2 \pm 36.0$, $p = 0.004$), although the effect of state is not significant within each condition (SI vs. WI, $p = 0.28$; SN vs. WN, $p = 0.73$). We also find a main effect of condition, in which direct references were significantly greater in the Tree-Incubation condition than in the No-Incubation condition ($I=61.7 \pm 35.4$, $N=0.68 \pm 3.3$, $p < 10e\text{-}9$). The effect of condition is also significant within each state (SI vs. SN, $p < 10e\text{-}7$, WI vs WN, $p < 10e\text{-}6$).

Group	Abbreviation	Subjects	Num. Verbal Reports	Num. Verbal Reports w/ “Tree” Reference	% of Verbal Reports w/ “Tree” Reference	Num. References	Num. Direct References	Num Indirect References
Sleep Tree-Incubation	SI	13	67	45	67.2%	91	77	14
Sleep No-Incubation	SN	12	69	1	1.4%	2	1	1
Wake Tree-Incubation	WI	12	56	29	51.8%	70	51	19
Wake No-Incubation	WN	12	48	0	0%	0	0	0

Table 1. Incorporation of “tree” into verbal reports. Modified from Table 1 of Horowitz et al. 2020.

3.2 Creativity Task Performance

3.2.1 Primary Endpoint

The Creativity Index, constructed using a weighted mean z-score across 15 creativity dimensions, facilitates a multifaceted assessment of creative performance (Figure 2, Table 2). The Creativity Index showed a significant main effect of state (S > W; $p < 0.0001$). There was also a significant effect of state within the Tree-Incubation condition (SI > WI, $p < 0.0001$) and within the No-Incubation condition (SN > WN, $p = 0.01$). The Creativity Index also showed a significant main effect of condition (I > N, $p = 0.024$). Within the sleep state, there was a significant effect of condition (SI > SN, $p = 0.023$). There was not a significant effect of condition in the wake state (WI vs. WN, $p = 0.45$).

3.2.2 Secondary Endpoints

The secondary endpoints, consisting of one composite measure and 17 individual creative performance dimensions, provide insight and interpretation to the results from the Creativity Index (Figure 2, Figure 3, Table 2).

Semantic Flexibility Index

The Semantic Flexibility Index, constructed using a mean z-score across semantic distance and semantic flexibility scales, facilitates the evaluation of subjects' ability to form distant semantic associations.

The Semantic Flexibility Index showed a significant main effect of state (S > W, $p < 0.001$) and condition (I > N, $p = 0.029$). Within the sleep state, there was a significant effect of condition (SI > SN, $p = 0.006$), but there was no significant effect of condition within wake (WI vs. WN, $p = 0.074$). Within the Tree-Incubation condition, there was a significant effect of state (SI > WI, $p < 0.001$), but no significant effect of state within the No-Incubation condition (SN vs. WN, $p = 0.13$).

Individual Creativity Dimensions

We measured 17 dimensions of creativity across three tasks (four in AUT, ten in CST, and three in VGT) (see Methods Section 2.4) and used Aligned Rank Transform ANOVA and contrast tests to understand differences in these creative performance dimensions across groups (Figure 3, Table 2).

On the Alternative Use Task (AUT), there was a significant main effect of state (S > W) across three of four measured dimensions: snapshot ratings ($p < 0.001$), individual use ratings ($p < 0.001$), and semantic distance ($p = 0.007$). Within the sleep state, there were significant effects of condition (SI > SN) for two dimensions: snapshot ($p = 0.02$) and individual use ratings ($p = 0.04$). Within the wake state, none of the dimensions showed a significant effect of condition (WI vs. WN, all $p \geq 0.19$). Within the Tree-Incubation condition, there were significant effects of state (SI > WI) for three dimensions: snapshot ratings ($p < 0.001$), individual use ratings ($p < 0.001$), and semantic distance ($p = 0.02$). Within the No-Incubation condition, there was a significant effect of state (SN > WN) for fluency ($p = 0.04$).

On the Creative Storytelling Task (CST), there were again significant main effects of state (S > W) for seven dimensions: overall creativity ($p = 0.007$), fantasy ($p = 0.006$), descriptiveness ($p = 0.014$), semantic flexibility ($p = 0.045$), imagery ($p = 0.008$), Coh-Metrix narrativity ($p = 0.003$) and referential cohesion ($p = 0.010$). There was also a significant main effect of condition (I > N) on imagery ($p = 0.007$). There was a significant interaction between state and condition for semantic flexibility ($p = 0.02$). Within the sleep state, there was a significant effect of condition (SI > SN) for semantic flexibility ($p = 0.01$). Within the wake state, there was a significant effect of condition (WI > WN) for imagery ($p = 0.02$). Within the Tree-Incubation condition, there were significant effects of state (SI > WI) for four dimensions: overall creativity ($p = 0.002$), fantasy ($p = 0.01$), semantic flexibility (p = 0.004), and Coh-Metrix narrativity (p = 0.006). Within the No-Incubation condition, there were significant effects of state (SN > WN) for three dimensions: descriptiveness, imagery, and Coh-Metrix referential cohesion.

On the Verb Generation Task (VGT), there was a significant main effect of state (S > W) for two dimensions: the subjective score (p = 0.029) and semantic distance (p = 0.045). There was a significant main effect of condition (I > N) for two dimensions: the subjective score (p = 0.008) and elaboration (p = 0.047). Within the sleep state, there was a significant effect of condition (SI > SN) for two dimensions: the subjective score (p = 0.006) and elaboration (p = 0.029). There were no significant effects of condition (I > N) in the wake state (all p ≥ 0.3). Within the Tree-Incubation condition, there was a significant effect of state (SI > WI) for the subjective score (p = 0.014). Within the No-Incubation condition, none of the three dimensions showed an effect of state (SN vs. WN).

Overall, we observe a significant main effect of state (S > W) across 12 of the 17 individually measured creativity dimensions, with several dimensions showing a significant effect of state within either of the two conditions (SI > WI for eight dimensions and SN > WN for four dimensions). We observe a significant main effect of incubation (I > N) across three of the 17 dimensions. Within the sleep state, there were five dimensions showing a significant effect of condition (SI > SN). Within the wake state, there was one creativity dimension showing a significant effect of condition (WI > WN). This pattern of results across these individual creativity dimensions mirrors the results seen in the Creativity Index: (1) a strong main effect of state maintained across conditions, and (2) a more moderate effect of condition seen more strongly in the sleep state than in the wake state.

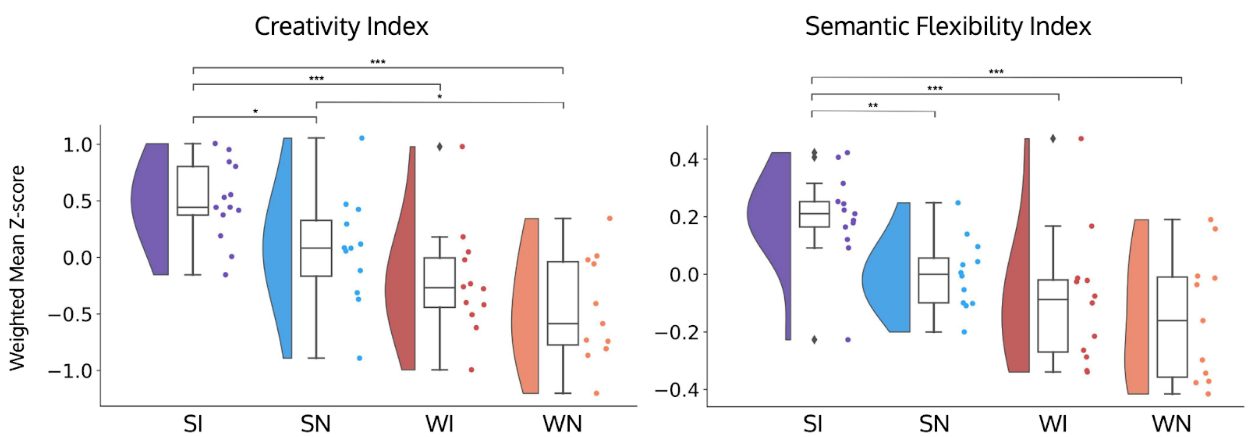

Figure 2. Composite measures of creative performance. Raincloud plots[302] (half violin plot, box plot, and raw data points) for the Creativity Index and Semantic Flexibility Index across all groups, with two-sided Aligned Rank Transform multifactor contrast test uncorrected significance bars (* = p < 0.05, ** = p < 0.01, *** = p < 0.001). Diamond markers above and below box plot indicate outliers as defined in Matplotlib.

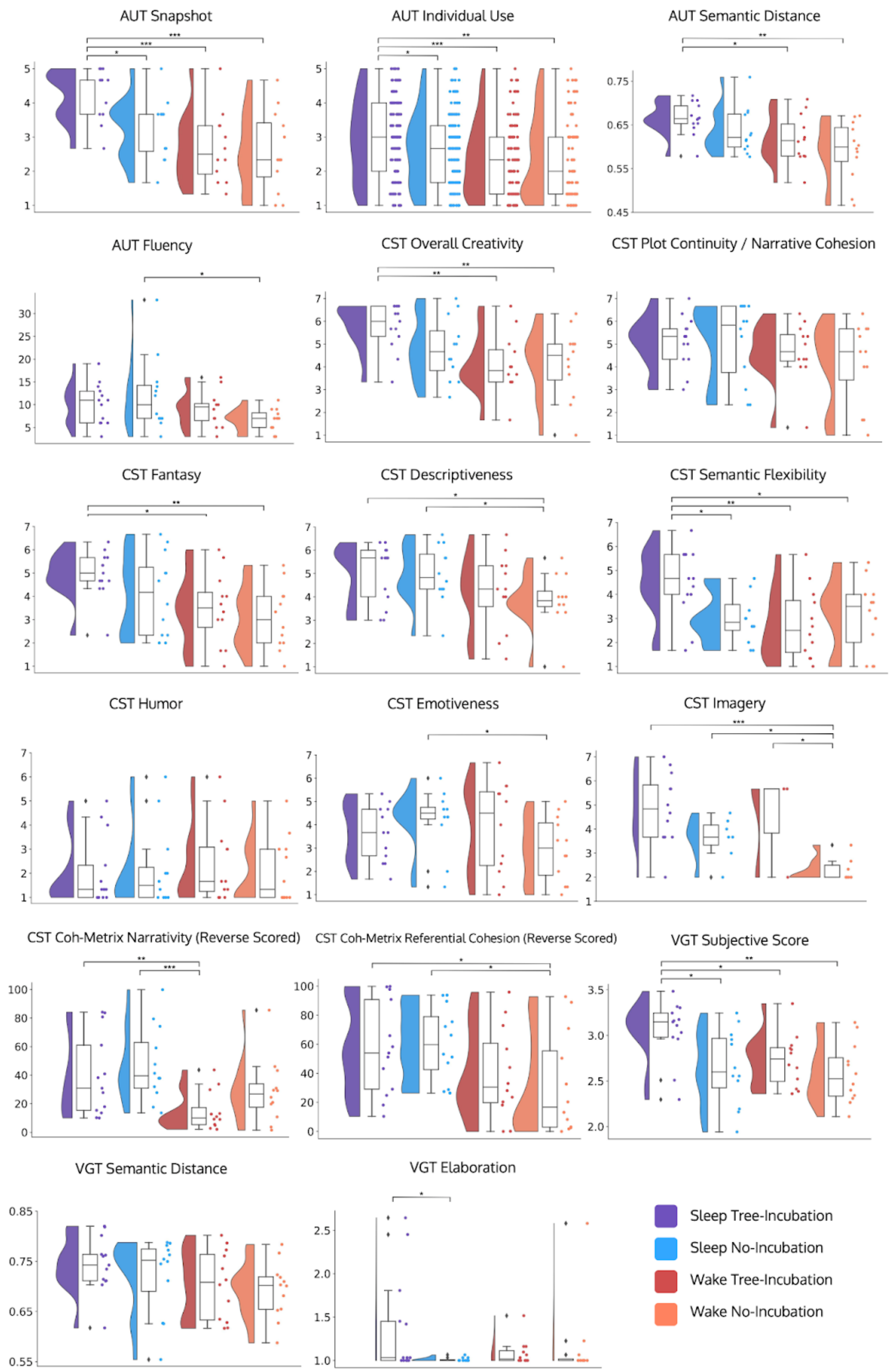

Figure 3. Individual dimensions of creative task performance. Raincloud plots[302] (half violin plot, box plot, and raw data points) for all creativity task dimensions with two-sided Aligned Rank

Transform multifactor contrast test uncorrected significance bars (* = p < 0.05, ** = p < 0.01, *** = p < 0.001). Diamond markers above and below box plot indicate outliers as defined in Matplotlib.

	Omnibus (Main Effects and Interaction) *Aligned Rank Transform ANOVA*			**Post-Hoc Pairwise Comparisons** *Aligned Rank Transform contrast tests (two-sided)*			
				condition effect per state		*state effect per condition*	
	State	**Condition**	**Interaction**	**SI vs. SN**	**WI vs. WN**	**SI vs WI**	**SN vs WN**
PRIMARY OUTCOME							
Creativity Index Weighted Mean Z-Score Composite	S = 0.29 ± 0.45 W = -0.3 ± 0.48 F = 21.49 p < 0.0001	I = 0.16 ± 0.54 N = -0.16 ± 0.53 F = 5.43 p = 0.024*	F = 1.19 p = 0.28	SI = 0.49 ± 0.34 SN = 0.07 ± 0.47 p = 0.023*	WI = -0.21 ± 0.47 WN = -0.4 ± 0.47 p = 0.45	SI = 0.49 ± 0.34 WI = -0.21 ± 0.47 p < 0.0001*	SN = 0.07 ± 0.47 WN = -0.4 ± 0.47 p = 0.01*
SECONDARY OUTCOMES							
Semantic Flexibility Index Mean Z-Score Composite (AUT Semantic Distance, CST Semantic Flexibility, VGT Semantic Distance)	S = 0.31 ± 0.51 W = -0.32 ± 0.66 F = 12.83 p < 0.001*	I = 0.19 ± 0.72 N = -0.19 ± 0.56 F = 4.79 p = 0.029*	F = 3.15 p = 0.08†	SI = 0.6 ± 0.47 SN = 0.0 ± 0.36 p = 0.006*	WI = -0.26 ± 0.67 WN = -0.39 ± 0.65 p = 0.74	SI = 0.6 ± 0.47 WI = -0.26 ± 0.67 p < 0.001*	SN = 0.0 ± 0.36 WN = -0.39 ± 0.65 p = 0.13
AUT Snapshot	S = 3.75 ± 0.93 W = 2.64 ± 1.07 F = 13.64 p < 0.001*	I = 3.48 ± 1.15 N = 2.92 ± 1.07 F = 3.25 p = 0.078†	F = 2.22 p = 0.14	SI = 4.21 ± 0.72 SN = 3.25 ± 0.88 p = 0.02*	WI = 2.69 ± 0.99 WN = 2.58 ± 1.13 p = 0.92	SI = 4.21 ± 0.72 WI = 2.69 ± 0.99 p < 0.001*	SN = 3.25 ± 0.88 WN = 2.58 ± 1.13 p = 0.095†
AUT Individual Use	S = 2.74 ± 1.13 W = 2.37 ± 1.11 F = 14.33 p < 0.001*	I = 2.66 ± 1.15 N = 2.53 ± 1.11 F = 1.91 p = 0.167	F = 2.15 p = 0.14	SI = 2.9 ± 1.16 SN = 2.6 ± 1.07 p = 0.04*	WI = 2.35 ± 1.05 WN = 2.4 ± 1.17 p = 0.90	SI = 2.9 ± 1.16 WI = 2.35 ± 1.05 p < 0.001*	SN = 2.6 ± 1.07 WN = 2.4 ± 1.17 p = 0.12
AUT Semantic Distance (GloVe)	S = 0.65 ± 0.05 W = 0.6 ± 0.06 F = 7.89 p = 0.007*	I = 0.64 ± 0.05 N = 0.61 ± 0.06 F = 3.10 p = 0.085†	F = 0.48 p = 0.49	SI = 0.66 ± 0.04 SN = 0.64 ± 0.05 p = 0.11	WI = 0.62 ± 0.05 WN = 0.59 ± 0.07 p = 0.41	SI = 0.66 ± 0.04 WI = 0.62 ± 0.05 p = 0.02*	SN = 0.64 ± 0.05 WN = 0.59 ± 0.07 p = 0.13
AUT Fluency	S = 11.16 ± 6.35 W = 7.88 ± 3.31 F = 3.31 p = 0.075†	I = 9.64 ± 4.1 N = 9.46 ± 6.4 F = 0.26 p = 0.613	F = 1.30 p = 0.26	SI = 10.23 ± 4.32 SN = 12.17 ± 7.87 p = 0.79	WI = 9.0 ± 3.74 WN = 6.75 ± 2.31 p = 0.19	SI = 10.23 ± 4.32 WI = 9.0 ± 3.74 p = 0.56	SN = 12.17 ± 7.87 WN = 6.75 ± 2.31 p = 0.04*
CST Overall Creativity	S = 5.28 ± 1.26 W = 4.14 ± 1.38 F = 7.90 p = 0.007*	I = 4.96 ± 1.4 N = 4.47 ± 1.44 F = 1.14 p = 0.291	F = 2.21 p = 0.14	SI = 5.74 ± 0.99 SN = 4.78 ± 1.32 p = 0.06†	WI = 4.11 ± 1.27 WN = 4.17 ± 1.48 p = 0.72	SI = 5.74 ± 0.99 WI = 4.11 ± 1.27 p = 0.002*	SN = 4.78 ± 1.32 WN = 4.17 ± 1.48 p = 0.36
CST Plot Continuity/ Narrative Cohesion	S = 5.11 ± 1.39 W = 4.43 ± 1.53 F = 3.09 p = 0.086†	I = 4.89 ± 1.19 N = 4.65 ± 1.75 F = 0.03 p = 0.870	F = 0.50 p = 0.48	SI = 5.1 ± 1.09 SN = 5.11 ± 1.65 p = 0.63	WI = 4.67 ± 1.25 WN = 4.19 ± 1.73 p = 0.71	SI = 5.1 ± 1.09 WI = 4.67 ± 1.25 p = 0.45	SN = 5.11 ± 1.65 WN = 4.19 ± 1.73 p = 0.17
CST Fantasy	S = 4.53 ± 1.42 W = 3.28 ± 1.41 F = 8.46 p = 0.006*	I = 4.24 ± 1.44 N = 3.58 ± 1.58 F = 1.85 p = 0.180	F = 0.33 p = 0.57	SI = 4.95 ± 0.97 SN = 4.08 ± 1.67 p = 0.13	WI = 3.47 ± 1.48 WN = 3.08 ± 1.3 p = 0.54	SI = 4.95 ± 0.97 WI = 3.47 ± 1.48 p = 0.01*	SN = 4.08 ± 1.67 WN = 3.08 ± 1.3 p = 0.093†
CST Descriptiveness	S = 4.99 ± 1.21 W = 4.04 ± 1.37 F = 6.58 p = 0.014*	I = 4.63 ± 1.45 N = 4.42 ± 1.27 F = 0.61 p = 0.437	F = 0.37 p = 0.54	SI = 5.0 ± 1.23 SN = 4.97 ± 1.18 p = 0.93	WI = 4.22 ± 1.56 WN = 3.86 ± 1.11 p = 0.27	SI = 5.0 ± 1.23 WI = 4.22 ± 1.56 p = 0.22	SN = 4.97 ± 1.18 WN = 3.86 ± 1.11 p = 0.02*
CST Semantic Flexibility	S = 3.79 ± 1.43 W = 2.94 ± 1.43 F = 4.26 p = 0.045*	I = 3.67 ± 1.64 N = 3.07 ± 1.24 F = 1.85 p = 0.180	F = 5.57 p = 0.02*	SI = 4.49 ± 1.41 SN = 3.03 ± 1.01 p = 0.01*	WI = 2.78 ± 1.4 WN = 3.11 ± 1.44 p = 0.54	SI = 4.49 ± 1.41 WI = 2.78 ± 1.4 p = 0.004*	SN = 3.03 ± 1.01 WN = 3.11 ± 1.44 p = 0.88
CST Humor	S = 2.11 ± 1.49 W = 2.26 ± 1.47 F = 0.21 p = 0.646	I = 2.24 ± 1.5 N = 2.12 ± 1.47 F = 0.34 p = 0.561	F = 0.47 p = 0.498	SI = 2.05 ± 1.37 SN = 2.17 ± 1.61 p = 0.98	WI = 2.44 ± 1.59 WN = 2.08 ± 1.3 p = 0.42	SI = 2.05 ± 1.37 WI = 2.44 ± 1.59 p = 0.53	SN = 2.17 ± 1.61 WN = 2.08 ± 1.3 p = 0.86
CST Emotiveness	S = 3.97 ± 1.25 W = 3.44 ± 1.68 F = 1.15 p = 0.289	I = 3.83 ± 1.56 N = 3.6 ± 1.43 F = 0.42 p = 0.522	F = 2.82 p = 0.10	SI = 3.74 ± 1.2 SN = 4.22 ± 1.26 p = 0.46	WI = 3.92 ± 1.87 WN = 2.97 ± 1.31 p = 0.09†	SI = 3.74 ± 1.2 WI = 3.92 ± 1.87 p = 0.65	SN = 4.22 ± 1.26 WN = 2.97 ± 1.31 p = 0.05†
CST Imagery	S = 4.4 ± 1.37 W = 2.97 ± 1.41 F = 8.17 p = 0.008*	I = 4.78 ± 1.49 N = 2.98 ± 0.93 F = 8.77 p = 0.007*	F = 0.92 p = 0.35	SI = 4.86 ± 1.42 SN = 3.62 ± 0.82 p = 0.07†	WI = 4.44 ± 1.73 WN = 2.33 ± 0.47 p = 0.02*	SI = 4.86 ± 1.42 WI = 4.44 ± 1.73 p = 0.59	SN = 3.62 ± 0.82 WN = 2.33 ± 0.47 p = 0.04*
CST Coh-Metrix Narrativity Percentile (Reverse Scoring)	S = 43.3 ± 26.58 W = 21.78 ± 19.11 F = 10.23 p = 0.003*	I = 27.67 ± 24.98 N = 38.06 ± 25.14 F = 3.16 p = 0.082†	F = 0.16 p = 0.69	SI = 39.57 ± 27.42 SN = 47.34 ± 25.02 p = 0.31	WI = 14.77 ± 12.9 WN = 28.78 ± 21.59 p = 0.07†	SI = 39.57 ± 27.42 WI = 14.77 ± 12.9 p = 0.006*	SN = 47.34 ± 25.02 WN = 28.78 ± 21.59 p = 0.05†
CST Coh-Metrix Referential Cohesion Percentile (Reverse Scoring)	S = 58.74 ± 27.83 W = 35.82 ± 32.02 F = 7.23 p = 0.010*	I = 48.73 ± 31.61 N = 46.25 ± 32.5 F = 0.08 p = 0.775	F = 0.53 p = 0.472	SI = 57.17 ± 30.72 SN = 60.45 ± 24.21 p = 0.81	WI = 39.58 ± 29.99 WN = 32.06 ± 33.52 p = 0.47	SI = 57.17 ± 30.72 WI = 39.58 ± 29.99 p = 0.14	SN = 60.45 ± 24.21 WN = 32.06 ± 33.52 p = 0.02*
VGT Subjective Score	S = 2.86 ± 0.41 W = 2.65 ± 0.3 F = 5.12 p = 0.029*	I = 2.9 ± 0.34 N = 2.62 ± 0.36 F = 7.62 p = 0.008*	F = 1.90 p = 0.17	SI = 3.06 ± 0.31 SN = 2.65 ± 0.4 p = 0.006*	WI = 2.73 ± 0.28 WN = 2.58 ± 0.31 p = 0.32	SI = 3.06 ± 0.31 WI = 2.73 ± 0.28 p = 0.014*	SN = 2.65 ± 0.4 WN = 2.58 ± 0.31 p = 0.49

VGT Semantic Distance (GloVe)	S = 0.73 ± 0.06 W = 0.7 ± 0.06 F = 4.26 p = 0.045*	I = 0.72 ± 0.06 N = 0.71 ± 0.07 F = 0.42 p = 0.522	F = 0.06 p = 0.80	SI = 0.74 ± 0.05 SN = 0.72 ± 0.07 p = 0.69	WI = 0.7 ± 0.07 WN = 0.69 ± 0.05 p = 0.51	SI = 0.74 ± 0.05 WI = 0.7 ± 0.07 p = 0.21	SN = 0.72 ± 0.07 WN = 0.69 ± 0.05 p = 0.13
VGT Elaboration	S = 1.2 ± 0.44 W = 1.12 ± 0.33 F = 1.36 p = 0.250	I = 1.24 ± 0.44 N = 1.08 ± 0.32 F = 4.18 p = 0.047*	F = 3.24 p = 0.079†	SI = 1.37 ± 0.56 SN = 1.01 ± 0.02 p = 0.029*	WI = 1.09 ± 0.14 WN = 1.16 ± 0.43 p = 0.30	SI = 1.37 ± 0.56 WI = 1.09 ± 0.14 p = 0.44	SN = 1.01 ± 0.02 WN = 1.16 ± 0.43 p = 0.68

Table 2. Creative task performance comparisons. Aligned Rank Transform ANOVA omnibus test comparing state and condition main effects and interaction. Post-hoc Aligned Rank Transform multifactor contrast tests (two-sided, uncorrected) to compare selected groups. A star (*) indicates p < 0.05 and a dagger (†) indicates p < 0.1, corresponding to green and blue shading, respectively. For all dimensions except the AUT Individual Use creativity rating and the CST Imagery rating, the sample sizes were as follows: SI = 13, SN =12, WI = 12, WN = 12. For the AUT Individual Use creativity rating, which compared individual alternative uses aggregated by assigned group (see Methods Section 2.4.1), sample sizes were as follows: SI = 133, SN = 146, WI = 108, WN = 81. For the CST Imagery dimension, ratings were only assigned to subjects who included drawings, resulting in the following sample sizes: SI = 12, SN = 7, WI = 3, WN = 7.

3.3 Regression of Creative Performance on Incubation

For each state, we regressed creativity performance on the degree of incubation of "tree" to assess the predictive relationship between incubation and creativity (Table 3). In the sleep state, we find that "Tree" Reports are a significant predictor of the Creativity Index (R2 = 0.135, F = 4.73, β = 0.081, p = 0.030). We also find five individual creativity dimensions for which "Tree" Reports are a significant predictor of creative performance: AUT snapshot rating (R2 = 0.18, F = 4.98, β = 0.185, p = 0.03), CST overall creativity (R2 = 0.29, F = 11.72, β = 0.323, p = 0.001), CST fantasy (R2 = 0.196, F = 6.92, β = 0.295, p = 0.009), CST semantic flexibility (R2 = 0.303, F = 8.71, β = 0.381, p = 0.003), and CST imagery (R2 = 0.181, F = 5.033, β = 0.283, p = 0.025). In the wake state, we do not find the Creativity Index or any individual creativity dimensions for which "Tree" reports are significant predictors of performance. Additionally, since none of the regressions for the wake state have a significant F-statistic, we fail to reject the null hypothesis that all of the regression coefficients are equal to 0.

	Regressands															
	(1) Creativity Index	**(2) Semantic Flexibility Index**	**(3) AUT Snapshot**	**(4) AUT Semantic Distance**	**(5) AUT Fluency**	**(6) CST Overall Creativity**	**(7) CST Plot Continuity /Narrative Cohesion**	**(8) CST Fantasy**	**(9) CST Descriptiveness**	**(10) CST Semantic Flexibility**	**(11) CST Humor**	**(12) CST Emotiveness**	**(13) CST Imagery**	**(14) VGT Subjective Score**	**(15) VGT Semantic Distance**	**(16) VGT Elaboration**
SLEEP STATE																
"Tree" Dream Reports	0.081* (0.030)	0.092 (0.06)	0.185* (0.03)	0.002 (0.68)	-0.102 (0.84)	0.323* (0.001)	0.017 (0.9)	0.295* (0.009)	0.084 (0.46)	0.381* (0.003)	0.022 (0.87)	-0.04 (0.74)	0.283* (0.025)	0.049 (0.21)	-0.001 (0.93)	0.079 (0.08)
Intercept	0.146 (0.29)	0.159 (0.24)	3.437* (<0.001)	0.65* (<0.001)	11.32* (p<0.001)	4.618* (<0.001)	5.01* (<0.001)	3.892* (<0.001)	4.77* (<0.001)	3.09* (<0.001)	2.098* (<0.001)	3.965* (<0.001)	3.793* (<0.001)	2.781* (<0.001)	0.735* (<0.001)	1.056* (<0.001)
F-statistic	4.73* (0.030)	3.54 (0.073)	4.98* (0.036)	0.17 (0.69)	0.04 (0.84)	11.72* (0.002)	0.02 (0.9)	6.92* (0.015)	0.55 (0.47)	8.71* (0.007)	0.03 (0.88)	0.11 (0.74)	5.033* (0.038)	1.545 (0.227)	0.009 (0.927)	3.073 (0.094)
R^2	0.135	0.15	0.18	0.01	0.001	0.29	0.001	0.196	0.02	0.303	0.001	0.005	0.181	0.06	<0.001	0.138
n	24	24	24	24	24	24	24	24	24	24	24	24	19	24	24	24
WAKE STATE																
"Tree" Wake Reports	0.088 (0.215)	0.049 (0.65)	0.051 (0.75)	0.004 (0.6)	0.804 (0.09)	0.093 (0.64)	0.135 (0.42)	0.264 (0.15)	0.193 (0.33)	-0.011 (0.96)	0.025 (0.89)	0.139 (0.55)	0.541 (0.102)	0.006 (0.87)	0.006 (0.49)	0.006 (0.87)
Intercept	-0.411* (<0.001)	-0.384* (0.02)	2.577* (<0.001)	0.599* (<0.001)	6.904* (<0.001)	4.027* (<0.001)	4.267* (<0.001)	2.959* (<0.001)	3.808* (<0.001)	2.957* (<0.001)	2.234* (<0.001)	3.277* (<0.001)	2.534* (<0.001)	1.114* (<0.001)	0.691* (<0.001)	1.114* (<0.001)
F-statistic	1.54 (0.228)	0.21 (0.654)	0.1 (0.757)	0.28 (0.602)	2.88 (0.104)	0.23 (0.64)	0.65 (0.43)	2.08 (0.164)	0.94 (0.342)	0.002 (0.963)	0.021 (0.887)	0.35 (0.561)	2677 (0.14)	0.026 (0.87)	0.03 (0.874)	0.026 (0.874)
R^2	0.095	0.016	0.006	0.013	0.167	0.013	0.022	0.1	0.057	<0.001	0.001	0.019	0.288	0.001	0.024	0.001
n	24	24	24	24	24	24	24	24	24	24	24	24	10	24	24	24

Table 3. Regression of creative performance on degree of incubation. For each state, bivariate Ordinary Least Square (OLS) regressions (with heteroskedasticity robust estimators) of creativity task dimensions on the number of verbal reports with a direct reference to "Tree" ("Tree" Wake Reports for subjects in the wake state; "Tree" Dream Reports for subjects in the sleep state). A star (*) and green shading indicates p < 0.05 for regressor coefficients and F-statistics. Darker green shading is applied to rows containing coefficients for the "Tree" Reports regressor.

3.4 Creative Self Efficacy

Subjective questionnaires given both before the period of nap or wake and after completion of the three creativity tasks revealed a differential effect of state on self-assessment of creative and flexible thinking. Before the experiment, subjects were asked "Do you consider yourself a creative thinker?" and "Do you consider yourself a flexible thinker?" After subjects completed the creativity tasks, these questions were repeated.

Pairwise comparisons on pre-experiment responses indicate no significant differences between groups (Table 4). However, post-experiment, there was significantly higher self-assessment of creative thinking following sleep compared to wake, both overall (p = 0.006) and within each condition (SI > WI, p = 0.04; SN > WN, p = 0.046). There was also a significantly higher self-assessment of flexible thinking following sleep compared to wake, both overall (p < 0.001) and within the incubation condition (p < 0.001). Relatedly, there was a significantly greater change between the pre- and post-experiment self-assessment for both flexible thinking (p < 0.001) at the 5% level and for creative thinking (p = 0.058) at the 10% level following sleep as compared to wake.

Self-Efficacy Measure	Omnibus (Main Effects and Interaction) *Aligned Rank Transform ANOVA*			Post-Hoc Pairwise Comparisons *Aligned Rank Transform Contrast Tests (two-sided)*			
				condition effect per state		*state effect per condition*	
	State	**Condition**	**Interaction**	**SI vs. SN**	**WI vs. WN**	**SI vs. WI**	**SN vs WN**
PRE-EXPERIMENT							
Creative Thinking	S = 7.8 ± 1.26 W = 7.36 ± 1.69 F = 0.68 p = 0.414	I = 7.38 ± 1.73 N = 7.83 ± 1.17 F = 0.69 p = 0.411	F = 0.12 p = 0.727	SI = 7.54 ± 1.34 SN = 8.08 ± 1.11 p = 0.32	WI = 7.18 ± 2.08 WN = 7.55 ± 1.16 p = 0.81	SI = 7.54 ± 1.34 WI = 7.18 ± 2.08 p = 0.83	SN = 8.08 ± 1.11 WN = 7.55 ± 1.16 p = 0.36
Flexible Thinking	S = 7.6 ± 1.52 W = 7.59 ± 1.47 F = 0.08 p = 0.784	I = 7.67 ± 1.72 N = 7.52 ± 1.21 F = 1.12 p = 0.295	F = 0.63 p = 0.43	SI = 7.77 ± 1.93 SN = 7.42 ± 0.86 p = 0.44	WI = 7.55 ± 1.44 WN = 7.64 ± 1.49 p = 0.86	SI = 7.77 ± 1.93 WI = 7.55 ± 1.44 p = 0.61	SN = 7.42 ± 0.86 WN = 7.64 ± 1.49 p = 0.67
POST-EXPERIMENT							
Creative Thinking	S = 7.84 ± 1.74 W = 6.3 ± 1.94 F = 8.26 p = 0.006*	I = 6.88 ± 1.88 N = 7.33 ± 2.07 F = 0.84 p = 0.364	F = 0.001 p = 0.98	SI = 7.54 ± 1.87 SN = 8.17 ± 1.52 p = 0.46	WI = 6.09 ± 1.56 WN = 6.5 ± 2.22 p = 0.44	SI = 7.54 ± 1.87 WI = 6.09 ± 1.56 p = 0.04*	SN = 8.17 ± 1.52 WN = 6.5 ± 2.22 p = 0.046*
Flexible Thinking	S = 8.28 ± 1.78 W = 6.22 ± 2.19 F = 17.13 p < 0.001*	I = 7.21 ± 2.33 N = 7.38 ± 2.14 F = 0.10 p = 0.755	F = 1.51 p = 0.23	SI = 8.31 ± 2.2 SN = 8.25 ± 1.16 p = 0.49	WI = 5.91 ± 1.73 WN = 6.5 ± 2.5 p = 0.28	SI = 8.31 ± 2.2 WI = 5.91 ± 1.73 p < 0.001*	SN = 8.25 ± 1.16 WN = 6.5 ± 2.5 p = 0.06†
CHANGE (POST - PRE)							
Creative Thinking	S = 0.04 ± 1.4 W = -0.71 ± 1.28 F = 3.80 p = 0.058†	I = -0.3 ± 1.57 N = -0.3 ± 1.2 F < 0.001 p = 0.997	F = 0.006 p = 0.94	SI = 0.0 ± 1.66 SN = 0.08 ± 1.04 p = 0.92	WI = -0.7 ± 1.35 WN = -0.73 ± 1.21 p = 0.93	SI = 0.0 ± 1.66 WI = -0.7 ± 1.35 p = 0.16	SN = 0.08 ± 1.04 WN = -0.73 ± 1.21 p = 0.16
Flexible Thinking	S = 0.68 ± 1.57 W = -1.14 ± 1.58 F = 19.90 p < 0.001*	I = -0.35 ± 2.12 N = 0.04 ± 1.43 F = 1.47 p = 0.231	F = 0.78 p = 0.38	SI = 0.54 ± 2.02 SN= 0.83 ± 0.8 p = 0.33	WI = -1.5 ± 1.63 WN = -0.82 ± 1.47 p = 0.46	SI = 0.54 ± 2.02 WI = -1.5 ± 1.63 p = 0.004*	SN = 0.83 ± 0.8 WN = -0.82 ± 1.47 p = 0.003*

Table 4. Creative self-efficacy assessment pre- and post-experiment. Aligned Rank Transform ANOVA omnibus test and post-hoc Aligned Rank Transform multifactor contrast tests to compare self-assessment

of creative thinking and flexible thinking pre- and post-experiment. A star (*) indicates $p < 0.05$ and a dagger (†) indicates $p < 0.1$, corresponding to green and blue shading, respectively.

4. Discussion

The Targeted Dream Incubation (TDI) protocol is designed for controlled induction of specific dream content at sleep onset. This protocol is available to anyone with sensors that can track sleep onset and a method to deliver and record audio. The Dormio device is built to enact this protocol automatically,[32] making the TDI protocol mobile and cheap in comparison to techniques which require polysomnography (PSG). This paper presents results which suggest the Dormio device can incubate and capture experimenter-chosen themes in hypnagogic dreams and that Targeted Dream Incubation has a significant beneficial effect on post-sleep creative performance.

The primary outcome of this study was the Creativity Index, a composite score constructed using 15 creativity dimensions. Given that the Creativity Index is constructed from a diverse set of both subjective and computationally-generated creativity dimensions, this composite provides a multifaceted measurement of creative performance (Table 2, Figure 2). The Creativity Index revealed a significant main effect of state (Sleep > Wake) overall and significant effects of state within both conditions (Sleep Tree-Incubation > Wake Tree-Incubation; Sleep No-Incubation > Wake No-Incubation), suggesting that hypnagogia engenders a creative brain state over and above waking mind-wandering, in line with past research.[4,195] In addition, there was a significant main effect of condition (Tree-Incubation > No-Incubation), suggesting that incubation of task-related content in offline cognition also confers a creative benefit, again in line with past creativity research.[88,303,304,4,193,279] However, this result differed per state, with a significant effect of condition shown within the sleep state (Sleep Tree-Incubation > Sleep No-Incubation), but an insignificant effect of condition within the wake state. This difference suggests that incubation in sleep may provide a larger benefit to creative performance than incubation in awake mind-wandering.

The secondary endpoints of this study aim to provide more granular interpretability of the Creativity Index. These outcomes include one composite measure (the Semantic Flexibility Index) and all of the 17 individual creativity dimensions (Table 2, Figure 2, Figure 3). The Semantic Flexibility Index is a composite score constructed using three measurements of semantic distance (one from each creativity task given, two computationally generated and one scored by hand). For the Semantic Flexibility Index, we find significant main effects of both state (Sleep > Wake) and condition (Tree-Incubation > No-Incubation), but upon pairwise comparisons find that the effect of state is restricted to only the Tree-Incubation condition (Sleep Tree-Incubation > Wake Tree Incubation) and that the effect of condition is restricted to only the sleep state (Sleep Tree-Incubation > Sleep No-Incubation). The directional trends and patterns of statistical significance observed in the 17 individual measured creativity dimensions mirrored those seen in the Creativity Index. We find 11 dimensions across the three tasks with a significant main effect of state, with 7 dimensions demonstrating an effect of state in the Tree-Incubation condition and 4 in the No-Incubation condition. These individual dimensions suggest that sleep combined with incubation provides a greater benefit to creativity than sleep alone. We find 2 dimensions with a significant main effect of condition, with 4 dimensions demonstrating an effect of incubation in the Sleep state and 1 in the Wake state. These secondary endpoints reflect the results from the Creativity Index, suggesting that while incubation in wake has limited benefit to creativity, incubation in sleep provides a much greater benefit.

In our regression of creative performance on degree of incubation, we observed only in the sleep state a predictive relationship between the number of verbal reports with a direct reference to “tree” and creative performance for the Creativity Index and five individual creativity dimensions (Table 3). We did not find any measures of creative performance for which direct references to “tree” predicted performance in the wake state. Evidence that degree of dream incubation positively predicts level of creative performance indicates that incubation of task-related hypnagogic dream content is tied to a creative boost, in line with past research linking dreams and creativity.[193,263,274,277,279,305] This result, along with the lack of any creativity task dimensions for which wake reports of “tree” are a significant predictor of creative performance, corroborates the results seen in our multiple comparison analysis and suggests incubation confers a creative boost in sleep.

The creative benefit of dream incubation is apparent in both subjective (human-rated) and computationally-generated objective assessments of both the ecologically-relevant CST and the extensively validated AUT and VGT. These benefits go beyond divergent thinking, including enhanced descriptiveness, fantasy, and semantic flexibility, as well as producing enhanced self-perception as a creative and flexible thinker that extends beyond the sleep and creative task period (Table 4). With our study design and TDI technique, we were able to independently vary task-relevant dreams without presenting the creativity tasks themselves as dream incubation stimuli. This study thus zeroes in on the first controlled experimental evidence supporting the positive effect of dream incubation on creative performance.

4.1 Limitations

Our experiment design is subject to a set of limitations. We use a single prompt (“tree”) for our three creativity tasks, limiting our ability to investigate the theme-specificity of the observed creative benefit. While our study suggests the incubation of dream content confers a creative benefit on tasks related to the incubated theme, the specificity of this creative benefit is yet to be established. In other words, a conservative interpretation of our findings is that presenting auditory stimuli at sleep onset improves creativity on any task, including ones unrelated to incubated themes. Further research is needed to determine whether creative benefits are limited to tasks related to the incubated theme or if they may also include tasks unrelated to the incubated theme. Such research would include an experimental condition that incubates dreams thematically unrelated to the post-sleep creativity task and/or the presentation of post-sleep creativity tasks with prompts unrelated to the incubated theme. In past studies using the AUT, CST, or VGT, subjects were often asked to respond to more than one prompt for a given task. Future research investigating the specificity of the benefit of dream incubation may benefit from a similar protocol which uses more than one prompt per subject for each creativity task.

Another prompt related limitation is the confound of high cognitive demand. Being instructed to specifically “think of a tree” (as in the Tree-Incubation condition) as opposed to “observe your thoughts” (as in the No-Incubation condition) may be a more cognitively demanding task, thus differently influencing brain state and perhaps levels of arousal at sleep onset. The observed benefit from the “Tree-Incubation” condition as compared to the “No-Incubation” condition is thus confounded with potential differences in brain state. Future work comparing groups which have both received prompts with differing themes (i.e. “think of a tree” and “think of a fish”) would clarify this confound.

4.2 Special Subjects

Within the sleep groups, we had two subjects with dream content that did not match their assigned condition. Subject 8 in the Sleep Tree-Incubation group did not report any dreams involving a tree, even though they received audio stimuli including the word “tree” and confirmed hearing said stimuli. This was the only subject in the Sleep Tree-Incubation group who reported 0 dreams of a tree. On the other hand, Subject 14 in the Sleep No-Incubation group did report dreams involving a tree, although they received no audio stimulus including the word “tree” and confirmed they were unaware of the “tree” dream incubation condition. This was the only subject in the Sleep No-Incubation group who reported a dream of a tree.

These two subjects provide an opportunity to observe trending relationships between dream content and post-sleep performance, regardless of incubation. This offers insight into the following questions: (1) If a subject is prompted with the word “tree” but reports no related dream content (*i.e.*, Sleep Tree-Incubation Subject 8), will underlying nonconscious processing, in the absence of conscious phenomenology, positively influence post-sleep performance? And (2) If a subject in an unprompted group reports “tree”-related dream content (*i.e.*, Sleep No-Incubation Subject 14), will that conscious phenomenology be accompanied by better task performance in the absence of the effect of whatever nonconscious processing accompanies the delivery of each incubation audio prompt?

To address these questions, , we compared the individual creative performance scores of these two subjects to the others in their respective groups using the Crawford-Howell t-test for single-case analysis (Table S1).[306,307] We conducted this analysis on the composite measures (the Creativity Index and the Semantic Flexibility Index) as well as 15 individual creativity dimensions for which we had scores for all subjects. Subject 8, from the Sleep Tree-Incubation group, performed below the group mean on both composite measures, as well as on 11 of the 15 individual dimensions (binomial test, $p = 0.059$), achieving significance for three of the 11 (CST overall creativity, fantasy, and semantic flexibility). Subject 14, from the Sleep No-Incubation group, performed above the group mean on both composites (Creativity Index: $p < 0.02$) and 12 of the individual dimensions (binomial test, $p = 0.018$), achieving significance for three of the 12 (AUT fluency, CST overall creativity, and CST humor). These results, the interpretation of which are of course constrained by the small sample size, suggest that task-related dream content may be tied to creative boosts regardless of incubation condition.

4.3 Hypnagogia in the Sleep Laboratory

Considerable anecdotal evidence supports the effectiveness of boosting creativity using sleep onset dream incubation. Reports by both Thomas Edison and Salvador Dali document its consistently successful application to the design of inventions and works of art, respectively.[279] In both of these cases, N1 dreams contained explicit images or thoughts that contributed to the creative resolution of complex problems. The most compelling laboratory evidence for the creative potential of hypnagogia comes from Lacaux et. al. (2021), who found that time spent in N1 during a resting period tripled the chance that participants had a moment of creative insight on a mathematical task compared to subjects who remained awake, although a clear link to hypnagogic dream content was not found. Importantly, if participants slipped into N2 sleep this creative benefit was lost.[195]

The N1 sleep state (hypnagogia) has been largely neglected by sleep scientists, but it appears to offer an ideal physiological and phenomenological cocktail for augmenting creativity. N1 is a hybrid state where cognitive control is less constrained than wake, potentiating cognitive flexibility and the exploration of distant semantic associations, but where executive control remains present enough for recognition and capture of task-relevant sleep mentation. This brain state is ideal for creativity as it is understood by Dietrich's transient hypofrontality model,[308] Campbell's Blind Variation and Selective Retention model,[309] and Stickgold and Zadra's NEXTUP Model.[279] Creative thinking involves, among others, the ability to break conventional rules of thinking and create new combinations of mental elements that form the basis of meaningful new representations. Each of these models of creativity suggests that transient periods of unconstrained exploration of semantic networks can be the source of such divergent ideation and exploration of possibilities, while transient increases in cognitive control can help sort and select for meaningful representation. We understand our results in light of these mechanistic frameworks for creativity, wherein N1 enables increased cognitive flexibility and improves performance on the AUT, CST and VGT via increases in semantic divergence in combination with maintenance of enough attention for selection according to task-relevance.

The method used to capture hypnagogic mentation across the span of a century, by Edison and Dali and Lacaux, is simple: one sleeps with a heavy object in hand and once muscle tone lessens in N1, that heavy object will drop and wake them amidst hypnagogic dreams. The Dormio system offers systematic improvements on this old methodology. Dormio reliably incubates specific dream themes at a far higher rate than these other techniques,[225] allows for multiple rounds of hypnagogic dreams in a single nap session,[225,278] automatically collects spoken dream reports so they are not lost to amnesia, does not necessitate the more complete awakening that a written report would require, and has adjustable wakeup parameters so that users do not enter N2 and lose this creative boost, as they are wont to do using the Edison technique.[195]

4.4 Feasible uses of Targeted Dream Incubation

TDI opens up avenues to probe all of the known correlational links between dreaming and post-sleep performance at the *causal* level. For instance, TDI about specific cues in a word pair memorization task could hypothetically enhance recall of an associated target word. TDI at sleep onset could contribute to sleep-dependent memory processing by identifying and tagging memories for further processing later in the sleep period.[225] This subsequent processing could perhaps extend to the amelioration of trauma and nightmares, where TDI at sleep onset could be used to either combat negative dream content or to seed specific memory content for effective processing during REM dreams.

Importantly, these experiments cannot make causal claims about dream *content* specifically; There exists no experimental methodology to separately examine the causal effects of a conscious experience and its concomitant neural instantiation, whether in wake or in sleep. Thus, our claims are limited to the effects of dream incubation on waking performance, where we acknowledge these effects include both dreams and, potentially, underlying nonconscious neural processes that may likewise affect post sleep performance.

Acknowledging these limitations, there are a number of exciting questions to ask about the effects of dream incubation. There is considerable comorbidity between sleep disorders and mental disorders, for instance, but little is known about disordered dreaming and even less about the potential efficacy of targeted dream-related interventions. TDI could open avenues into this research by enabling the control of dream content related to waking mental disorders. Whether the dreams or instead the underlying neural changes induced by TDI are causally related to changes in symptoms, the important question is whether dream incubation can effect improvement. To quote Siclari (2020): "Sleep medicine has greatly developed in the past decades, mostly through knowledge gained from managing millions of patients with sleep apnea and insomnia, but the phenomenology and physiology of dreaming have been overlooked, even though they bear relevance to sleep clinicians."[152]

4.5 Researching Dreams: "The hard problem"

We hope this evidence, as well as the protocol which enabled it, inspires a host of experiments probing the causal contribution of dream incubation to sleep-mediated cognitive processing. In the past, dream experience has often been explained as the unimportant, and indeed random, result of nonconscious cognitive processing ongoing in sleep.[8,133,310] We argue, based on the data reported here, that dreaming—a combination of experiential phenomenology and brain physiology— itself is important and that targeted dreaming can offer benefits to our understanding and augmentation of creativity, learning, and memory.

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Author contributions

A.H.H., P.M, and R.S. conceived the study and designed the experiment. A.H.H. and T.V.G. engineered tools for the experiment. A.H.H. conducted the experiment. K.E. designed and conducted statistical analyses. A.H.H. and K.E. interpreted statistical findings and wrote the manuscript.

5. Supplementary Material

5.1 Comparison of Special Subjects to Experimental Group

Subject Number	8	14
Group	Sleep Tree-Incubation (SI)	Sleep No-Incubation (SN)
"Tree" in Dream Report	No	Yes
Composite Measures		
Creativity Index	Group: μ = 0.53, σ = 0.33 Subject: 0.008, Z = -1.65 p = 0.079	Group: μ = -0.01, σ = 0.39 Subject: 1.06, Z = 2.71 p = 0.013*
Semantic Flexibility Index	Group: μ = 0.62, σ = 0.50 Subject: 0.36, Z = -0.51 p = 0.313	Group: μ = -0.03, σ = 0.38 Subject: 0.29, Z = 0.83 p = 0.222
Individual Creativity Dimensions		
AUT Snapshot	Group: μ = 4.28, σ = 0.74 Subject: 3.33, Z = -1.28 p = 0.121	Group: μ = 3.21, σ = 0.96 Subject: 3.67, Z = 0.47 p = 0.321
AUT Semantic Distance	Group: μ = 0.66, σ = 0.04 Subject: 0.71, Z = 1.21 p = 0.134	Group: μ = 0.63, σ = 0.05 Subject: 0.68, Z = 0.94 p = 0.195
AUT Fluency	Group: μ = 10.58, σ = 4.50 Subject: 6.00, Z = -1.02 p = 0.174	Group: μ = 10.27, σ = 5.20 Subject: 33.0, Z = 4.37 p < 0.001*
CST Overall Creativity	Group: μ = 5.94, σ = 0.76 Subject: 3.33, Z = -3.42 p = 0.004*	Group: μ = 4.58, σ = 1.25 Subject: 7.00, Z = 1.94 p = 0.046*
CST Narrative Cohesion	Group: μ = 5.06, σ = 1.17 Subject: 5.67, Z = 0.52 p = 0.309	Group: μ = 4.97, σ = 1.73 Subject: 6.67, Z = 0.98 p = 0.186
CST Fantasy	Group: μ = 5.17, σ = 0.66 Subject: 2.33, Z = -4.30	Group: μ = 3.85, σ = 1.62 Subject: 6.67, Z = 1.74

	p < 0.001*	p = 0.063
CST Descriptiveness	Group: μ = 5.17, σ = 1.18 Subject: 3.00, Z = -1.84 p = 0.053	Group: μ = 4.82, σ = 1.17 Subject: 6.67, Z = 1.58 p = 0.079
CST Semantic Flexibility	Group: μ = 4.69, σ = 1.31 Subject: 2.00, Z = -2.05 p = 0.037*	Group: μ = 3.15, σ = 1.02 Subject: 1.67, Z = -1.46 p = 0.097
CST Humor	Group: μ = 2.14, σ = 1.45 Subject: 1.00, Z = -0.78 p = 0.232	Group: μ = 1.91, σ = 1.50 Subject: 5.00, Z = 2.06 p = 0.38*
CST Emotiveness	Group: μ = 3.86, σ = 1.23 Subject: 2.33, Z = -1.25 p = 0.129	Group: μ = 4.21, σ = 1.38 Subject: 4.33, Z = 0.09 p = 0.402
CST Coh-Metrix Narrativity (Reverse Scored)	Group: μ = 41.73, σ = 28.67 Subject: 13.57, Z = -0.98 p = 0.182	Group: μ = 50.41, σ = 25.04 Subject: 13.57, Z = -1.47 p = 0.095
CST Coh-Metrix Referential Cohesion (Reverse Scored)	Group: μ = 59.51, σ = 32.31 Subject: 29.12, Z = -0.94 p = 0.189	Group: μ = 59.38, σ = 26.23 Subject: 72.24, Z = 0.49 p = 0.317
VGT Subjective Score	Group: μ = 3.05, σ = 0.34 Subject: 3.17, Z = 0.38 p = 0.349	Group: μ = 2.62, σ = 0.42 Subject: 3.01, Z = 0.93 p = 0.198
VGT Semantic Distance	Group: μ = 0.74, σ = 0.06 Subject: 0.76, Z = 0.32 p = 0.365	Group: μ = 0.72, σ = 0.08 Subject: 0.79, Z = 0.91 p = 0.203
VGT Elaboration	Group: μ = 1.40, σ = 0.60 Subject: 1.03, Z = -0.62 p = 0.280	Group: μ = 1.01, σ = 0.02 Subject: 1.00, Z = -0.54 p = 0.302

Table S1. Comparison of special subjects to their experimental group. Individual scores (and equivalent z-scores) of Subject 8 and Subject 14 along with the mean (μ) and standard deviation (σ) of the other subjects in their respective groups. P-values generated by the Crawford-Howell t-test for single-case analysis. A star (*) and dark shading denotes a significant difference between the subject and their group. For both light and dark shading, red denotes when a subject scored below their group; blue shading denotes when a subject scored above their group.

5.2 Imagery in the Creative Storytelling Task

For the Creative Storytelling Task, in which subjects were told writing was necessary and drawing was additionally allowed, groups generated such drawings with varying frequencies. Because of the low number of drawings (for example, only three instances in the Wake Tree-Incubation group), we ran a two-sided Fisher's exact test to compare the frequency of imagery generation across groups and found significance ($p = 0.007$), indicating that there are significant differences in the imagery generation frequency between groups. Comparisons of imagery ratings between groups are included in Table 2.

Group	Subjects	No Imagery	Imagery (# subjects who drew)	Imagery Ratings (for subjects who drew)
Sleep Tree-Incubation	13	1 (7.7%)	12 (92.3%)	4.86 ± 1.42
Sleep No-Incubation	12	5 (41.7%)	7 (58.3%)	3.62 ± 0.82
Wake Tree-Incubation	12	9 (75.0%)	3 (25.0%)	4.44 ± 1.73
Wake No-Incubation	12	5 (41.7%)	7 (58.3%)	2.33 ± 0.47

Table S2. Imagery generation and imagery ratings in the creative storytelling task.

5.3 Experimental Procedures

5.3.1 Dormio Device

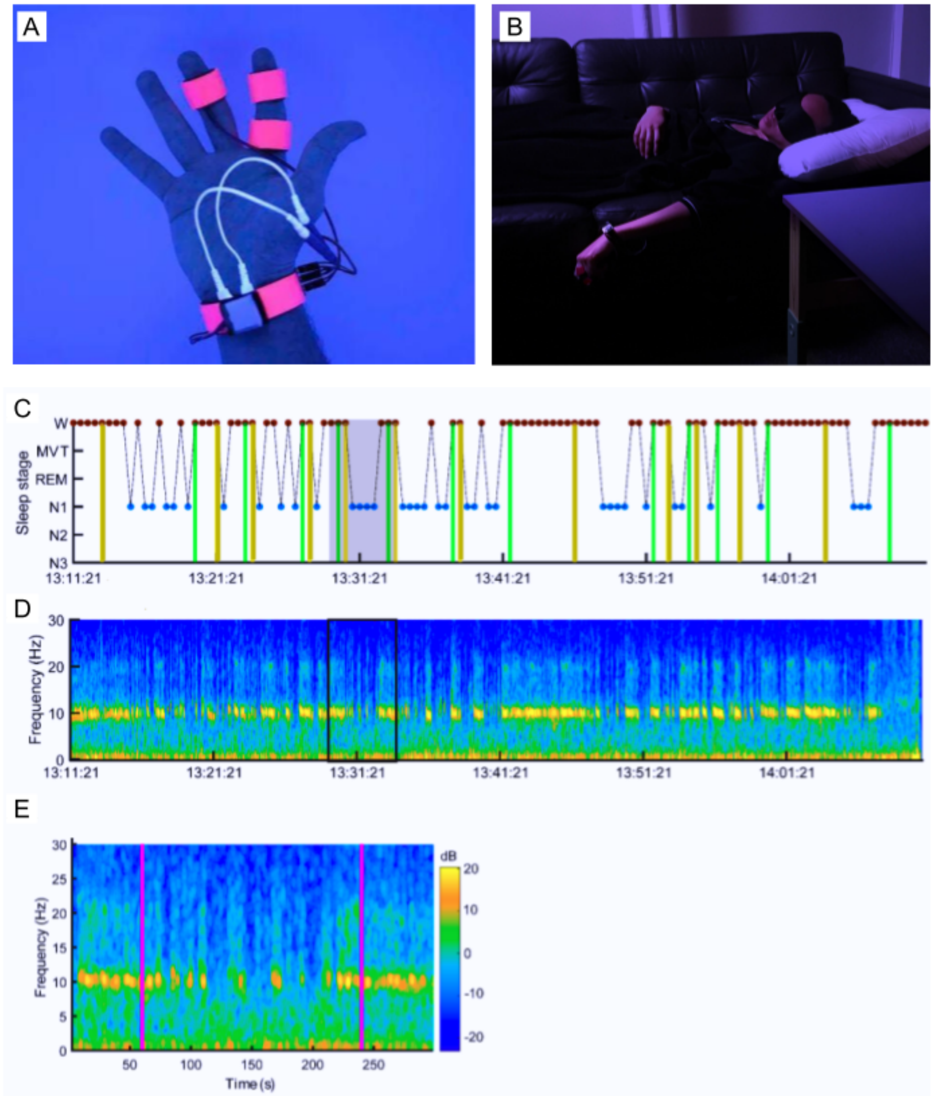


Figure S1. Dormio system and polysomnography recording. A. Handwork form-factor facilitates measurement of EDA, HR, and muscle flexion. **B.** The lack of headworn sensors enables comfortable sleeping with the Dormio device. A and B images by Oscar Rosello. C-E Polysomnography recording during a Dormio incubation session. **C.** Hypnogram displaying sleep staging throughout the session. Note that the subject remained in wake and N1 sleep throughout the protocol. Yellow bars mark the verbal prompt at the beginning of an incubation period, green bars indicate the recording timestamp for dream reports given at the end of each incubation period following Dormio initiated awakenings. **D.** Multitaper spectrogram of the frequency dynamics of the EEG signal during the incubation period. Note the attenuation of alpha (~10Hz) rhythm activity during periods of N1 sleep. **E.** Enlarged view of spectral dynamics during a single incubation period (gray box in C and D). The incubation period began while the subject was awake. They quickly entered N1 sleep, characterized by the marked reduction in the alpha rhythm. A few minutes later, the Dormio woke the subject and asked for a dream report, which it recorded, and the alpha rhythm reappeared. Spectrogram derived from activity at electrode O1 (left occipital lobe).

5.3.2 Experimental Instructions Read to Subjects

Below are the specific instructions given to the subjects in each experimental group. As the instructions are critical to correctly initiate dream incubation and hypnagogic imagery, attempts at replication should closely mirror the instructions below:

Group 1 (Sleep Tree-Incubation): "This experiment is investigating the relationship between mental rest and cognitive flexibility. Varied imagery, memories, words, or bodily feelings may come up throughout the experiment. The aim of this exercise is to observe them, stay with them, follow them lightly and see where they go. One thing not to worry about is questioning whether you are asleep. This period in between sleep and wake feels to some people like sleep, to others just like relaxation or mind wandering. All are completely fine, just watch your mind and relax. Sleep cannot be forced, just allowed. Head towards sleep, but don't worry at all where you are in it, just relax."

"After you lie down, you will be asked to think of a theme. Relax, hold that theme in your mind. A few times, you will be told you are falling asleep and reminded of the dream theme. These prompts are not to wake you up fully, just to make sure you do not descend into deep sleep, and to keep you aware so that you can keep observing your mind. Just stay still when the prompts come. Again, we're interested in your thinking in this semi-lucid period. Whenever you are prompted to report, please just vocally report what was going through your mind, and report whether you think you were asleep, by either saying awake, halfway or asleep. Then relax and drift towards sleep again."

Group 2 (Sleep No-Incubation): "This experiment is investigating the relationship between mental rest and cognitive flexibility. Varied imagery, memories, words, or bodily feelings may come up throughout the experiment. The aim of this exercise is to observe them, stay with them, follow them lightly and see where they go. One thing not to worry about is questioning whether you are asleep. This period in between sleep and wake feels to some people like sleep, to others just like relaxation or mind wandering. All are completely fine, just watch your mind and relax. Sleep cannot be forced, just allowed. Head towards sleep, but don't worry at all where you are in it, just relax."

"After you lie down, you will be asked to observe your thoughts. Relax, and see where your thoughts go. A few times, you will be told you are falling asleep and reminded to observe your thoughts. These prompts are not to wake you up fully, just to make sure you do not descend into deep sleep, and to keep you aware so that you can keep observing your mind. Just stay still when the prompts come. Again, we're interested in your thinking in this semi-lucid period. Whenever you are prompted to report, please just vocally report what was going through your mind, and report whether you think you were asleep, by either saying awake, halfway or asleep. Then relax and drift towards sleep again."

Group 3 (Wake Tree-Incubation): "This experiment is investigating the relationship between mental rest and cognitive flexibility. Varied imagery, memories, words, or bodily feelings may come up throughout the experiment. The aim of this exercise is to observe them, stay with them, follow them lightly and see where they go. One thing not to worry about is questioning whether you are mind wandering or focused. All are completely fine, just watch your mind and relax."

“After you close your eyes, you will be asked to think of a theme. Relax, hold that theme in your mind. A few times, you will be told to observe your thoughts and reminded of the theme. These prompts are just to keep you aware so that you can keep observing your mind. Just stay still when the prompts come. Again, we're interested in your thinking in this period of mental rest. Whenever you are prompted to report, please just vocally report what was going through your mind. Then relax and let your mind drift again.”

Group 4 (Wake No-Incubation): “This experiment is investigating the relationship between mental rest and cognitive flexibility. Varied imagery, memories, words, or bodily feelings may come up throughout the experiment. The aim of this exercise is to observe them, stay with them, follow them lightly and see where they go. One thing not to worry about is questioning whether you are mind wandering or focused. All are completely fine, just watch your mind and relax.”

“After you close your eyes, you will be asked to observe your thoughts. These prompts are just to keep you aware so that you can keep observing your mind. Just stay still when the prompts come. Again, we're interested in your thinking in this period of mental rest. Whenever you are prompted to report, please just vocally report what was going through your mind. Then relax and let your mind drift again.”

5.3.3 Prompts for Dream Incubation and Reports

Group 1: Sleep Tree-Incubation involved a prompted hypnagogic nap, wherein we used the Dormio system to incubate the dream theme “tree.” Upon lying down, the Dormio web app instructed these subjects to “*Think of a Tree.*” Once N1 sleep was detected by the system, a variable timer was triggered. This timer instigated wakeups from 1:00 to 5:00 minutes after N1 detection. At the end of this time, the computer audio alerted subjects they were falling asleep ("*You're falling asleep*"), asked them to verbally report the thoughts they were currently having ("*Please tell me, what's going through your mind*"), and recorded their response. Once subjects finished speaking, the system asked about their sleep state (“*And were you asleep?*”), to which subjects had been instructed to respond with ‘Awake’, ‘Halfway’ or ‘Asleep’. The system then instructed them to think of the dream prompt ("*Remember to think of a tree"*) and to go back to sleep ("*You can fall back asleep now*"). This loop of events was repeated for 45 minutes, enabling multiple entries into and exits from hypnagogia. At the end of the last loop, the experimenter instructed the subject to wake up fully.

Group 2: Sleep No-Incubation involved an unprompted hypnagogic nap, wherein we used the Dormio system solely to extend the hypnagogic period across serial sleep onsets and to capture dream reports. The Dormio system functioned as it did in Condition 1, except the prompt, “Remember to think of a Tree” was replaced with “Remember to observe your thoughts.”

Group 3: Wake Tree-Incubation involved a prompted period of time-matched wake. Subjects sat upright with head unsupported (so the experimenter could survey for muscle tone loss, which would indicate sleep onset), eyes closed, and were instructed to stay awake. Subjects were instructed “not to worry about controlling your mind, mind wandering is completely fine, just watch your mind and relax.” The Dormio web app then instructed these subjects to “think of a Tree”. Once 7:00 minutes had passed, approximating sleep onset time, a variable timer was triggered from 1:00 to 5:00 minutes. At the end of this timer window, the computer audio alerted subjects and asked them to verbally report the thoughts they were currently having ("Please tell me what's going through your mind"), and their response recorded. Once subjects finished speaking, the system prompted them again, "Remember to think of a tree."

Group 4: Wake No-Incubation involved an unprompted period of time-matched wake. Subjects sat upright with eyes closed. The Dormio system functioned as it did in Condition 3, except replacing the prompt, “Remember to think of a Tree,” with “Remember to observe your thoughts”.

5.4 Phenomenological Reports

5.4.1 Verbal Reports

Subject	Group	Verbal Reports
10	Sleep Tree-Incubation	Awakening 1: Trees, many different kinds, pines, oaks Awakening 2: Who I'm going to have over for dinner on Saturday, and occasionally trees, and how I'm not falling asleep Awakening 3: A tree from my childhood, from my backyard. It never asked for anything. Awakening 4: Trees splitting into infinite pieces Awakening 5: I'm in the desert, there is a shaman, sitting under the tree with me, he tells me to go to South America, and then the tree...
37	Sleep No-Incubation	Awakening 1: The desert Awakening 2: I was thinking about how someone else would have to fall asleep here Awakening 3: The sea, sharks, lots of movement Awakening 4: Clouds, and movement and mhmm Awakening 5: The mothering feeling... in the middle... safe Awakening 6: I lost it! I wasn't thinking of anything.
19	Wake Tree-Incubation	Report 1: I'm thinking about an X Files episode where a creature ties people to trees Report 2: Thinking about climbing a tree and reading at the top of it Report 3: I'm thinking about walking through orange and almond groves Report 4: The adventure I'm going to have this weekend Report 5: I'm thinking about the tree that the peach grew on in james and the giant peach
42	Wake No-Incubation	Report 1: Oh I’m just awake Report 2: Thinking about what I have to do tonight Report 3: I was thinking about the election Report 4: I was thinking about the itch on my ear

	Report 5: I was thinking about thinking about what I should be thinking about

Table S3. Verbal Reports. Examples of verbal reports following report prompts given by the Dormio device.

5.4.2 Post-Experiment Reports

Subject	Group	Post-Experiment Report
11	Sleep Tree-Incubation	“My dream was pleasant and mysterious. I never knew what the next part of my dream was going to be. My dream did involve a tree. I was following the roots with someone and the roots were transporting me to different locations. At each location I was trying to find a switch. It was unclear why I had to turn on the switch, but at the final location a window with a bright light was revealed. I saw a familiar face, but I couldn't place where I'd seen them. In the background, the moon was shining bright and illuminating the face. I was dreaming this while awake and not fully asleep...I could hear myself talking to someone about finding a switch. I could hear my breathing, my footsteps, the wind, and an air conditioner. When I bumped into objects, I can hear the noise of the collisions. I could hear the roots of the tree pulsating with energy as if they were leading me to some location.”
3	Sleep Tree-Incubation	“I think it's really, really useful for creativity...at the beginning of my dreaming experience I was seeing scenes that were the same size and functionality of real trees, but then the second time I was much bigger than the trees and I could eat them like finger food. You wouldn't come up with that idea at the beginning, but this time I had hundreds of them. The hope is to break out of the banal stories. Which is why I liked this experiment. I'm afraid when I walk out that I will see everything changing like fantasies. But yeah why not. Who says that I must live in the world that everyone is living in? I could write it as if I'm living in a novel.”
6	Sleep Tree-Incubation	"I particularly remember feeling that my consciousness was almost entirely untethered when I thought about the subject of my post-sleep story about a tree - when a person began exploring the freedom of space through tree imitation, before collapsing in a twisted heap and fully becoming a tree. Then, they proceeded to explore four dimensions - which was thoroughly confusing but a lot of uninhibited fun."
12	Sleep Tree-Incubation	“I’d start with a tree, I'm like thinking of a tree, for the first few minutes I didn't really go anywhere with the tree, I was just looking at it, it was like really colorful, but each time it woke me up, the path and depth in terms of how much it became a story went deeper. I started to go down a story path every time the word tree was mentioned, and when I was told that I was sleeping and to think of a tree again I switched back to the tree and took a different path. Very interesting, relaxing, and really made me think...I felt much more creative than usual. I never really think of myself as a creative person but it felt easier to think of abstract things and stories, like it just came to me.”
37	Sleep No-Incubation	“I feel like my story was far more open and interesting than it would have been regularly, and that the thoughts I had flowed into each other much more easily than what otherwise might have been.”
28	Sleep No-Incubation	“I think it would be good to think about ideas for art in this state because everything feels looser and your mind goes places it might not go otherwise. Even reflecting on your day feels good because the thoughts don't seem permanent...my thoughts kept jumping around so I didn't really have a normal sense of time. I don't think I really had any sense of time. It felt shorter than 45 min when the experiment ended...I let myself think about anything I wanted to and my mind felt very relaxed because I was sort of asleep. It definitely felt

		different from my normal cognitive state. I think I could see my whole self at some points, so kind of like an out of body experience."
29	Sleep No-Incubation	"I feel more at ease. And as compared to earlier today - when I couldn't even read more than a few pages without feeling distracted - I feel calm. I feel creative. The writing activity especially was very calming, and makes me feel like that sort of random thought exercise can be a source of inspiration for me moving forward. I just feel more in tune with my experiences and memories - and feel like I want to be more artful... I definitely didn't feel like I had been asleep for 45 minutes. I felt it was more likely around 10-15 minutes. So in that sense, dreams felt a lot slower to me. I didn't really imagine my body. At some points it felt like I wasn't even there, and I was just a pair of eyes observing the memories and world around me - without necessarily physically being there. It's like I was just a visitor, looking at my life as if it were in an enclosure. Life is very beautiful, but sometimes when we get lost in the minutiae of daily activities - we forget that. I felt like I was seeing a highlight reel of peculiar memories, and it really made me want to be more reflective about my life and really decide what I do on an everyday basis with intention and purpose. I just felt much more relaxed during the experience. I didn't feel inhibited by any of the constraints I feel when I have to convey experiences with actual words - it felt like I could communicate without any sort of language (verbal or otherwise) - I just understood everything around me for what it was."
33	Sleep No-Incubation	"I went from imagining something that I thought might induce a dream, to beginning to dream about that imagined thing. Then, there would be a transition from imagined experience to dream, sometimes that was continuous, and sometimes not continuous at all. When not continuous, my mind would jump from what I had been imagining to something entirely different, and this lack of control indicated to me that I was dreaming. I never lost full awareness of where I was, such that when I was woken I was not surprised to find myself in this reality...However, I seemed to have some kind of creative inspiration while I wrote that seemed somewhat self directed similar to how dreams are. Certainly, I thought of some strange things that I would never have thought about were I not somewhat asleep. I had a dream that I was hovering through the air, and throwing what were like miniature bombs to the ground that would explode into literal mushrooms, not mushroom clouds. I consider ideas like these to be creative."
35	Sleep No-Incubation	"I had a lot of strong images and some narrative stuff- didn't experience any big hypnic jerk but I guess some little ones. My mind wandered a fair amount from physical locations that were made up to ones that resembled ones I knew. I remember a rather horrifying story from the experience of a train with a pig's face and a piglet who was talking to me and saying I didn't understand what it was like for my mother to be taken away. There was a period of time in which there was narration that sounded a lot like an Oliver Sacks book and like his voice and I had some v mild hallucination type things of colors fluctuating in a thermal-imagery type way. I daydreamed about things I wanted to do in the coming weeks. I saw myself turn around, wearing a veil. I saw maxwelton and bone caves with swing sets at the entrances, and my friends who I just went on a caving trip with sitting in them. I imagined several strange and implausible things and honestly can't remember 90% of them just bc the images went by so quickly"
19	Wake Tree-Incubation	"I had a mostly pleasant experience. During the first portion, I found my mind mostly wandering between the task at hand (thinking about trees) and thinking

		about the study overall and thinking about my heartbeat/breathing...I thought about the word t-r-e-e and I would recall past experiences when I was around trees. It was interesting how I often think of trees as secondary items that are in the environment around me but not really primary. I can't say the thoughts I had were creative.”
42	Wake No-Incubation	“My thoughts were about recent events including the experiment itself. I thought about what I should think about and tried to guess what would trigger the device. I also felt a sense of tightness in my stomach and wondered if it's because I was overly concentrated on my thoughts. I wasn't really trying to be creative. I felt more of what my body is feeling than if I had my eyes open.”

Table S4. Post Experiment Reports. Examples of verbal reports given after the conclusion of creative tasks regarding dream (sleep groups) or mind-wandering (wake groups) experiences.

Chapter 4: Non-Contact TDI (Experiment 2)

Summary

Hypnagogia, the period between wakefulness and sleep, is a brain state involving spontaneous dreams, long distance mnemonic and semantic associations, and the engagement of brain networks instrumental to creativity.[195,311,312] A recent paper corroborates the association of hypnagogia and creativity, showing that hypnagogia facilitates insight in the Number Reduction Task.[195] Yet research into the hypnagogic state remains sparse, and studies that do exist typically require cumbersome and costly EEG-based polysomnography to track sleep onset. In our earlier work (Experiment 1) we developed a wearable electronic device "Dormio" to identify hypnagogic states without EEG polysomnography and demonstrated reliable incubation of specific dream content in the hypnagogic state using auditory stimuli, as well as further evidence that hypnagogia fosters creative problem-solving.[203,225,277] Experiment 2 moves beyond the wearable form factor and makes hypnagogia even more accessible to researchers by identifying techniques for hypnagogic research using a completely hardware-free, web-based version of Dormio. Participants (n=80, age = 36.0 ± 12.4 (S.D.)) completed a counterbalanced mind-wandering and hypnagogia task following instructions to think about a common everyday object (either 'fork' or 'tree') while engaged in mind-wandering, and to think of a distinct everyday object (either 'fork' or 'tree') while in hypnagogia. Following each session, participants reported hypnagogic or mind-wandering mentation and completed a series of phenomenological questionnaires. We found marked differences between hypnagogia and waking mind-wandering reports based on both phenomenological assays and computational semantic analyses. We thus corroborated previous research finding experiential differences between hypnagogia and mind-wandering and offer a novel, effective method of dream research that can be applied remotely, without expensive hardware, and with the possibility to collect data from multiple participants simultaneously.

Note: This Experiment is a collaboration between Paul Seli (Duke University), Lucas Bellaiche (Duke University), Kathleen Esfahany (MIT), Mason McClay (UCSB), Ottavia Personeni (MIT), Christina Chen (Wellesley) and Dan Denis (Goldsmiths). Experiment design was conducted by Adam Haar Horowitz (MIT), Paul Seli and Lucas Bellaiche (Duke). Experimental subjects were run by Lucas Bellaiche and Paul Seli (Duke). Analysis was conducted by Paul Seli (Duke), Lucas Bellaiche (Duke), Mason McClay (UCSB), and Dan Denis (Goldsmiths).

Introduction

Mind-wandering and mind-blanking – the experiences which accompany lapses of attention, the former with recalled phenomenological content and the latter without– are both described in the cognitive sciences under the blanket term *spontaneous thought*, and described colloquially as daydreaming. Spontaneous cognitive events are often contrasted with goal-directed thought and described as largely independent of any ongoing tasks. [77] Much like dreaming, spontaneous thoughts involve sensory attenuation, a dampening of incoming environmental and bodily stimuli, and cognitive contents which are more associative, self-focused, bizarre and emotionally negative than attentional thought. [78,16] Mind wandering and dreaming seem to be supported by overlapping neural networks, including the Default Mode Network (DMN). [16] As the DMN is observed most clearly in wake when subjects engage in the task of self-reflection, it is theorized that both daydreaming and dreaming can be important routes to insight. [79,80] The similarities go further; Recent research suggests that slow waves, a brainwave event which typifies slow-wave NREM sleep, can in fact occur in local areas of the brain outside of NREM sleep in wakefulness. [81] While the local decrease in slow-wave activity over parietal brain regions correlates with the occurrence of dreams, a local decrease during wakefulness over the same regions correlates with an increase in spontaneous thoughts. [82]

Recent theory suggests nighttime dreaming can be understood as an intensified form of mind-wandering, yet these mind-states are distinguished by their level of consciousness as daydreaming happens during wakefulness and dreaming during sleep. While daydreaming involves lapses in volitional control, these are transient and short in comparison to nighttime dreaming, and dreams are immersive in a way that even vivid daydreams are not. [16] The carefully orchestrated circadian and ultradian timing of dreams sets them apart from daydreams, which do not seem to adhere closely to either internal or external schedules. [90] Research on the dream-lag effect, for instance, suggests that night time dreams have a pattern for the incorporation of waking experiences, such that we are most likely to dream of events experienced the preceding day and 5–7days before, and less likely to dream of events from days 2–4 before. [91]

Though comparisons of dream mentation sampled from REM and NREM sleep stages have produced a relatively consistent pattern of differences in recall frequency, report length, and some content categories, comparisons between dreaming and daydreaming qualitative attributes have not provided such clear findings. On the one hand, there are general relationships between elements of nighttime dreams and daydreaming style within individuals; for example, a daydreaming style characterized by anxiety and distractibility is correlated with nighttime dreams that are highly bizarre and emotional.[313] Further, a qualitative review of studies that have assessed the content of dreams and daydreams concluded that the two were similar in several respects, i.e., consisting of predominantly audiovisual sensory content containing emotion reflecting current concerns and long-term memories, and lacking meta-awareness.[16] On the other hand, dream content is distinct from waking daydreams in that dreams contain more unfamiliar settings, bizarreness, and victimization than do waking daydreams.[314] In particular, bizarre content, including incongruous, discontinuous or impossible events, is more prominent in dreams than in daydreams. [315]

The lack of consistency between studies of dreaming and daydreaming is complicated by the fact that daydreaming is often retrospectively assessed as opposed to being systematically induced. Yet recent research has suggested it is possible to prime specific mind-wandering content, for instance finding that priming performance-related concerns induces task-related mind-wandering.[316] Researchers suggest that experiments priming specific content can elucidate links between disturbed dreaming and anxious daydreams but “controlled laboratory comparisons of the dreams and daydreams of frequent nightmare sufferers have not been conducted”.[317] Recent research suggests subjects can engage in selective retention of spontaneous thought and purposefully incubate their mind-wandering content with specific themes, opening up avenues for controlled research into task-related, stimulus-independent thought.[316] We build on this research to create a content-controlled experiment on the differences between these brainstates using induction of specific daydreaming content via auditory prompts from the Dormio system, in tandem with TDI of specific N1 dream content. Experiments like this one can offer clinical insight, clarify 24 hour DMN function, and uncover mechanisms which underlie the creative, affective and mnemonic effects of spontaneous thinking across the circadian cycle.

Methods

Subjects were enrolled from the online crowdsourcing site Prolific. Participants had to be at least 18, speak English fluently, be US residents, have at least a 90% approval rate on previous Prolific studies, and had to have participated in at least 50 Prolific studies in the past. 132 subjects meeting these requirements were subsequently enrolled; however, participants had to report having stayed awake during the mind-wandering task and having slept either fully or halfway during the hypnagogia task. Excluding participants who did not meet this criteria, we report 80 participants here (*n* = 46, male; M = 36.01, SD = 12.42). Participants were compensated $24.00 for an average experiment length of 2.6

hours. Participants were guided to a ‘Dormio’ website that provided timings of auditory incubation (in either mind-wandering or dreaming), awakenings, and requests for verbal reports and automated recording of responses. Participants were prompted, by both written instructions and pre-recorded video instructions, with the object about which to dream/mind-wander (randomly assigned as either Fork or Tree and counterbalanced across condition), and to enter their name and record audio instructions that the website would replay throughout the experiment in their own voice. These messages were (1) a prompt message serving to incubate dream content (‘Think of a Fork/Tree’), and (2) a wakeup message (‘Tell me what’s going through your mind’) prompting each verbal dream report. Participants were instructed to sit upright with eyes closed and remain awake in the mind-wandering condition, and to lie down with eyes closed and fall asleep in the dreaming condition.

Figure 28 The Dormio web interface allowed participants to record cues and receive TDI. Credit Christina Chen

Timing of audio prompting created the following parameters: Subjects in each condition would take 10-15 minutes to initially fall into hypnagogia/mind-wandering, stay in hypnagogia/mind-wandering for 3 minutes, catch 4 dreams/mind-wandering thoughts, take 60 seconds to provide verbal reports as cued by their audio messages, and take 7 minutes to fall back into sleep/a stable mind-wandering state following each awakening/interruption of mind-wandering. These parameters were chosen for several reasons. Though individual differences exist in sleep behavior, past literature suggests that hypnagogic dreaming is achieved rather rapidly after sleep onset, hence the shortened amount of time to fall into the respective states. In addition, we believed that staying 3 minutes in each state provided adequate time for descriptive stories to develop without a loss of memory of dream content (dream amnesia) before each of the 4 reports. Participants recorded 4 reports, each for 60 seconds, over an hour-long condition of either MW or N1. Following each condition, participants again reported their thoughts/dreams manually in a free-response question in Qualtrics. We assessed the content of participants’ thoughts, both when awake and in hypnagogic sleep, using a modified version of the thought probe scale adapted from Smallwood et al (2016)[318] after the conclusion of each subject’s hypnagogia or mind-wandering period. The modified scale consists of a set of 13 questions measuring features of thoughts, including intentionality, valence, vagueness, and orientation (Table 1).

Content	Item	Response Scale
Positive valence	The content of my thoughts was positive.	Completely disagree – Completely agree (1-5)
Negative valence	The content of my thoughts was negative.	Completely disagree – Completely agree (1-5)
Structure: images	My thoughts were in the form of images.	Completely disagree – Completely agree (1-5)
Structure: words	My thoughts were in the form of words.	Completely disagree – Completely agree (1-5)
Novelty	My thoughts were novel (that is, I've never experienced or thought them before).	Completely disagree – Completely agree (1-5)
Freedom of thought flow	My thoughts were freely moving (i.e., I wasn't guiding them)	Completely disagree – Completely agree (1-5)
Topical shifts	My thoughts were jumping from topic to topic.	Completely disagree – Completely agree (1-5)
Meaningfulness	The content of my thoughts was important and meaningful to me.	Completely disagree – Completely agree (1-5)
Goal-directed	My thoughts were focused on uncompleted personal goals.	Completely disagree – Completely agree (1-5)

Unusualness	**My thoughts were bizarre and unusual.**	**Completely disagree – Completely agree (1-5)**
Emotionality	**My thoughts were emotional.**	**Completely disagree – Completely agree (1-5)**
Intentionality	**My thoughts were…**	**(1) engaged deliberately, with emotion** **(2) came to mind spontaneously, out of nowhere**
Temporality	**My thoughts were focused on the…**	**(1) Past (2) Present (3) Future (4) None of these**

Table 1 13 item modified version of the thought probe scale adapted from Smallwood et al (2016)

Computational Methods

To get at objective computational differences between daydream reports and reports from N1, we used two computational linguistic methods. **Coherence**, alternately called Temporal Coherence, is a measure of linguistic variability over time. Specifically, coherence is a measure of the similarity of each sentence in a report to its adjacent sentences, then applied as a sliding window over an entire document.[319] By accounting for time, this measure is an index of moment-to-moment variability. Here we apply the Universal Sentence Encoder (USE) to measure semantic similarity. USE applies a transformer model, a natural language processing algorithm that is trained to take into account the context of a sentence.[320] **Cue Centrality** uses USE to extract the overall similarity of each report to its respective cue, eliminating direct incorporations of the cue from analysis of each report to control for frequency of incorporation.

Results

Effectiveness of cueing procedure

As a first analysis, we wanted to confirm that participants showed a higher number of incorporations of the cued word relative to the uncued item. In other words, when participants were cued to think about a fork, did they show more incorporations of a fork than of a tree (and vice versa). Effect sizes of ANOVAs below are reported as np2 when comparing >2 groups (partial eta squared, an effect size measure for one-way or factorial ANOVA) or as Cohen's d when comparing 2 groups (is an effect size used to indicate the standardized difference between means). For np2, np2= 0.01 indicates a small effect; np2 = 0.06 indicates a medium effect; np2 = 0.14 indicates a large effect.[321] Cohen's d effect sizes are commonly interpreted as small (d = 0.2), medium (d = 0.5), and large (d = 0.8) based on benchmarks suggested by Cohen (1988).[322] We found a significant 3-way interaction between cue (fork, tree), incorporation content (fork, tree) and incorporation type (direct, indirect incorporation measured in the same manner as Experiment 1); F(1, 80) = 60.19 p < .001, np2 = .43. Regardless of incorporation type, participants reported significantly more incorporations of the cued item relative to the uncued item (all p < .001, all d >

0.84). Incorporations of the cued item (i.e. tree incorporations during the tree session, fork incorporations during the fork session) were all significantly greater than zero (all p < .001, all d > 0.84). Equally importantly, incorporation rates of the uncued item (i.e. fork incorporations during the tree session, and vice versa), were all not significantly different from zero (all p > .094, all d < 0.19). As such, this analysis shows that the primary manipulation was successful in terms of enabling participants to incorporate a particular item into their ongoing thoughts, and that carryover effects of prompts across counterbalanced conditions were insignificant.

Rates of incorporation by mental state

We next asked whether the number of incorporations of the cued item differed by mental state (i.e., between hypnagogia and mind wandering). A 2 (condition: hypnagogia, mind wandering) x 2 (incorporation type: direct, indirect) repeated-measures ANOVA revealed a significant main effect of incorporation type (F(1, 80) = 59.99, p < .001, np2 = .42), with more direct incorporations being reported than indirect incorporations. There was no main effect of condition (F(1, 80) = 0.61, p = .44, np2 = .008), suggesting that the overall number of incorporations of the cued item did not differ depending on whether cueing occurred during hypnagogia or mind wandering. There was also no significant interaction between condition and incorporation type (F(1, 80) = 0.11, p = .75, np2 = .001). Given that there were a number of participants who reported zero incorporations, we re-ran the analysis including only those participants who reported at least one incorporation. This did not substantially alter any of the results, with there still being no effect of condition (*F* (1, 70) = 0.21, *p* = .65).

Comparing rates of incorporation between online and laboratory studies

Of the 80 participants included in the analysis, 73 of them (91%) reported at least one incorporation during hypnagogia. This compares to recent laboratory work that found that out of 37 participants, 34 of them (92%) reported at least one incorporation of a cued item during hypnagogia. Comparing frequencies using a chi-squared test we find insignificant differences between these groups (chi^2=0.0006, p=.980546). As such, these results suggest that cueing during hypnagogia in an online setting, without a sensor, yields similar incorporation rates to that of more controlled laboratory studies.

Correlations between number of incorporations and dimensions of thought

Next, we looked at whether the rate of incorporation during hypnagogia may be driven by phenomenological aspects of the hypnagogia experience. First, we correlated the incorporation rate during hypnagogia with aspects of subjective experience during the hypnagogia session. Collapsing across direct and indirect incorporations, we found that reporting a higher incorporation rate was associated with a higher score on three items: **1)** “Thoughts were in images”, *r* = .12, *p* = .048; **2)** “Content of thoughts was important/meaningful”, *r* = .12, *p* = .042) and **3)** “Thoughts were jumping from topic to topic”, *r* = .16, *p* = .010. A significant positive correlation was observed between the number of direct incorporations during hypnagogia and bizarreness of thought (r = .33, p = .003) was observed. A similar result was obtained during the mind wandering condition (r = .26, p = .020). All other correlations were non-significant. We supplemented these results by dividing the sample into participants who reported more incorporations during hypnagogia, and those who reported more incorporations during mind wandering. We then compared these two groups with respect to their subjective experience during hypnagogia. Participants who reported more indirect incorporations during hypnagogia than during mind wandering experienced their hypnagogia as being more negative (*t* (43.96) = 2.31, *p* = .026), and reported that they were more focused on uncompleted personal goals (*t* (45.45) = 2.04, *p* = .047).

Dreaming versus mind-wandering reports

To evaluate phenomenological differences between mind-wandering thoughts and hypnagogic dreams, we conducted 11 paired t-tests corresponding to the first 11 questions in Table 1. Questions 12 and 13 are structured differently than 1-11, and as such we analyzed responses to q11 and q12 using a binomial logistic regression and a multinomial logistic regression, respectively. In order to correct for multiple comparisons, while also maintaining high power and controlling the false discovery rate (FDR), we use the Benjamini-Hochberg (BH) method; this permits a less conservative but more powerful approach than Bonferroni correction.[323] Results for the dream versus mind-wandering responses for the 13-item inventory are shown in Table 2. Before corrections, three variables were found to be significantly different between mind-wandering and hypnagogic dreaming: hypnagogia was more freely moving than mind-wandering, mind-wandering was more intentional than hypnagogia, and mind-wandering was more present-focused than hypnagogia. Intentionality and temporality p-values reflect goodness-of-fit of the respective experimental models versus baseline models. Specifically, for temporality, participants shifting from dreaming to mind-wandering were 87.6% more likely to have their thoughts remain in the present compared to a baseline atemporal state (p = 0.011). After multiple comparison corrections for items 1-13, no significance survives but results trend towards significance in line with past literature.

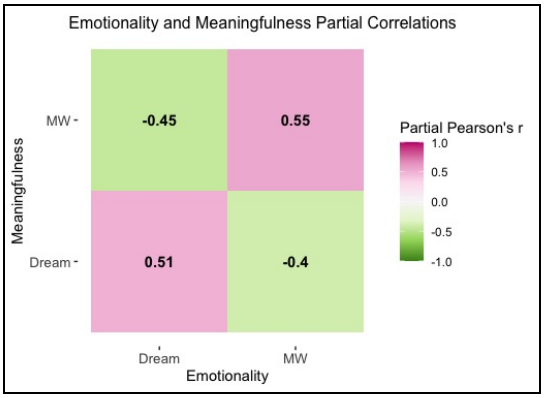
Item	Dream-MW Estimate	Raw two-sided *p*-value	BH Adjusted *p*-value
Freedom of thought flow	0.3125	**.018**	.137
Intentionality*	N/A	**.027**	.137
Temporality*	N/A	**.032**	.137
Words	-0.2375	.138	.445
Unusualness	0.1750	.171	.445
Current concerns	-0.1625	.334	.652
Novelty	0.1250	.430	.652
Emotionality	-0.1250	.438	.652
Negative valence	-0.1000	.465	.652
Images	0.0625	.518	.652
Meaningfulness	-0.1000	.552	.652
Topical shifts	0.0500	.726	.753
Positive valence	0.0375	.753	.753

Table 2 Results for the dream versus mind-wandering responses for the 13-item inventory are shown in Table 2. **p*-values come from logistic regression goodness-of-fit tests, not paired *t*-tests

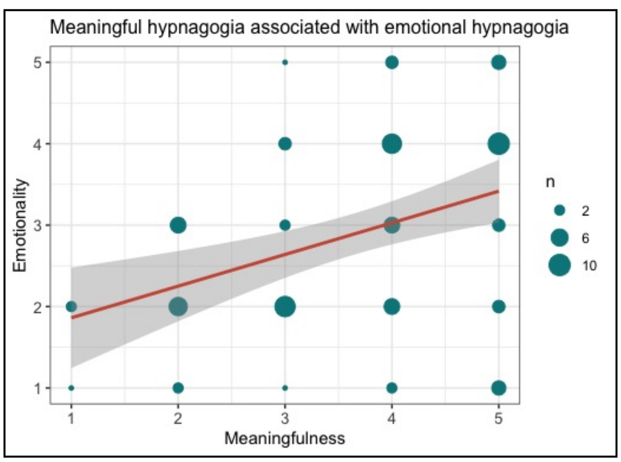
Correlations

We ran partial Pearson's *r* correlations on items 1-11 of the thought probe battery for each condition, in addition to age and number of dreams reported during the hypnagogia task (Supplementary Materials: Table A). Items 12 and 13 of the thought probe battery were not included as they were not continuous or ordinal in structure. Of note, higher emotionality of thoughts is associated with higher meaningfulness of thoughts within each condition ($\text{Meaningful}_{dream}$~$\text{Emotional}_{dream}$: $r = .51$, $p < .001$; Meaningful_{MW}~Emotional_{MW}: $r = .55$, $p < .001$). However, across conditions, higher emotionality correlated with lower scores of meaningfulness ($\text{Meaningful}_{dream}$~$\text{Emotional}_{MW}$: $r = -.40$, $p = .002$; Meaningful_{MW}~Emotional_{dream}: $r = -.45$, $p < .001$). This suggests further functional differences between the states of hypnagogic dreaming and mind-wandering, given within-condition mechanisms of emotionality, but inverse relationships across conditions (Figure 1). Additionally, the unusualness of dreams significantly correlated with the novelty of the content of dreams (*r* = .43, *p* = .005), but such a relationship was not seen within mind-wandering (*r* = .22, *p* = .10), implying perhaps that as novel thoughts are formed, there is inhibition of unusual thoughts in waking, but a lack of such inhibition in dreaming. Number of dreams reported was also significantly correlated with the novelty of the content of dreams (*r* = .31, *p* = .019), suggesting a relationship between how novel and how memorable a dream is. We also found that as age increased, participants tended to experience more vivid dreams (*r* = .28, *p* = .035), but less vivid mind-wandering thoughts (*r* = -.30, *p* = .023).

(a)



(b) **(c)**



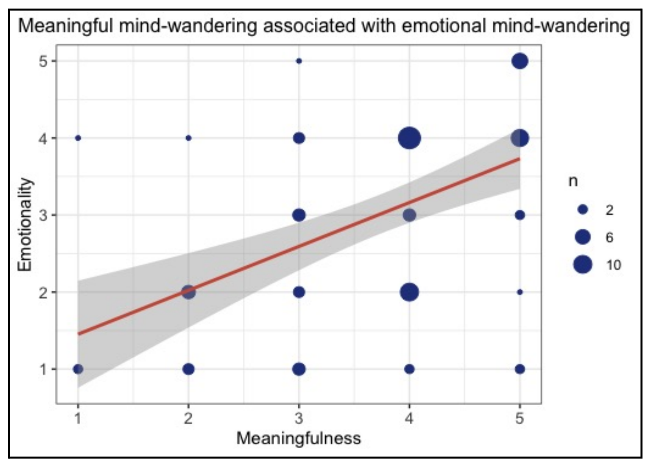


Fig. 1: Emotionality and meaningfulness correlations between and within conditions. **(a)** Heatmap displaying emotionality and meaningfulness are positively correlated with one another within each condition (e.g., dreaming emotionality positively associated with dreaming meaningfulness), but negatively correlated across conditions (e.g., dreaming emotionality negatively associated with mind-wandering meaningfulness). **(b)** Scatter plot of ratings for meaningful hypnagogic dreams against emotional hypnagogic dreams (*r* = .51, *p* < .001). **(c)** Scatter plot of ratings for meaningful mind-wandering thoughts against emotional mind-wandering thoughts (*r* = .55, *p* < .001).

Computational comparisons of dreaming versus mind-wandering reports

Dream reports have trending but insignificantly less temporal coherence than mind-wandering reports (p=.057). Coherence interacts with condition to predict cue-centrality (how semantically-similar to the prompt each report is), where dream coherence significantly but negatively predicts the prompt centrality (r = .033, p = .04) while mind-wandering positively, but insignificantly, predicts the prompt centrality (r =.013, p=0.19).

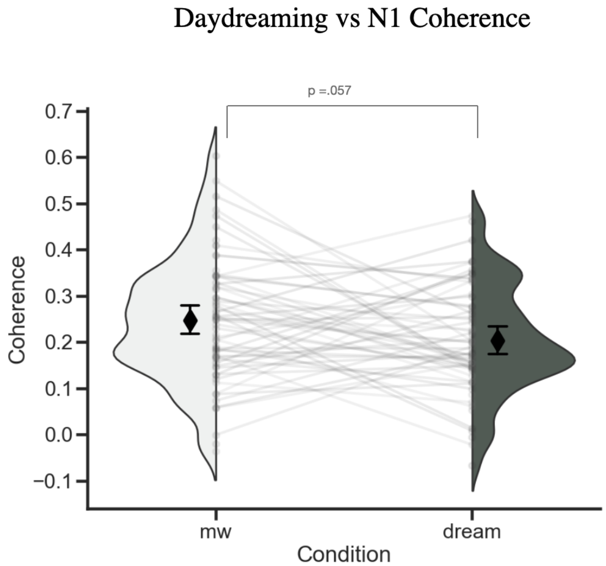


Figure 29 Computational measures of coherence were trending but insignificantly different (p=.057) between Daydreaming and N1

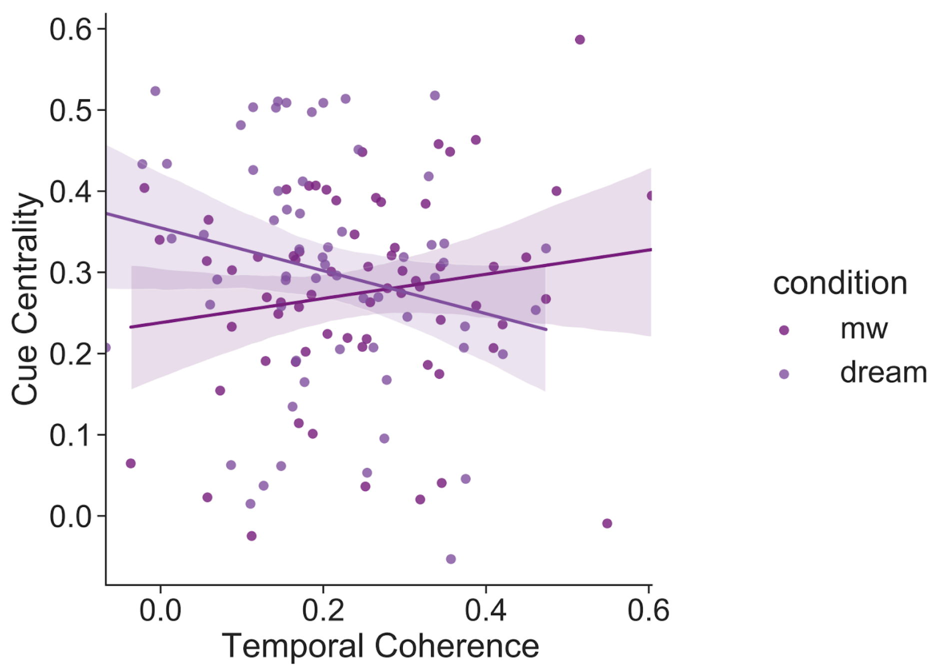


Figure 30 Coherence interacts with condition to predict cue-centrality where dream coherence significantly negatively predicts the prompt centrality (r = .033, p = .04) while mind-wandering insignificantly but positively predicts the prompt centrality (trending in the positive direction; r =.013, p=0.19).

Discussion

Our experiment applied the Dormio web interface to both systematic induction of mind-wandering *and* dream content, allowing for a controlled comparison of these brainstates. The primary question investigated here is whether we can incubate hypnagogic states, and further compare them to waking states, using a hardware-free, mobile and essentially cost-free system. We found that we can. Participants reported direct incorporation of cues into dreams as well as mind-wandering content. Comparing incubated dreams with incubated mind-wandering, we found partial correlations which indicate phenomenological differences between hypnagogia and daydreaming in ratings of meaningfulness, emotionality and vividness in line with recent research.[312] Computational semantic analyses provide further support for a difference in phenomenological experiences between conditions, wherein daydreams and N1 dreams exhibit relationships between coherence and cue centrality in opposing directions. These differences suggest possible functional differences between hypnagogia and mind-wandering, as past literature suggests phenomenology reflects function in dreams.[173] Yet importantly, we also find similarities across both states, for instance a significant positive correlation between the number of direct incorporations and bizarreness of thought across N1 and daydreams.

We offer a novel and successful method of dream research that can be applied remotely and cheaply, and corroborate previous research in finding both experiential differences and similarities between hypnagogia and daydreams. We also report significant correlations between a number of incorporations of the cue into dreams and the phenomenological content of these dreams in terms of imagery, bizarreness and meaningfulness. In the future, such correlations could be used to create a scale of 'incubatability' wherein the reported characteristics of an individual's dreaming could be used to predict whether they are a good candidate for TDI, much like the 'hypnotizability' scale used for hypnosis.[324]

How can such a system help us reframe the purported links between dreams and daydreams and their respective benefits? The early mind-wandering cognitive science literature focused largely on detrimental effects of inattention on cognitive performance and mood.[325] This was a view of mind-wandering which assumed that a failure of attention implies a lack of ongoing functional processing, as in the case of 'mindless reading' when the eyes scan sentences without effectively intaking written information. [84] [85] Yet newer literature argues against this notion and emphasizes instead possible benefits of inattentive mind wandering for creativity, future planning, and memory consolidation – likewise recently suggested to benefit from nighttime dreaming. [86,87] This work informs a more complex view of mind-wandering and dreaming, suggesting that across both states there are benefits accrued in time spent with incomplete cognitive control. We have presented our results in poster form at the 2022 meeting of the Society for the Neuroscience of Creativity (Figure 31).

In the future, we should corroborate these findings with neuroimaging data, and dive deeper into the complex links between phenomenology, neurophysiology and function of daydreams and dreams. Experimentation examining the relationship between anxious ruminative mind wandering, current concern related mentation at sleep onset, and idiopathic nightmares could help us understand how intrusive memories enter our thinking across the circadian cycle. Intervention experiments which incubate mind-wandering content and aim to ameliorate rumination at sleep onset could serve as nightmare reduction strategies, while incubation of creative problems during daytime mind-wandering might enable task-relevant mind-wandering over 24 hours. There is so much to know about how our thinking evolves outside of the attentional spotlight, in the shadow of daytime and the dark of night. We hope that this new form of Targeted Dream Incubation, without the need for complex and costly sensors, enables a host of new studies on the 24-hour mind.

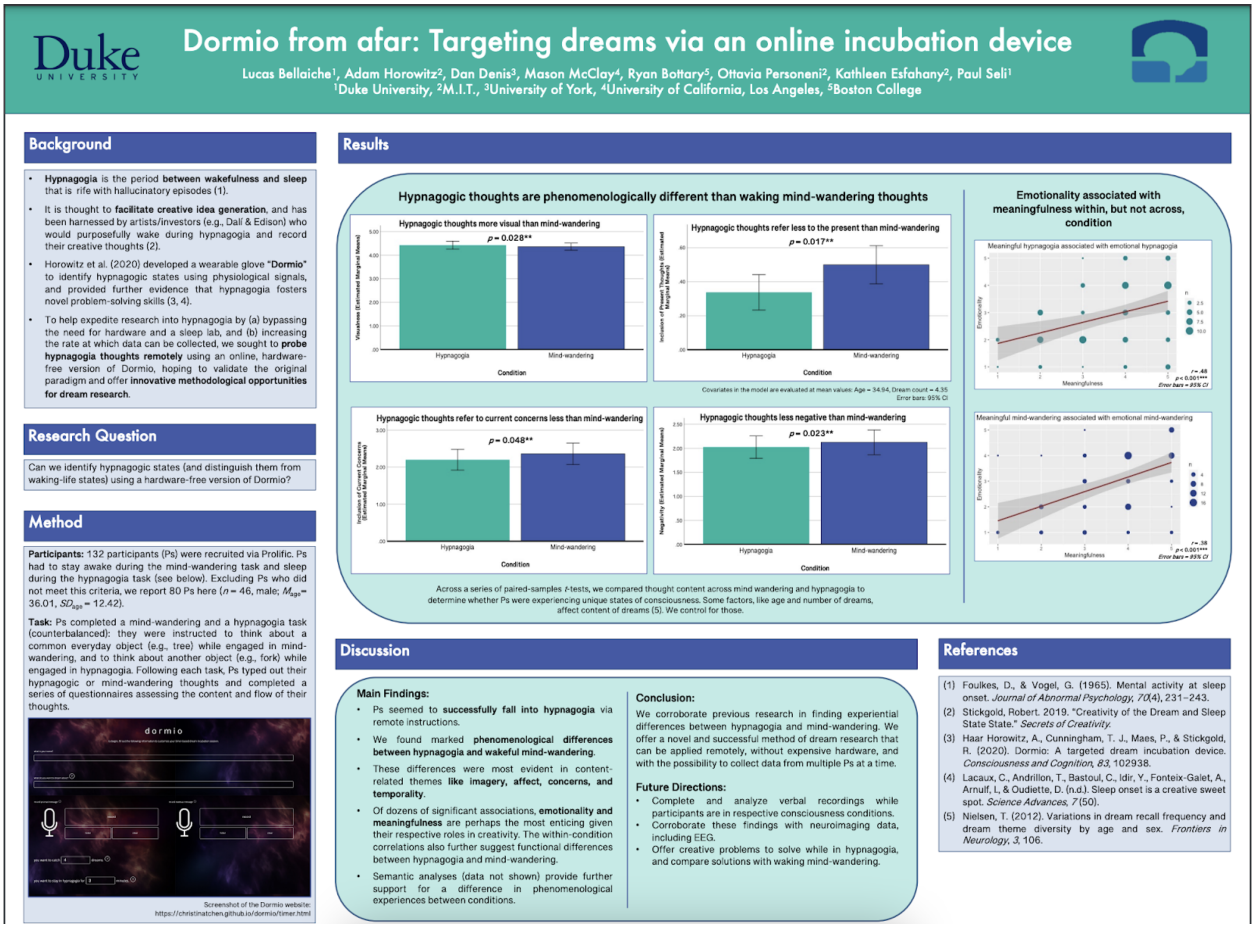


Figure 31 Poster on Experiment 2 presented at Society for the Neuroscience of Creativity 2022 (SfNC), and the International Association for the Study of Dreams 2022 (IASD). Poster from Professor Paul Seli and Lucas Bellaiche (Duke University)

Chapter 5: Locus of Control (Experiment 3)

Summary

This experiment investigates the potential for induction of dream content to change waking sense of self-efficacy. In Experiment 1,[277] we found that subjects performed more creatively after having incubated dreams using the Dormio system, and further that a period of sleep led to pre vs post increases in self-assessment of creative capacity and cognitive flexibility compared to a period of wake. This suggests a shift in *creative self-efficacy* (the degree to which one thinks one is creative) and is interesting insofar as creative self-efficacy significantly predicts the degree to which subjects in fact *are* creative.[326] High creative confidence correlates with reduced self-censorship and increased cognitive flexibility.[327] How is it that seeing one's own cognition in dreams enables an altered sense of one's own capacity? The answer may be that one's dreams are recognized as an aspect of oneself, but not a self one entirely knows--dream characters can surprise us or reveal unseen solutions even though they *are* us--and as such they can change who we think *we* are.[12,328] Experiment 3 aims to take advantage of this capacity of dreams to shift self-concept, aiming to induce changes in subjects' degree of dream-related self-efficacy (also called dream locus of control, DLOC). We show here that experiencing successful TDI can cause a shift in the degree to which a subject thinks of themself as in control of their dreams (a significant increase in DLOC). As there is existing research suggesting a correlational relationship between increased DLOC and reduced nightmare distress in the clinical context, we are hopeful that successfully shifting DLOC can cause a shift in mental set related to the generation or interpretation of disturbing dream content in therapeutic contexts.

Note: This study was designed and analyzed in collaboration with Kathleen Esfahany (MIT), Westley Youngren (University of Kansas, Veterans Affairs Finger Lakes Healthcare System), Michelle Carr (University of Rochester Medical Center), Pattie Maes (MIT), and Robert Stickgold (Harvard Medical School). We also thank Antonio Zadra (UMontreal) for feedback on experimental design.

Introduction

Chronic and repeating nightmares are one of the most distressing and treatment-resistant features of Posttraumatic Stress Disorder, with emotional continuity between the dream and daytime causing debilitating daytime stress.[187] One of the leading treatment options for these nightmares is behavioral therapy with rescripting elements. Rescripting therapies (such as Imagery Rehearsal Therapy and Exposure Relaxation & Rescripting Therapy, IRT & ERRT) focus primarily on rescripting dreams, the process of rewriting a nightmare into a more desirable dream and then reading or rehearsing this new version prior to falling asleep.[329] Rescripting-focused treatment options have produced mixed results, with some studies showing significant reductions following IRT and ERRT [330] while others have shown no significant difference between IRT, ERRT, and active controls.[331] Further, non-initiation of treatment and treatment dropout are key challenges for IRT, specifically amongst combat veterans diagnosed with PTSD. [332] With evidence of varying levels of effectiveness, and the challenge of treatment dropout, research is needed in order to improve the efficacy of rescripting-oriented therapies.

A significant predictor of dropout in imagery rehearsal therapies amongst veterans with PTSD is low perceived treatment credibility. [332,333334] To some subjects, it simply does not seem believable that one could control or rescript elements of a dream. Sleep related beliefs like these are a mediating factor in insomnia and nightmare symptoms. Recent clinical trials have shown that therapeutic targets including faulty beliefs and attitudes about sleep are responsive to treatment and can play a key mediating role in reducing insomnia symptoms and in maintaining sleep improvements over time. [335] In veteran populations, for instance, specifically altering feelings of helplessness related to sleep has been shown to improve insomnia symptoms and daytime fatigue. [336] But despite increasing recognition of the importance of cognitive factors in the etiology of insomnia, there are few instruments specifically designed to evaluate and alter patient-specific sleep related beliefs relevant for therapy.

One particular avenue of approach lies in altering one's confidence in the ability to control dream content (also referred to as dream locus-of-control, dream self-efficacy, DLOC). Dream self-efficacy is a subset of a larger concept of self efficacy, popularized by Bandura's theory of self-efficacy (1977) that suggests an individual's expectations and perceptions of a task significantly influence the quality of a person's effort at the task, and therefore impacts their ability to perform that task [337]. Dream self-efficacy specifically was first demonstrated by Miller et al (2014), who reported that after a successful completion of a rescripting therapy, individuals' locus-of-control centered around their dreams significantly increased. This aligns with results from Rousseau and colleagues (2018) who demonstrated a significant relationship between nightmare reductions following IRT and perceived dream self-efficacy.[338]

> *"The most frequently cited mechanism of action for IRT's effectiveness was an increased sense of mastery. Sense of mastery is defined as the conviction patients have that they can control their dreams and nightmares; this feeling would be gained through concrete experiences of control"* [338]
>
> Adrienne Rousseau, *Self-efficacy as a Mechanism of Action of IRT's Effectiveness* (2018)[338]

Importantly, situation-specific LOC (e.g., control over work, control over health) is not considered traitlike and stable, but instead can change with new experiences. [339] Research suggests feelings of low locus of internal control are tied to feelings of helplessness, which can aggravate sleep complaints and insomnia symptoms. [340,341] Several studies have explored, with encouraging results, improving locus of control by allowing subjects to control somatic functions through biofeedback training.[342,343]

Insomnia severity, dysfunctional beliefs about sleep, and depressive symptoms are all negatively correlated with sleep self-efficacy.[344] There is evidence that sleep self-efficacy is negatively correlated with anxiety symptoms and positively correlated with subjective sleep quality.[345] A perceived lack of control over nocturnal thoughts and lack of control over sleep is related to higher insomnia symptoms.[346] Alteration of small details in an otherwise traumatic dream, giving participants a sense of control over the dream state, have been shown to alleviate repetitive nightmares in a small case study.[347] In veteran populations, altering feelings of helplessness related to sleep has been shown to improve insomnia symptoms and daytime fatigue [336]. This background research suggests improving a subject's DLOC could impact the effectiveness of a rescripting oriented therapy such as IRT or ERRT. This impact could be seen in a reduction in feelings of helplessness, treatment dropout rates, insomnia symptoms, daytime fatigue, nightmare content, or an increase in perceived treatment credibility.

The key question for this experiment is whether TDI is an effective intervention for modulating DLOC; Can firsthand experience of successful Targeted Dream Incubation (TDI) lead to a first order effect of higher ratings on scales of dream self-efficacy? If TDI is in fact successful at modulating DLOC, it is an easy and fast intervention, and so could be used to modulate sleep related beliefs before treatment begins and hopefully improve both outcomes and treatment dropout rates in therapies such as IRT and ERRT. An exploratory analysis will shed light on second-order effects of TDI on nightmare prevalence and complaints. Direction of causal effect is unclear for much of the research relating IRT and sleep features (i.e. whether IRT efficacy mediates insomnia changes, vice versa, or effects are bidirectional). This experiment, and future work administering TDI before IRT, could help shed light on causal relationships between changes in sleep-related beliefs, dream phenomenology and sleep features.

Methods

We enrolled 25 participants (mAge=31.55, σ=15.08) to participate in a daytime napping study. Participants filled out a pre-experiment survey and were screened for nightmare frequency. 11 of 25 participants qualified for diagnosis of a moderate nightmare disorder.[348] Participants arrived at the laboratory in the afternoon between the hours of 12:00 pm and 4:00pm, optimizing for the postprandial increase in sleepiness. All participants were told the experiment investigated the relationship between rest and cognitive flexibility. After reading and signing consent forms, subjects completed Self-Report Measures 1-6 (described below under **Self Report Measures**). Experimenters remained in the room with subjects, out of sight. All subjects were then asked to put on a sleep mask, the Dormio handworn system, and the Hypnodyne ZMax EEG before lying down and being asked to fall asleep. Upon sleeping, all subjects received a Targeted Dream Incubation protocol incubating the dream theme of a "Tree". Dream reports were collected via serial awakening and post-sleep reports. Ten minutes after their last verbal report, all subjects completed Self-Report Measures **1-6** again, for the purposes of pre-post comparison. Upon completion of these surveys, subjects were instructed to keep and submit a dream journal for 1 week, and to repeat all questionnaires after 1 week.

Sleep was scored using Dormio, as described in Experiment 1, in tandem with a Hypnodyne ZMax EEG. Scoring with two devices allowed for confirmation of sleep staging across sensors: EEG sleep scoring is more widely validated than Dormio and is needed for legitimizing purposes, as this study was meant as a pilot for future clinical trials of TDI in nightmare sufferers. Wireless transmission on the Hypnodyne uses a proprietary protocol to achieve a steady ultra-low 3.5ms latency. Hypnodyne streams two EEG channels, F7 and F8, and both referenced to Fpz, and has an input impedance of 0.8-2.0 Gohm, a sample rate of 256/second and a bandwidth of 0.1-128Hz. This forehead-worn EEG has a smaller footprint than typical polysomnography and is less cumbersome for sleepers to wear. It has been validated in multiple laboratories and proven reliable when compared with gold-standard polysomnography. [237]

Visual scoring of N1 sleep was done according to the AASM Manual for Sleep Scoring.[56] Slow rolling eye movements were defined as regular, sinusoidal with an initial deflection lasting >500ms. An attenuation of frontal alpha in tandem with an increase in 4-7Hz activity was used as an indicator of N1, as well as the presence of vertex sharp waves and occasional K-complex activity. Epochs of 30s were used and awakenings were done after 2 subsequent epochs of N1 sleep were scored.

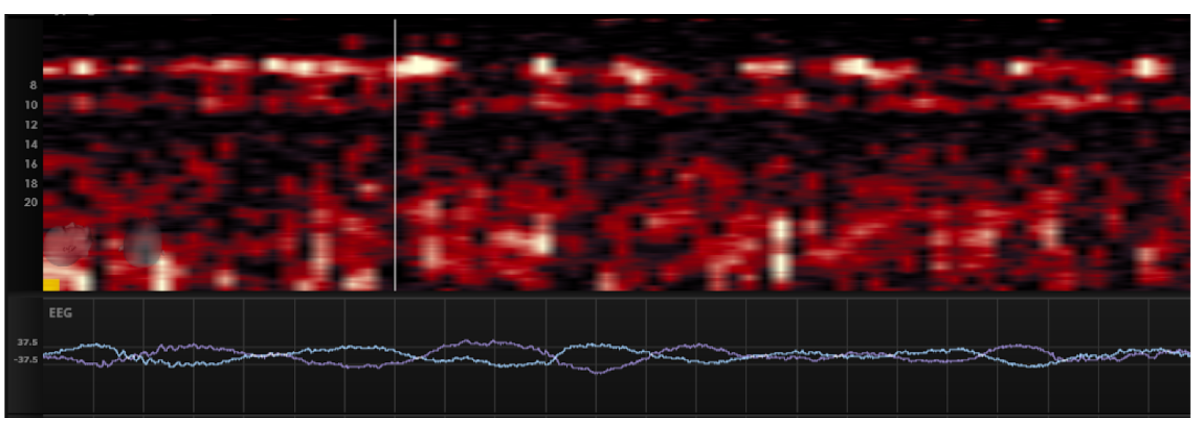


Figure 32 Example of N1 sleep from Experiment 3, Subject 1 as detected via Hypnodyne EEG. Attenuation of alpha rhythm in the red spectrogram (top, 8-20 Hz) coincides with initiation of slow rolling eye movements with initial deflection of >500ms (bottom).

Experimental Protocol

Condition 1, Sleep Tree-Incubation: a prompted hypnagogic nap, using the Dormio system to incubate the dream theme 'Tree'. Upon lying down, the Dormio web app instructs participants to "*think of a Tree*". Once entry into hypnagogia is determined by the system, a variable timer is triggered. This timer instigates wakeups from 1 to 5 minutes after hypnagogia detection, to allow participants an experience of TDI at different depths of sleep. At the end of this timer window, the computer audio alerts participants they are falling asleep ("*You're falling asleep*") and asks participants to verbally report the thoughts they are currently having ("*Please tell me, what's going through your mind*"), and records their verbal response. Once subjects finish speaking, the system asks about their sleep state ("*And were you asleep?*"), to which subjects are instructed to respond 'Awake', 'Halfway' or 'Asleep'. The system then instructs them to think of the dream prompt ("*Remember to think of a tree"*) and to go back to sleep ("*You can fall back asleep now*"). This loop of events is repeated for a total experiment time of 45 minutes, enabling entering and exiting hypnagogia multiple times. At the end of the last loop, the experimenter instructs the participant to wake up fully. TDI methods replicate methods from Experiment 1. [225,277]

Instructions for Condition 1: *"This experiment is investigating the potential for subjects to change the content of their own dreams. Varied imagery, memories, words, or bodily feelings may come up throughout the experiment. The aim of this exercise is to observe them, stay with them, follow them lightly and see where they go. One thing not to worry about is questioning whether you are asleep. This period between sleep and wake feels to some people like sleep, to others just like relaxation or mind wandering. All are completely fine; just watch your mind and relax. Sleep cannot be forced, just allowed. Head towards sleep, but don't worry at all where you are in the process, just relax and let yourself drift toward sleep.*

After you lie down, you will be asked to think of a specific theme. Relax, holding this theme in your mind. A few times you will be told you are falling asleep, and asked to report on your thoughts. These prompts shouldn't wake you up fully. Just stay still when the prompts come. Again, we're interested in your thinking in this semi-lucid period. Whenever you are prompted to report, please just vocally report what was going through your mind before you were told you were falling asleep, and report whether you think you were asleep, by saying either 'awake','halfway' or 'asleep'. You will then be reminded to think about the dream theme, and you can relax and drift back towards sleep."

Self-Report Measures Pre/10-min Post/1 Week Post TDI

1. **Multidimensional Health LOC Scale–Form C (Primary Endpoint)** This scale is widely cited and assesses locus of control related to health outcomes (adapted for dream assessment by Miller (2014). [349]
2. **Dream Self-Efficacy Scale (Rousseau, Belleville 2018)** This scale assesses self efficacy related to dreams and has been shown to increase with successful IRT.
3. **Sleep Self-Efficacy Scale** The Sleep Self-Efficacy Scale served is a significant predictor of multiple insomnia symptoms (Lacks, 1987).
4. **Inventory of Dream Experiences and Attitudes** [350] assesses dream-related beliefs and investigates their relations to waking-state variables.

5. **Credibility/Expectancy Questionnaire** [351]: Used in Cook et. al. (2013) to assess two factors of therapies that aim to alter nightmare content: credibility (three items, e.g., How logical does the therapy offered to you seem?) and expectancy (three items, e.g., How much do you really feel that therapy will help you to reduce your nightmares?). The two factors have high internal consistency and are stable across different populations, including veterans (Borkovec & Nau, 1972).
6. The frequency of nightmares assessed by the **Nightmare Frequency Questionnaire** + **Nightmare Distress Questionnaire** to understand fear of sleep (Krakow et al., 2000).

Statistical Methods

We ran paired two-sided t-tests to evaluate the significance of changes in participants' responses to a collection of both individual questions and composite scores at different points in the experiment. For each comparison across time, we report the mean change and p-value from the two-sided t-test. Subjects completed a collection of assessments at four time points relative to the study: (1) during recruitment for the study, (2) prior to the experiment, (3) directly after the experiment, and (4) one week after the experiment). We refer to these four time points as "recruitment", "pre-experiment", "post-experiment" and "one week post-experiment" in our analysis. Each assessment was given at two or three of the four timepoints bridging the period before and after the experiment (see *Methods* above)

We constructed a composite score for each of the six assessments using the responses to the individual questions for each assessment. For a given assessment, to construct the composite score, we first oriented all of the individual questions such that a positive change in response reflected a positive change in qualitative outcome (i.e. reverse scoring necessary questions). For each subject, at each time point, a mean response was calculated from the responses to the individual questions constituting the assessment. We call this mean response the composite score for the assessment and compare these scores using paired t-tests. This statistical analysis is equivalent to constructing a composite score by calculating a mean difference across two time points from the responses to the individual questions in an assessment, followed by running a one-sample t-test on these mean differences (with a null hypothesis that $\mu = 0$). We follow the primary and secondary endpoint framework for our statistical analysis.[295] Our primary endpoint is the Multidimensional Health LOC Scale composite, the most widely cited assessment of LOC as it relates to health outcomes. Our secondary endpoints, provided to supplement the interpretation of the primary endpoint, include all individual measured dimensions of LOC and other composites which assess downstream effects of changing LOC, i.e. changes in nightmare complaints. For our secondary endpoint analysis, we interpret each result individually, providing uncorrected p-values.[298]

We further ran three regressions to investigate the predictive relationship between different elements of the experiment:

Regression Type 1: We ran a bivariate ordinary least squares regression (with heteroskedasticity-robust estimators) to investigate the predictive relationship between the degree of success of the TDI protocol and the change in responses to questions (assessing topics such as dream locus of control and the credibility of the TDI protocol). We assessed the regressor "degree of success of the TDI protocol" as the number of distinct "tree" references in the post-sleep dream report and the regressand "change in self-efficacy" as the change in participants' responses to assessment questions at different points in the experiment. We use the fitted regression model Y (change in response) = α + 1 X (degree of success of TDI).

Regression Type 2: We ran a multivariate OLS regression (with heteroskedasticity-robust estimators) to gain insight into the predictive relationship of nightmare frequency and the change in self-efficacy.
We quantified the additional regressor "nightmare frequency" as participants' response to "How often do you have nightmares a week?" in the recruitment questionnaire. The other regressor "degree of success of the TDI protocol" and the regressand "change in self-efficacy" were both assessed the same way as in Regression 1. We use the fitted regression model Y (change in response) = α + 1 X (degree of success of TDI) + 2 X (nightmare frequency).
Regression Type 3: We ran a bivariate OLS regression (with heteroskedasticity-robust estimators) to gain insight into the predictive relationship of pre-experiment beliefs about the TDI protocol and the degree of success of the TDI protocol. We quantified the regressor "pre-experiment belief in TDI" as participants' response to "At this point, how much do you really feel this technique will work?" in the recruitment questionnaire. The regressand "degree of success of the TDI protocol" was assessed the same way as in Regression 1. We use the fitted regression model Y (degree of success of TDI) = α + 1 X (pre-experiment belief in TDI).

Results

Dream Incorporation

92% of subjects report direct incubation of the theme "Tree" in at least one N1 dream report.
42% report direct incorporation in the week following the experiment.

Primary Endpoint

The Multidimensional Health Locus of Control composite score, our primary endpoint, increases significantly after a period of TDI (pre vs. post). Composite MHLOC scores increased by 0.52 ($p = 0.027$) directly after a period of TDI (Figure 33). One week post-experiment, the MHLOC composite score maintains a positive shift relative to pre-TDI levels of 0.50 ($p = 0.042$) from pre-TDI levels, similar to the increase seen immediately post-TDI.

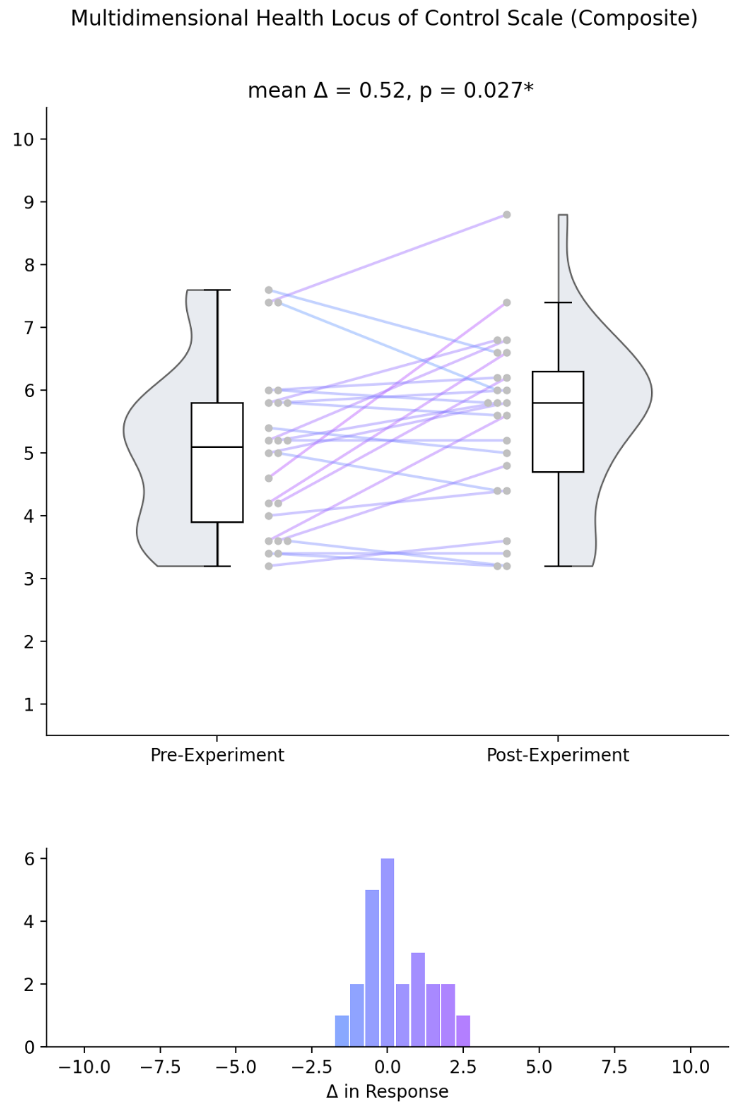


Figure 33 **(Top)** Distribution of composite MH-LOC responses (boxplot, half-violin plot) and individual responses (scatter points) for two time points. Lines connect the scatter points in each time period belonging to the same subject. Line color corresponds to the change in the participant's response, with pink indicating an increase and blue indicating a decrease. (**Bottom**) Distribution (histogram) of changes in response between the two time points, with color corresponding to the lines in the top plot.

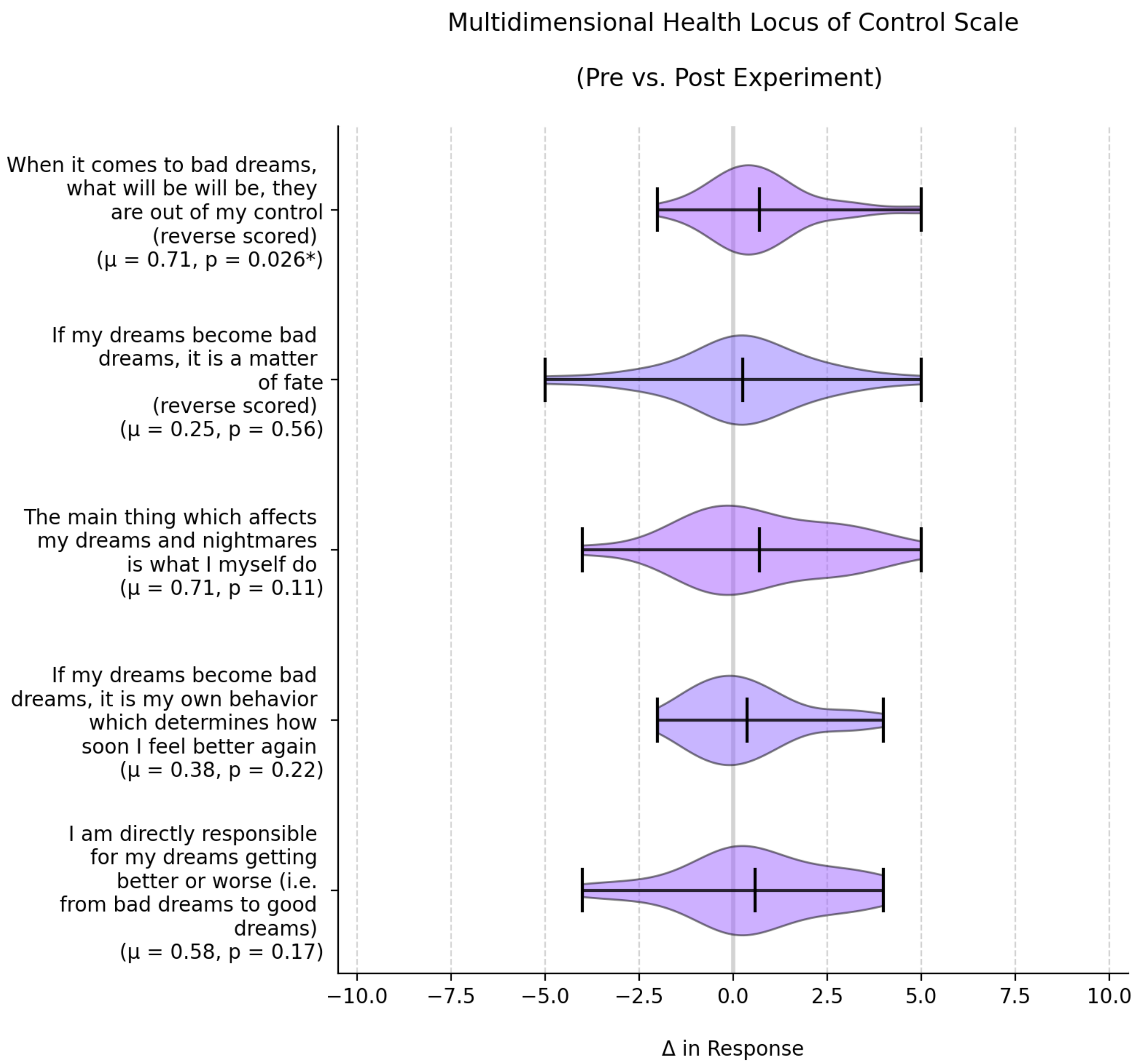


Figure 34 Distribution of delta in response to each component of the adapted Miller (2014) Multidimensional Health Locus of Control composite score. Each violin plot shows the distribution of the change in response directly following the TDI period, with the center lines illustrating the mean change. For each individual component, mean change and p-values from a paired t-test are in the y-axis labels.

Subjects reporting a nightmare frequency of ≥ 1 nightmare/week during study recruitment displayed an insignificant but negative mean change in the composite score between the immediately post-TDI assessment and one week post-TDI assessment, while subjects reporting a nightmare frequency of 0 nightmares/week showed an insignificant but positive mean change on the same metric across the same period (Figure 35).

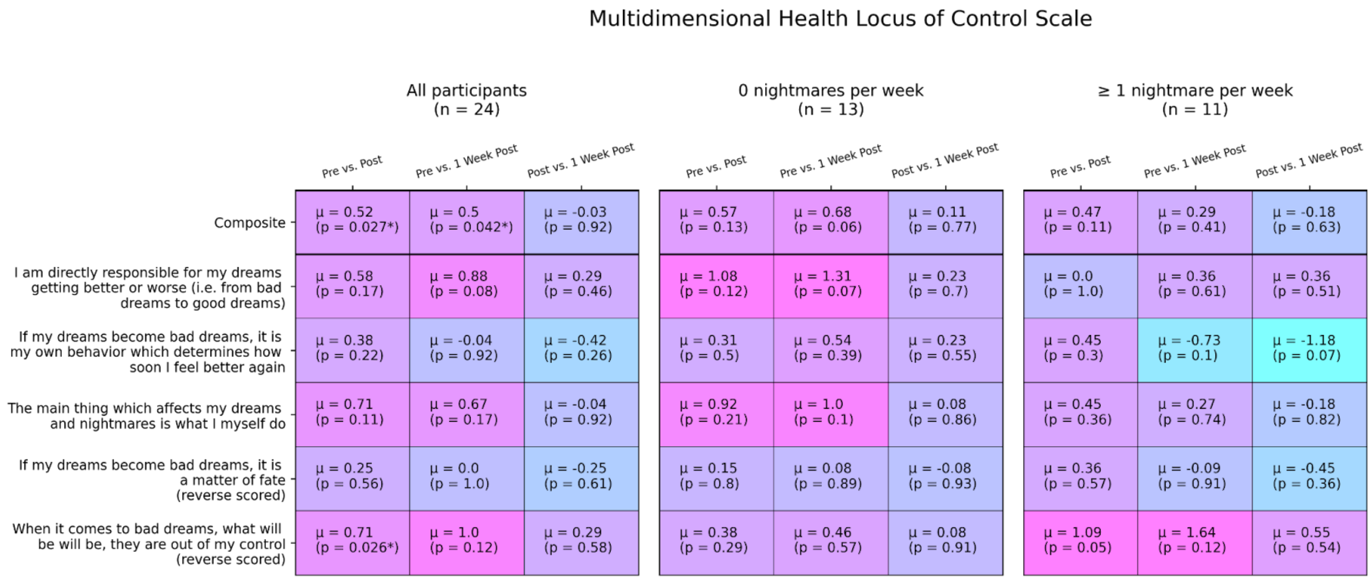


Figure 35. Mean change in response for the adapted Miller (2014) MH-LOC composite and individual questions, separated by nightmare frequency level as measured at recruitment. Color scale goes from purple (indicating positive delta) to blue (indicating negative delta) with saturation indicating degree of significance.

Secondary Endpoints

Secondary endpoints include all composites other than the MH-LOC shown above, as well as their component questions. Analysis of secondary endpoints reveals a more complex picture of our TDI intervention. For instance, while the responses to the Dream Self-Efficacy Scale question, “To what extent do you feel able to control the content of your dreams?”, show a significant positive mean increase of 1.33 (p = 0.03) pre vs post experiment, at 1-week post experiment, most of this gain is lost, with a significant negative mean decrease from post experiment of -0.96 (p = 0.03; Figure 36). Further, while we see significant positive shifts in Locus of Control pre vs. post comparisons, we see insignificant shifts in many of our exploratory composites which might have shown related downstream effects, i.e. the Credibility/Expectancy Questionnaire composite. A comprehensive writeup of all secondary endpoints is outside the scope of this thesis.

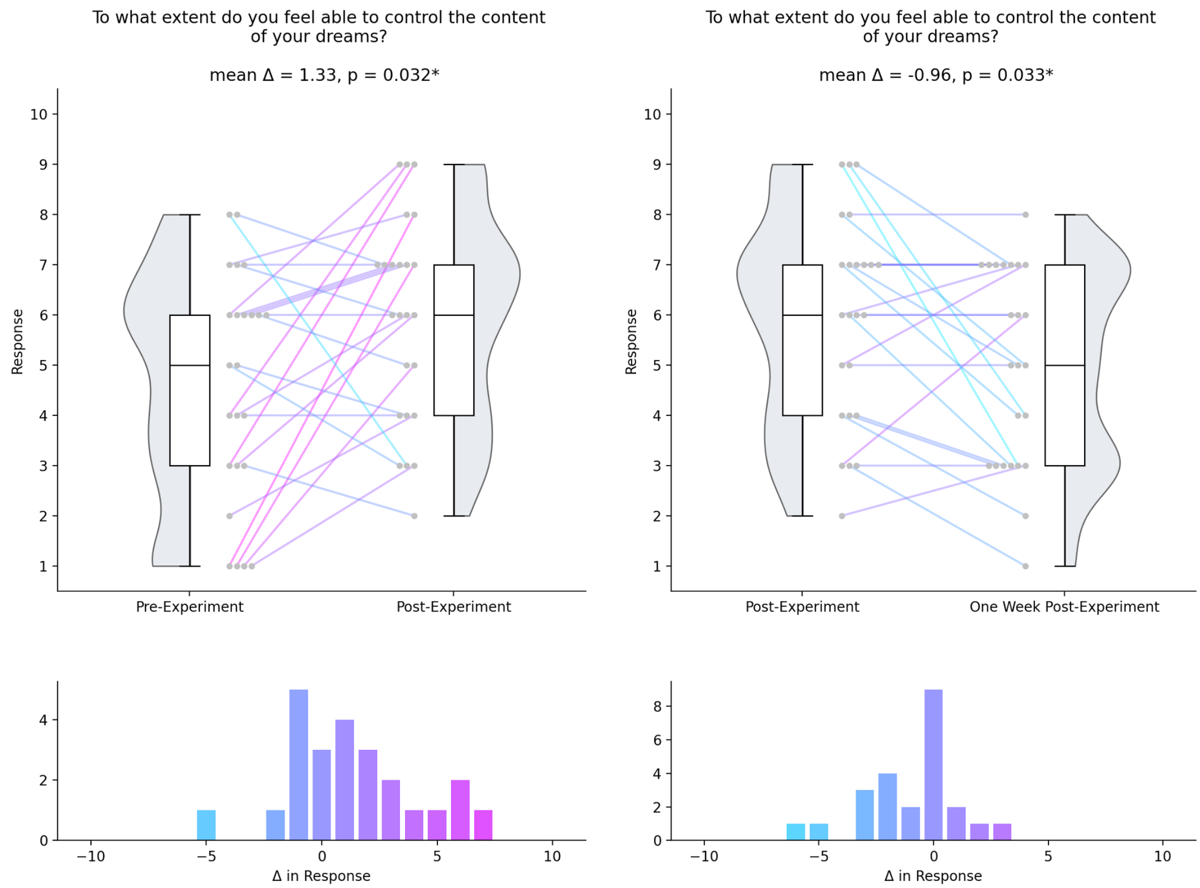


Figure 36 In response to the Dream Self-Efficacy Scale question, “To what extent do you feel able to control the content of your dreams?” participants displayed a significant positive mean increase of 1.33 (p = 0.03) immediately following the experiment. Yet in response to the same question participants displayed a significant negative mean decrease of -0.96 (p = 0.03) one week post experiment as compared to immediately following the experiment.

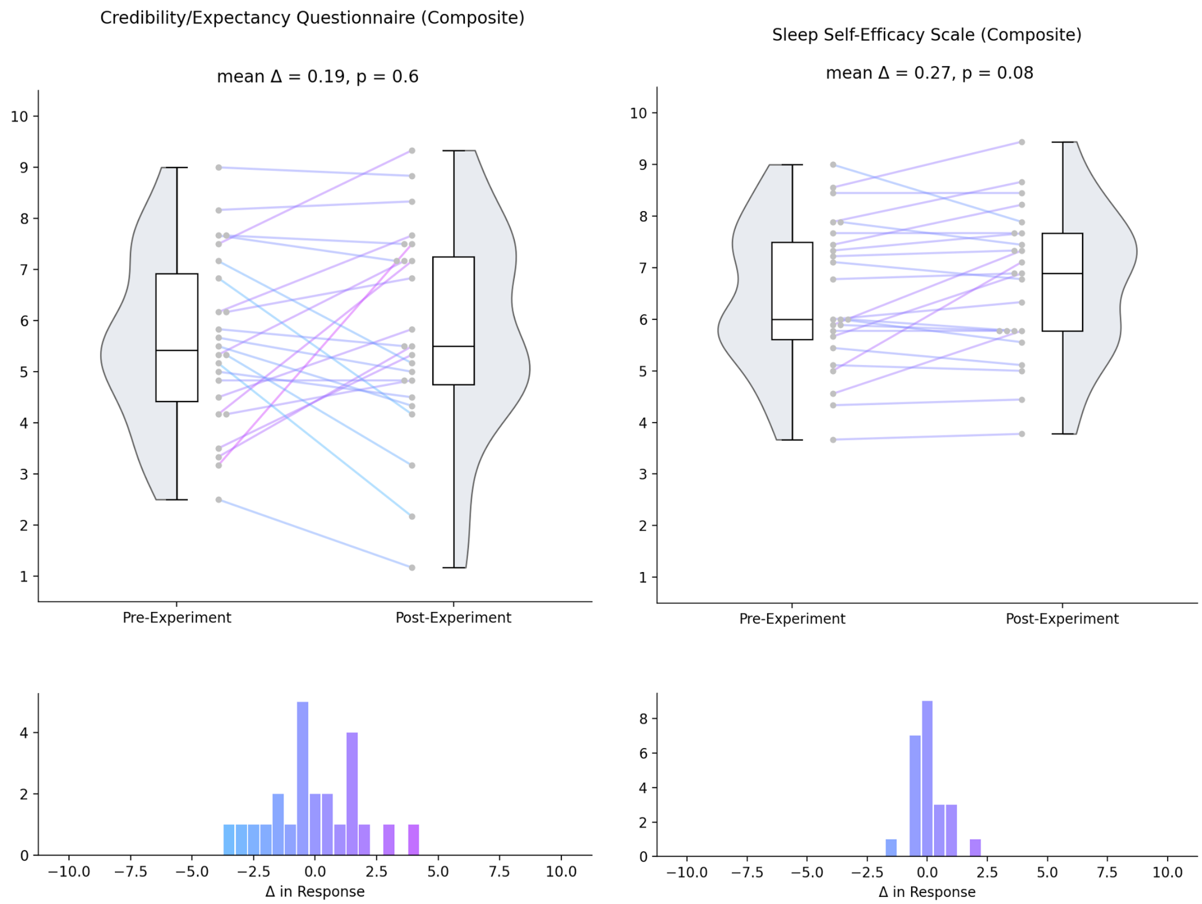


Figure 37 Composite Credibility composite scores increased insignificantly by 0.19 (p = 0.6) after a period of TDI. Sleep Self-Efficacy composite scores increased insignificantly by 0.27 (p = 0.08) after a period of TDI.

Regression Results

Regression Type 1: The degree of success of the TDI protocol is predictive of the change in dream locus of control from the pre-TDI period to both immediately after the TDI period (β = 0.6, p = 0.019, R2 = 0.19) and one-week following the TDI period (β = 0.35, p = 0.041, R2 = 0.12). The success of TDI was more predictive of the change immediately post-TDI than the change one week after the experiment. The degree of success of the TDI protocol is similarly predictive of the change in TDI credibility from the pre-TDI period to both immediately after the TDI period (β = 0.44, p = 0.005, R2 = 0.17) and one-week following the TDI period (β = 0.39, p = 0.004, R2 = 0.16).

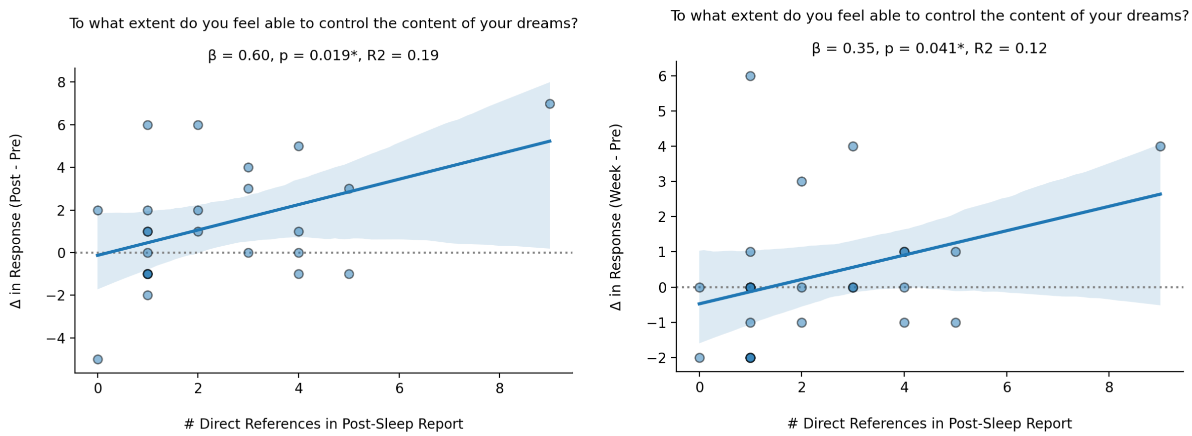


Figure 38 The degree of success of the TDI protocol is predictive of the change in dream locus of control from the pre-TDI period to both immediately after the TDI period (β = 0.6, p = 0.019, R2 = 0.19) and one-week following the TDI period (β = 0.35, p = 0.041, R2 = 0.12).

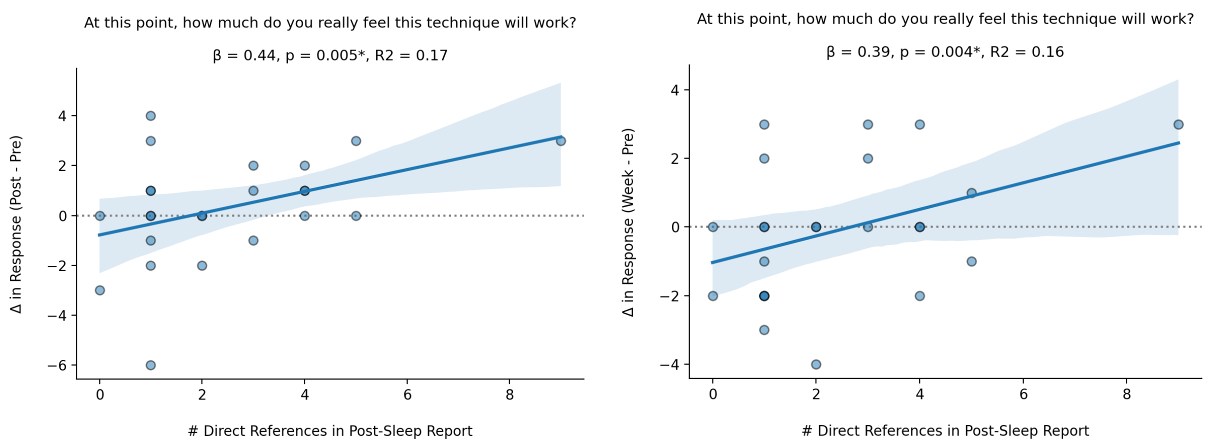


Figure 39 Participants were asked “At this point, how much do you really feel this technique will work?”. The degree of success of the TDI protocol is similarly predictive of the change in TDI credibility from the pre-TDI period to both immediately after the TDI period (β = 0.44, p = 0.005, R2 = 0.17) and one-week following the TDI period (β = 0.39, p = 0.004, R2 = 0.16).

Regression Type 2:

Participants were asked to fill in the Nightmare Distress Questionnaire (NDQ) two times: during study recruitment before the TDI period and one week post-TDI period. For the composite NDQ Nightmare frequency was predictive of change in response pre vs one week post, with subjects experiencing a higher frequency of nightmare occurrence demonstrating a larger beneficial decrease in response (β = -.656, p = 0.002, R2 = 0.329). The degree of success of the TDI protocol was not predictive of the change in response (β = -0.097, p = 0.408, R2 = 0.329). We found significant predictive relationships for two component questions of the NDQ. For “Do nightmares affect your well-being,” the degree of success of the TDI protocol was not predictive of the change in response (β = -0.16, p = 0.5, R2 = 0.19) . Nightmare frequency was predictive of the change in response, with subjects experiencing a higher frequency of nightmare occurrence demonstrating a larger beneficial decrease in response (β = -0.86, p = 0.009, R2 =

0.19) across the recruitment and one week post TDI. Nightmare frequency was also predictive of change in response to "Do you feel you have a problem with bad dreams" with subjects experiencing a higher frequency of nightmare occurrence demonstrating a larger beneficial decrease in response (β = -1.085, p = 0.002, R2 = 0.483). The degree of success of the TDI protocol was not predictive of the change in response (β = -0.033, p = 0.795, R2 = 0.483).

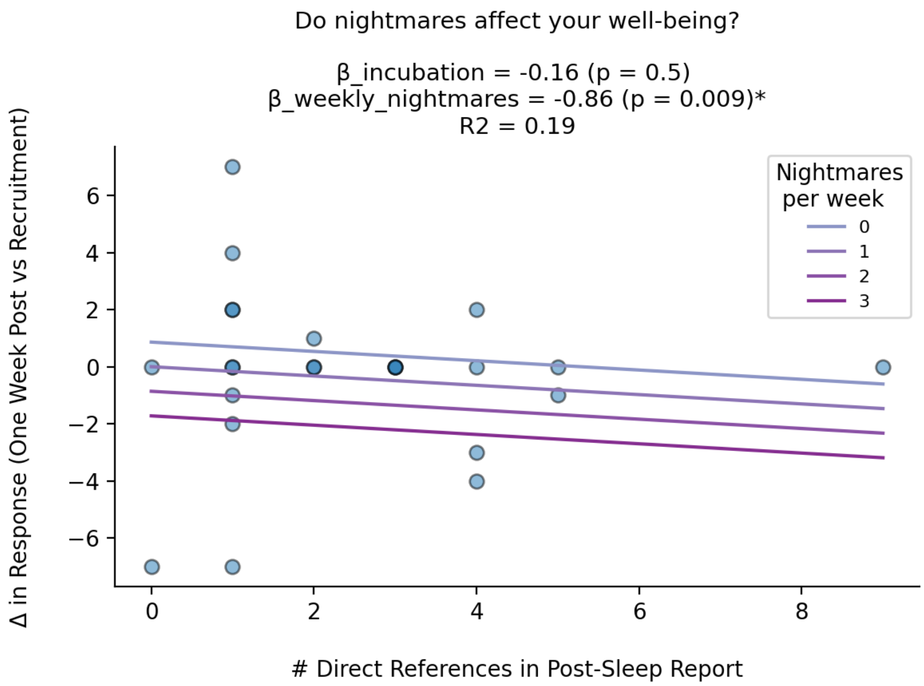


Figure 40 The degree of success of the TDI protocol was not predictive of change in nightmare complaints. Nightmare frequency was predictive, with subjects experiencing a higher frequency of nightmare occurrence demonstrating a larger beneficial decrease in response (β = -0.86, p = 0.009, R2 = 0.19) across the recruitment and one week post-TDI period.

Regression 3

Immediately prior to the experiment, participants were asked "At this point, how useful does the technique offered to you seem?" to evaluate how useful they believed the TDI protocol to be. We regressed the number of direct references to "tree" (the incubated theme in the TDI protocol) in participants' post-sleep reports on their pre-experiment view of TDI. The degree of belief in the usefulness of the TDI protocol is predictive of the degree of success of the TDI protocol (β = 0.39, p = 0.0005, R2 = 0.15).

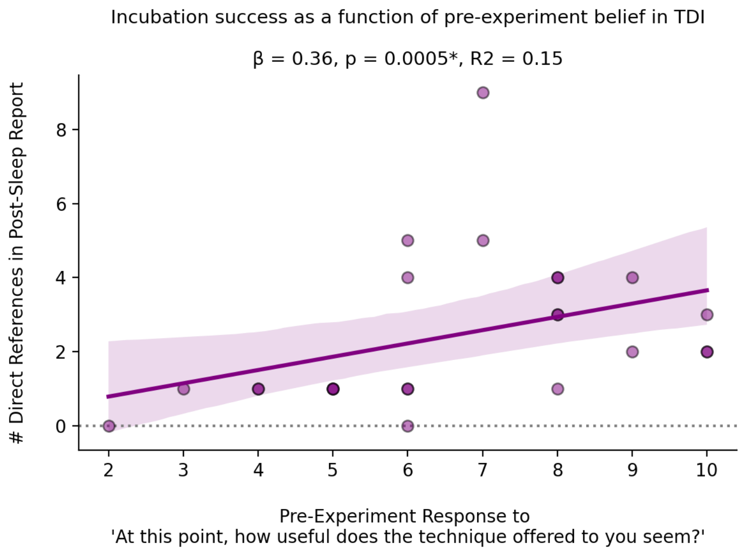


Figure 41 The degree of belief in the usefulness of the TDI protocol is predictive of the degree of success of the TDI protocol (β = 0.39, p = 0.0005, R2 = 0.15).

Discussion

Our experiment suggests Targeted Dream Incubation is an effective intervention for modulating dream related locus of control (DLOC) as measured by the adapted Miller (2014) MH-LOC scale. This effect is specifically mediated by degree of direct incorporation of incubation themes into dreams, wherein more effective incubation increases post-sleep DLOC incrementally. The experience of successfully controlling one's dreams, evidenced in recalled dreams which incorporate chosen themes directly, appears to increase subjective feelings of control over sleep mentation. Effective dream incubation is in turn predicted by high pre-experiment ratings of TDI credibility, suggesting that education regarding TDI could form a crucial part of the TDI protocol in future work.

We see that 1 week after conclusion of the experiment, reduction in nightmare complaints on the Nightmare Distress Questionnaire is predicted by high levels of reported nightmares at recruitment, suggesting TDI is more beneficial to those with more nightmares. While this work was carried out on a non-clinical population, nearly half of our participants qualified for a moderate nightmare disorder based on self-reported nightmare frequency. This is a high proportion of nightmare sufferers for a random sample, suggesting that future studies should take care to control for selection bias as subjects with more nightmares may be more interested in studies that offer techniques to change dream content. Taken as a whole, these data indicate TDI has potential additive benefit when included with cognitive behavioral therapy for insomnia (CBTi) and Imagery Rehearsal Therapy (IRT) programs for common nightmare sufferers. TDI is an easy and fast intervention, and could be used to modulate sleep and dream related beliefs before IRT or CBTi treatment begins and improve both outcomes and treatment dropout rates in therapies.

Research shows that perceived lack of control over dreams and lack of control over sleep is related to higher insomnia symptoms, while therapies altering feelings of helplessness related to sleep have been shown to improve insomnia symptoms and daytime fatigue. [336] We extend this research and offer an effective intervention for modulating dream related beliefs to improve feelings of control over dreams and reduce nightmare complaints. This research thus suggests improving a subject's DLOC via TDI could impact the effectiveness of a rescripting oriented therapy such as IRT and ameliorate nightmare symptomatology.

Within the context of this thesis, it is interesting to note we see the same proportion of subjects report direct incubation of the theme ‘Tree’ in N1 dreams in Experiment 1, 3 and 4, with statistically insignificant differences between dream incorporations across experiments. This suggests the EEG data used in Experiment 3 and 4 in addition to data from the Dormio device for sleep staging added little to improve incorporation rates. Thus the smaller, cheaper Dormio, or perhaps even the hardware-free Dormio Web Interface would be an appropriate choice for clinical use of TDI for altering DLOC, as it would not be cost-prohibitive for clinicians or patients.

Chapter 6: TDI in REM (Experiment 4)

Summary

This experiment tests whether Targeted Dream Incubation (TDI) can effectively direct specific dream content in REM sleep as well as N1. Participants napped for 30 minutes with serial awakenings in N1 and TDI via audio cues, and then were allowed to sleep until a subsequent REM period occurred (within a 90 minute sleep total opportunity), after which TDI was repeated with serial awakenings from REM and dream reports gathered from REM. A first experimental question here is whether TDI of N1 content will continue to affect dream content as subjects go into REM sleep, as seen in their first REM reports. A second is whether awakenings from REM and subsequent incubation with audio cues in REM sleep inertia will lead to incorporation in subsequent REM dreams.

Wakeup and dream report from the first REM period revealed moderate effect of TDI in earlier N1 on later REM content. Subsequent awakenings from REM revealed a stronger effect of TDI in REM on subsequent REM awakenings. An investigation of Alternative Use Task performance indicates that REM TDI benefits creativity less than the N1 TDI seen in Experiment 1. We are hopeful that extending TDI protocols into REM will enable future work on the varied contributions of dream content across distinct sleep stages to waking cognition. These results are interpreted in light of literature which investigates continuity of dream content across sleep stages and relationship to potential mnemonic functions of dreaming in REM.

Note: This study was designed and analyzed in collaboration with Kathleen Esfahany (MIT), Pattie Maes (MIT), and Robert Stickgold (Harvard Medical School).

Introduction

Work on dream science is complicated by the fact that dream scientists do not agree on what a dream is.[352] One classic view suggests REM sleep is “the physiological concomitant of the subjective experience of dreaming” and suggests dreaming should be defined largely by sleep stage.[353] In this view, dreams are mental experiences that happen in REM sleep and NREM dreams are aberrations. However, recent research suggests that although there is an important link between REM sleep and dreaming, they are in fact doubly dissociable states; REM can occur without dreaming and dreaming can occur without REM.[352] For instance, dopaminergic agents increase the frequency, vivacity, and duration of dreaming without similarly affecting the frequency, intensity and duration of REM sleep while damage to ventromesial frontal fibers obliterates dreaming but spares the REM cycle. [354,355] Research which aims to discriminate sleep stages based on their dream reports has had varying degrees of success. Dream reports from REM are typically longer than those collected from other sleep stages but both Foulkes (Foulkes & Schmidt 1983) and Antrobus (1983) found that when length of report was statistically controlled, qualitative differences diminished and often disappeared.[356] This research runs into another sticky issue; Definitions drive analyses. In a summary of 25 studies of mentation recall from REM and NREM sleep over 5 decades, the common definition of what a dream is drives the data that experimenters choose to report (Figure 42), which in turn makes for biased analyses.[357]

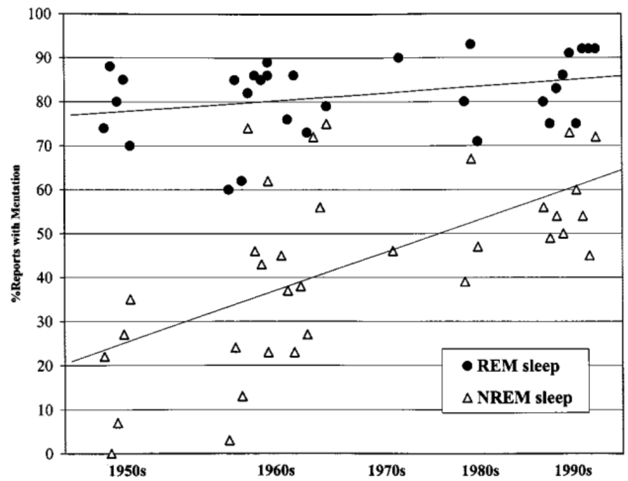


Figure 42 Summary of 35 studies of mentation recall from REM and NREM sleep over five decades. The percent of verbal reports whose cognitive content after awakenings from NREM sleep was characterized as a dream increased from the 1950s to the 90s, whereas the comparable percentage of awakenings characterized as a dream from REM awakenings remained relatively constant. This difference is likely due to the widespread implementation in the 60s of more liberal criteria in defining 'dreaming'. Image credit Nielsen (2000). [357]

In part, we can distinguish sleep stages based on physiology, phenomenology and function. REM sleep is physiologically distinct from late stage NREM sleep, with higher frequency EEG activity than NREM and particularly increased theta oscillations.[358] REM sleep is linked to increased insight and creativity over and above NREM sleep,[5] with dream imagery described as hyper-associative and metaphorical.[359] REM sleep is specifically functionally involved in emotion regulation, and intense negative dreams in REM can interfere with this function and cause distress in waking life. [360,361] Positive dreams in REM may have the inverse effect, associated with improved sleep quality and subsequent mood.[70] One recent study suggests that TMR during REM is specifically effective for emotional memories, and can significantly decrease subjective arousal in wake related to negative stimuli.[362] Hinting at differing mnemonic functions across sleep stages, a recent meta-analysis of 91 experiments reactivating memories which are largely not emotionally laden found that TMR is effective when administered in N2 and N3 but not significantly effective in REM.[243]

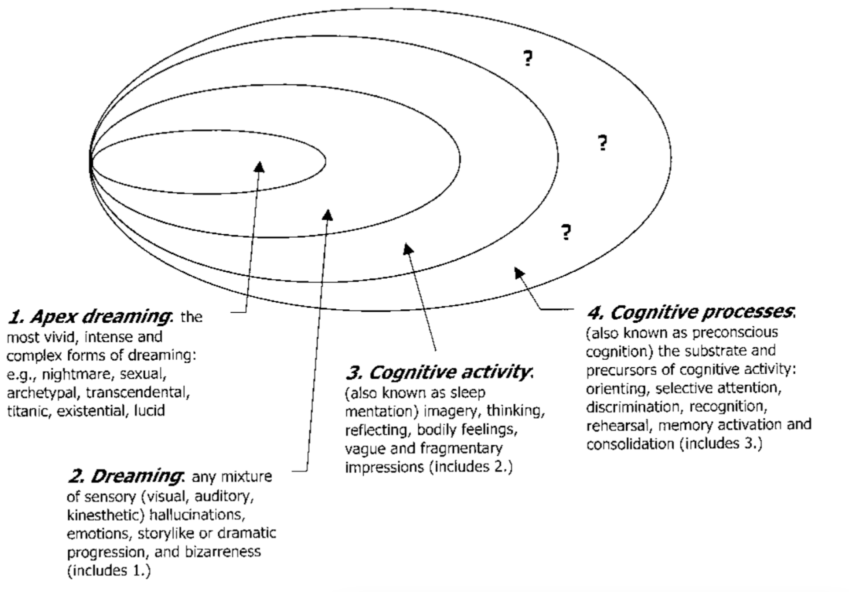


Figure 43 Four levels of specificity in defining sleep mentation. With an increasingly specific definition of sleep mentation, differences between REM and NREM mentation become more apparent. The two most specific levels (1 and 2) tend to occur much more exclusively in REM sleep. Cognitive activity (3) other than dreaming is predominant in NREM sleep. Beyond cognitive activity, there is likely an even more general level of cognitive processes (4) that consists of preconscious precursors to cognitive activity and that may be present in different degrees throughout REM and NREM sleep. Figure from Tore Nielsen. [357]

Differences are less clear when we consider the NREM1 (N1) and REM sleep stages. N1 mentation is remarkable because it can equal or surpass in frequency and length of mentation from REM sleep. [363,364] Moreover, much N1 mentation (from 31–76% depending upon EEG features) is clearly hallucinatory dreaming as opposed to isolated scenes, flashes or non hallucinated images. [352,364] Points of view differ as to whether scientists consider all NREM sleep mentation, including N1, to stem from imagery processes that are fundamentally the same as or different from those that produce REM sleep mentation. Foulkes's 1-gen model – the most influential – stipulates that mentation report from REM and NREM sleep arise from the same processes: (1) memory activation, (2) organization, and (3) conscious interpretation and the availability of diverse memory elements, not sleep stage physiology, determines the form of sleep mentation.[363] As part of his NEXTUP model, Stickgold proposes that in N1 "what's happening is that these thoughts are being tagged with some sort of label so, once you are in deeper sleep, the brain can ensure that important information is put into memory." [365] If this is indeed the case, and we accept that dreams are a legitimate window into underlying processing ongoing in sleep, studies which examine *both* N1 and REM dreams offer a window into overnight memory evolution. A TDI protocol which affects REM and N1 content could further research into mnemonic and affective processing over varied sleep stages.

Past efforts to influence REM dream content have largely relied on affectively laden stimuli; as REM sleep is functionally tied to emotion processing, it is sensemaking that REM dreams are preferentially sensitive to incorporating current concerns. Klinger, and Barta (1981), for example, had subjects list their current concerns and throughout the next three nights presented them with tape-recorded concern and nonconcern stimuli during Stage 2 and REM sleep.[366] The stimuli, consisting of one or two words derived either from the subject's own concerns questionnaire or from another's questionnaire, were presented (without inducing arousal) shortly before each awakening. Results revealed that concern stimuli were incorporated into REM sleep significantly more often than were non-concern stimuli. Cartwright (1974) analyzed the REM dreams of subjects who, as they fell asleep, repeated aloud to themselves a conscious wish to be more like their ideal selves. In this study, a judge found "some evidence of the target word or its opposite being descriptive of the dream characters in one or more of their REM reports" for 15 of 17 subjects.[207]

It's not clear, though, whether these pre-sleep incubations are altering dream incorporation or simply experimenters are collecting naturally occuring dreams of current concerns. Bisson (1994) asked 16 subjects to write about their current concerns for 25 minutes prior to sleep, formulate a dream incubation question about a concern, and repeat that question to themselves before falling asleep.[367] In this exploratory study, independent judges found that at least one of subjects' three major concerns were incorporated into most dream reports, but incorporation of the incubated concerns was not reliably more frequent than that of the non-incubated concerns; it appears that concerns affect REM content regardless of incubation protocol. A study by Griffin and Foulkes (1977) found similarly that presleep incubation of the current concerns of one's peers, as opposed to one's own concerns, does not significantly influence dream incorporation.[368] It appears that conscious presleep incubation of dream content is not a reliable method for incubation of REM dream content.

Clearly a novel methodology is needed to incubate REM dreams without relying on current concerns of experimental subjects. The currently used methodologies do not enable controlled study of REM dreams, as current concerns vary greatly across subjects. A more controlled methodology for incubation will enable experimental insight into REM-related emotional processing and memory evolution, as well as continuity of dream content across sleep stages. We propose Targeted Dream Incubation in REM as a tool for incubation of stimuli which is not restricted to subjects' current emotional concerns.

Methods

We enrolled 15 university students (mAge = 21 +/- 2) to participate in a daytime napping study. Participants arrived at the laboratory in the afternoon between the hours of 12:00pm and 4:00pm, optimizing for the postprandial increase in sleepiness. Three subjects were excluded from analyses for a) failure to fall asleep or b) failure to follow experimenter instruction. Subjects were given a consent form to read and sign and were told the experiment investigated the relationship between rest and cognitive flexibility. After reading and signing consent forms, subjects were fitted with the Hypnodyne ZMax headworn EEG. Sleep opportunities totalled 90 minutes, and subjects were awakened 2 or 3 times from REM, depending on time constraints.

All subjects begin the experiment with TDI in N1, using the Dormio system to incubate the dream theme 'Tree'. Upon lying down, the Dormio instructs participants to "think of a Tree". Once entry into hypnagogia is determined by the system, a variable timer is triggered. This timer instigates wakeups from 1 to 5 minutes after hypnagogia detection, to allow participants an experience of different depths of sleep. At the end of each timer window, the computer audio alerts participants they are falling asleep ("You're falling asleep") and asks them to vocalize the thoughts they are currently having ("Please tell me, what's going through your mind"), and recorded audio. Once subjects finish speaking, the system asks about their sleep state ("And were you asleep?"), to which subjects respond 'Awake', 'Halfway' or 'Asleep'. The system then instructs them to think of the dream prompt ("Remember to think of a tree") and to go back to sleep ("You can fall back asleep now"). This loop of events is repeated for a total time of 30 minutes, enabling entering and exiting hypnagogia multiple times, after which participants are given an additional 90 min sleep opportunity. When two contiguous epochs of REM are scored, the computer audio asks participants to report the thoughts they are currently having ("Please tell me, what's going through your mind"), and records audio of responses. Once subjects finish speaking, the system repeats the dream prompt ("Remember to think of a tree") and lets subjects return to sleep. Detection of subsequent REM (two contiguous epochs) triggers collecting a REM dream report again, and then playing the dream prompt to incubate the following dream. This process is repeated until the sleep opportunity ends. After the sleep opportunity ends, subjects are awakened and asked to fill in a free-form response reporting all dream content they can remember across the entire session, in order. After this 'post sleep report' is concluded, subjects completed the Alternative Uses Task (AUT). The AUT has been widely validated as a measure of creativity which specifically indexes divergent thinking abilities, namely the ability to broaden representational search space and produce wide ranging responses to queries. Furthermore, task performance is correlated with and predictive of real-world creative achievements.[285,287] For this task, subjects were prompted to"list all the creative, alternative uses you can think of for a tree" and given three minutes to provide written responses. Subjects were explicitly told to be creative. Explicit instructions to be creative have been consistently shown to influence creativity across a wide variety of tasks, including divergent thinking.[288] The AUT task used and method of administration are the same as in Experiment 1.

Sleep Scoring

Sleep was scored using a Hypnodyne ZMax EEG. Wireless transmission on the Hypnodyne uses a proprietary protocol to achieve a steady ultra-low 3.5ms latency. Hypnodyne streams two EEG channels, F7 and F8, both referenced to Fpz, with input impedances of 0.8-2.0 Gohm, a sample rate of 256/second and a bandwidth of 0.1-128Hz. This forehead-worn EEG has a smaller footprint than typical polysomnography and is less cumbersome for sleepers to wear. It has been validated in multiple laboratories and shown to be reliable when compared with gold-standard polysomnography. Visual scoring of REM sleep was done according to the AASM Manual for Sleep Scoring.[56] Rapid Eye Movements were defined as conjugate, irregular and sharply peaked eye movements with an initial deflection lasting <500ms. Low amplitude, mixed frequency EEG, the presence of increased 2-6Hz activity in the form of sawtooth waves, and the absence of large bodily movements were also used as stage REM indicators. Epochs of 30 seconds were used and awakenings were done after two contiguous epochs of REM were scored.

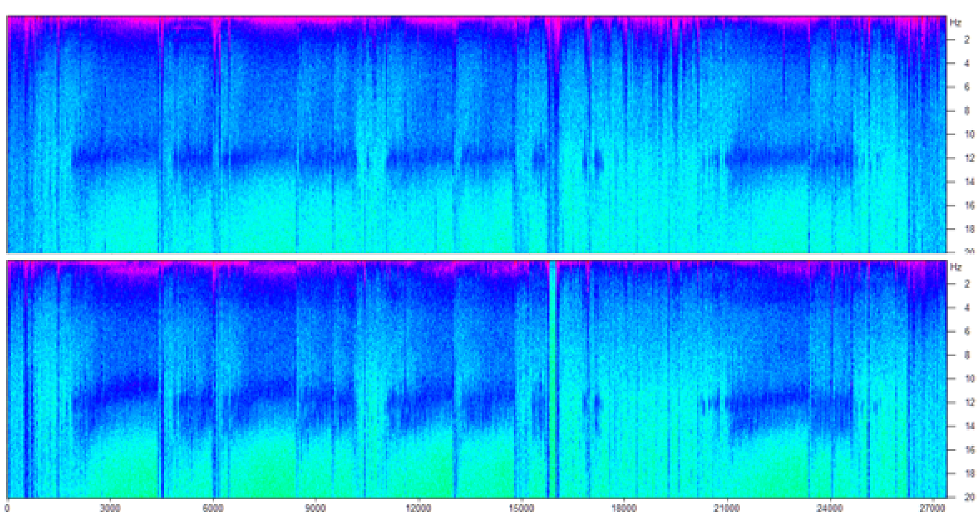


Figure 44 Top: EEG from Hypnodyne channel F7 - Bottom: EEG from F4 lead from standard PSG recording. The Hypnodyne ZMax EEG signal is virtually indistinguishable from EEG signal acquired with gold-standard PSG.

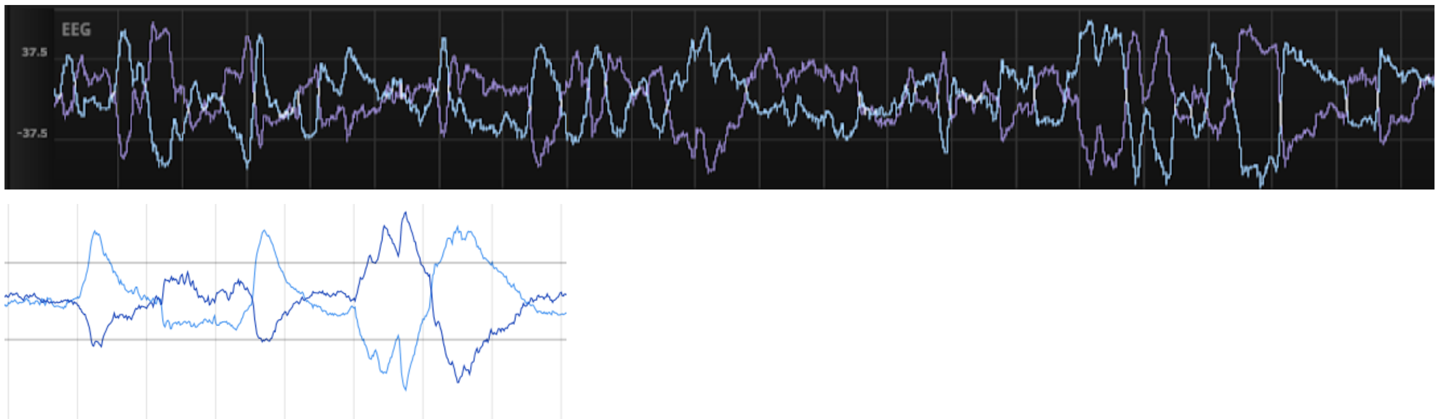


Figure 45 Top: Extraction of eye movement data from ZMax EEG channels, Subject 1, Experiment 4; Below: canonical extraction of eye movement recordings from ZMax data based on the Zmax sleep scoring manual.

Computational Methods for Scoring AUT

Methods replicate those in Experiment 1. Global Vectors for Word Representation (GloVe) is an unsupervised learning algorithm for obtaining vector representations of words.[294] GloVe is trained based on a co-occurrence matrix and outputs word vectors that capture meaning in vector space. Using GloVe, we can predict co-occurrence ratios of words and thus quantify the semantic similarity or distance between two words. GloVe outperforms other similar methods for quantifying semantic similarity, including the commonly used word2vec, on several word similarity tasks.[294] We used a 300-dimensional word vector space from a GloVe model trained on 42 billion tokens and their aggregated global word-word co-occurrence statistics. We calculated the cosine distance between word vectors to calculate semantic distance.

We computationally evaluated semantic distance of post-sleep AUT responses. Semantic distance was evaluated by taking the cosine distance between the GloVe embeddings of the prompt word “tree” and each use case reported by a subject. For use cases given as a multiple-word response (such as “clothes hanger”), the semantic distance was calculated by taking the mean of the semantic distances between each component word in the response and the word “tree.”

Results

REM Reports

8 of 12 subjects (66%) fell into REM sleep and gave at least one REM report (Figure 47). All 8 subjects who were awakened from REM returned to >1 REM period after their awakening as determined by Hypnodyne EEG readings. The remaining 4 of 12 (33%) did not show polysomnographic signs of REM sleep in any part of the experimental period. 6 of 8 subjects who gave REM reports (75%) showed direct incorporation of the dream theme (50% of all 12 subjects). Of the 6 subjects who showed direct incorporation of the dream theme in REM reports, 4 of those showed direct incorporation in their first REM report (67%; an effect of TDI cues given after N1 awakenings earlier in the session) while 5 showed direct incorporations in subsequent REM reports (a combined effect of TDI cues given in N1 and after REM awakenings). Compared to typical dreams of a sample of 1181 university age students as assessed by the Typical Dreams Questionnaire,[369] REM reports showed significantly more direct incorporation of “Tree” than those reported by the TDQ (two tail $p < .001$).

N1 Reports

10 of 12 subjects (83%) showed direct incorporation of the theme "Tree" in N1 dream reports. This proportion is insignificantly different from the proportion of direct incorporation in REM (chi^2=.127, p=.72). Compared to typical dreams of a sample of 1181 university age students as assessed by the Typical Dreams Questionnaire,[369] N1 reports showed significantly more direct incorporation of "Tree" vs TDQ (two tail p < .001).

Post Sleep Reports

10 of 12 subjects include a direct reference to "tree" in their post-sleep report (in which subjects do not distinguish between N1 and REM content). This proportion is insignificantly different from the proportion of direct incorporation in REM (chi^2=.127, p=.72) and N1 (chi^2=0, p=1). Compared to typical dreams of a sample of 1181 university age students as assessed by the Typical Dreams Questionnaire,[369] post-sleep reports showed significantly more direct incorporation of "Tree" vs TDQ (two tail p < .001).

AUT Performance

Mean AUT semantic distance was significantly lower (p=.01) for subjects in the Experiment 4 REM "Tree" TDI condition compared to subjects in the Experiment 1 N1 "Tree" TDI condition (Figure 46).

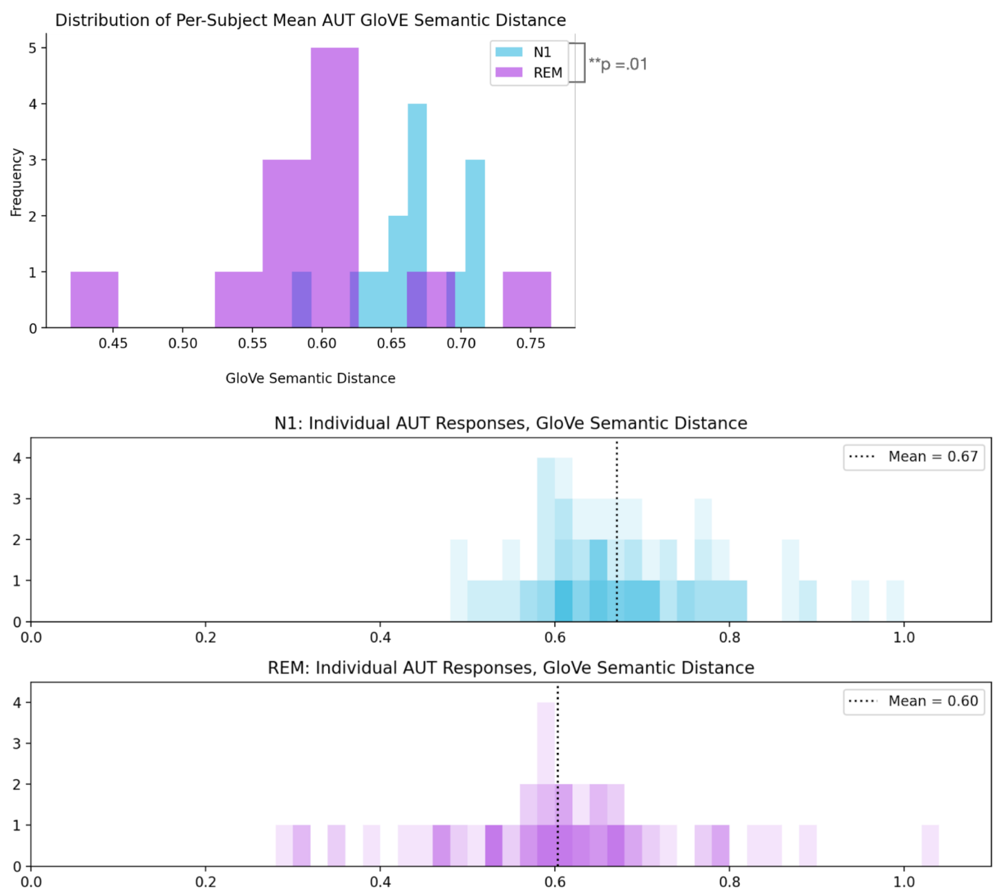


Figure 46 Mean AUT semantic distance was significantly lower (p=.01) for subjects in the Experiment 4 REM "Tree" TDI condition compared to subjects in the Experiment 1 N1 "Tree" TDI condition.

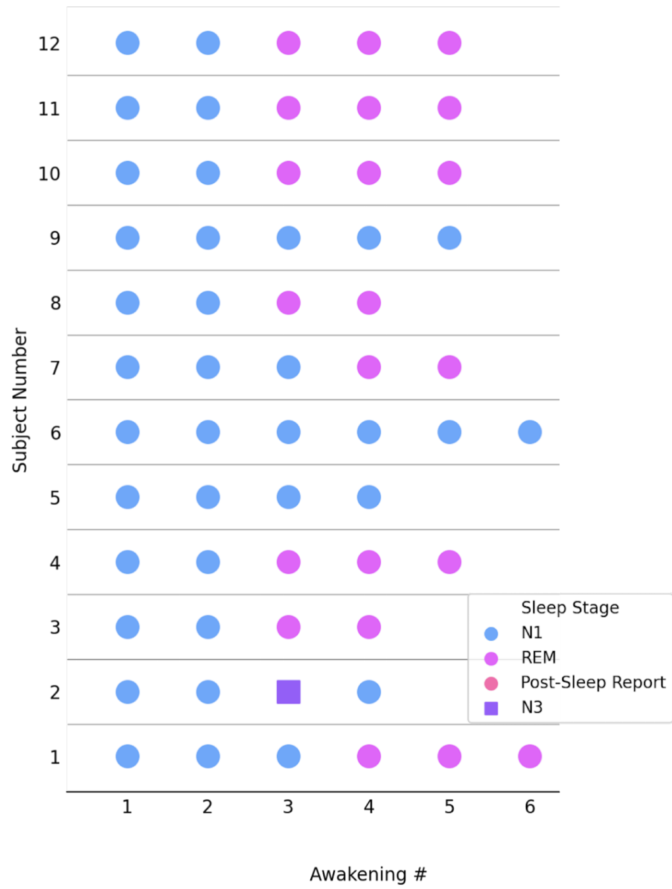


Figure 47 Distribution of sleep stages upon awakenings per subject. Serial awakenings per subject = 4.83 ± 0.69 (mean ± std)

Discussion

This pilot study suggests TDI can indeed incubate REM dream content. We see direct incorporation of the incubation theme 'Tree' in 75% of REM reports, as compared to 84% of N1 reports; incorporations of the dream theme 'tree' in both sleep stages are significantly greater than in representative samples of subjects from similar demographics as assessed by the Typical Dreams Questionnaire. These incorporation rates are similar to past studies which investigate incubation of personal current concerns in REM dreams via pre-sleep rehearsal. I.e. 88% incorporation in Cartwright (1974).[207] The measure of incorporation was much less stringent in the Cartwright study ("some evidence of the target word or its opposite being descriptive of the dream characters in one or more of their REM reports") than our measure of direct incorporation of "Tree" in dreams, and further that study could not distinguish between naturally occurring dreams related to individual concerns and those related distinctly to an incubation protocol. Dream reports from the first REM awakening in our subjects reveal strong effects of TDI in N1 at the start of the nap period on later REM content (67%, compared to 84% for N1; chi^2= .083, p = .773). Wakeups from later REM reveal a slightly stronger effect of TDI in REM on subsequent REM reports. We note that N1 incorporation rates are similar to rates seen in our previous work (Experiments 1, 2 and 3), suggesting experimenters who replicate our TDI methods can expect these approximate rates. Higher incorporation rates in N1 than in REM further align with evidence from past literature which suggest N1 is especially subject to influence of incubation.[59] Lastly, we report evidence of significantly lower creative benefit from this REM TDI protocol than our earlier N1 TDI protocol, in line with recent evidence that N1 is a particular creative sweet spot.[195]

This study is subject to a series of limitations. It's clear we can incubate REM content but it is unclear why in some cases content continues from N1 incubation and in others an additional TDI cue following a REM awakening is necessary. Our subject group is small, and so we lack data for in-depth computational linguistic comparisons of dream reports. With more power, analyses could reveal linguistic differences between sleep reports and shed light on what 'a dream' about the same theme is across varied stages.

This current study tests a novel methodology for incubation of REM dreams with experimenter chosen themes. This allows for controlled examination of a single theme across diverse subjects, as distinct from past studies of REM incorporation of varied individual current concerns. Our current study also offers tools to study similarities and differences between forms of stimulus incorporation in NREM1 and REM reports in a controlled manner. Understanding how experimental stimuli are incorporated into dreams in distinct ways across varied stages offers insight into the relative gating mechanisms inherent to each sleep stage, in which sleepers have varied levels of sensory filtering and access to differing memory sources.

Future studies using our method for targeted influence of REM dream content should focus on comparison of dreams across sleep stages, as well as alteration of REM related functions. REM sleep is, for instance, specifically useful for processing emotional memory; a future experiment using TDI in REM could test benefits to *targeted* processing of emotional stimuli in instances of impaired emotional regulation related to traumatic memory. In the future, suites of dream incubation tools in combination with brain imaging and memory task data could give us a 24 hour picture of information processing mechanisms at the psychological, physiological and behavioral level. In sum, TDI in REM does work for some of the people some of the time, both in our study and in others. Future investigators should focus on a clear specification of the set of conditions that favor the success of TDI, including current concerns and sleep stage of subjects.

Part 3: Discussion

Chapter 7: Community Building

> *"The freest type of psychic play occurs in sleep, and the social acceptance of the dream would therefore constitute the deepest possible acceptance of the individual."*
> William Domhoff, *Senoi Dream Theory* (2003)

The Dormio and the experimental data presented in Experiments 1-4 are only useful insofar as there are practitioners ready to put these tools and techniques to use and place them in contexts where they fit. Dream research is interdisciplinary, linking concepts from psychobiology, neuroscience, engineering, design, anthropology and the humanities. In some disciplines, dreams have been purposefully relegated to the fringes as a research topic. Now it is necessary to build a community of active, interdisciplinary researchers who can produce work of high scientific caliber and credence, while remaining open to the subtle, subjective, and personal character of dreams. If we open the doors to citizen scientists and oneironauts of all kinds, we can build a movement with a more pluralistic approach to the use and experience of dreaming. Perhaps then we can hold in hand simultaneously the best of psychological, psychiatric and physiological approaches to dreams. We have built tools to make using dreams in a directed manner more easy and accessible, and yet we recognize we cannot possibly know all the potential uses of dreams. We should thus insist on the most ample understanding of what dreams are for. This chapter aims to broaden our understanding of what dreams are for, and outlines efforts at building a diverse community of thinkers around dreams and the dream sciences.

What Dreams are For: Futures, Freedom and Insight

> *"Imagination fosters real possibilities: you can't imagine it, you can't have it…dreaming is not irresponsible; it is first-order human business. It is not entertainment; it is work."*
> Toni Morrison, *The Source of Self-Regard* (2020)[370]

Dreaming is meant, according to the NEXTUP model,[173] in large part to predict and prepare a dreamer for the future. Dreaming is a sort of remembering in which a possible world is created by quilting past experiences into novel combinations. Recent research in the memory neuroscience field has found a striking overlap in the brain activity associated with remembering past experiences and imagining or simulating possible future experiences.[371] Dan Schachter's *constructive episodic simulation hypothesis* holds that the episodic memory system supports the construction of future events by extracting and recombining stored information into a simulation of a novel event, relying in large part on the brain's Default Mode Network.[371] This research links daydreaming, dreaming, remembering and imagining intimately in terms of neural substrate, associative cognitive structure, and function.

Framing dreaming, imagining and remembering as functional in future planning serves to collapse the difference between the two meanings of a *dream,* the colloquial metaphor of a dream (as possible futures invoked in wake) and the biological fact of one (as possible futures experienced in sleep). Matthew Spellberg, a scholar studying the history of dreams, writes beautifully about this link: "The association between the two is very old, and very widespread. There is some kind of overlap between those concepts in almost all European languages, and many traditions the world over see dreams as places where thought is particularly likely (even dangerously likely) to turn into reality…Dreams are continuous proof, of a kind, that it really is possible, under certain conditions at least, to make things real by thinking of them." [372]

Historian Robin Kelley insists that dreaming, in both senses, has served a crucial function in the practice of liberation politics. Dreams have engendered freedom in waking metaphor (MLK's *"I have a dream"*) and as the literal act of sleeping dreaming (Mandela's shared dream content in *Long Walk to Freedom*).[373,374] Imagination is not immaterial if it inspires material movements; Kelley writes that "too often, our standards for evaluating social movements pivot around whether or not they 'succeeded' in realizing their visions rather than on the merits or power of the visions themselves…yet it is precisely these alternative visions and dreams that inspire new generations to struggle for change."[375]

> *"If this superstitious fear of Spirits were taken away, and with it, Prognostiques from Dreams, false Prophecies, and many other things depending thereon, by which, crafty ambitious persons abuse the simple people, men would be much more fitted then they are for civil Obedience."*
> Thomas Hobbes, *Leviathan* (1651)

If dreams can make a freer future possible, we must remain vigilant; the capacity to imagine, just like the capacity to remember, can be compromised. Presleep ruminating on intrusive thoughts increases the frequency of threatening dreams, and there is a correlation between the average severity of daytime threats and the presence of threats in dreams. [376,377] Dreams are subject to the same invasion by oppression and insult as daytime life; When Frantz Fanon analyzed the dreams of Algerians living under French colonialism, he noted that many involved scenes of running and jumping, expressions of the longing for physical freedom that the reality of colonial rule denied them. Even sleep did not provide a respite from the psychological impacts of oppression.[378]

The dreamscape has long been a site of political contestation. Regimes of power, from ancient Near and Middle Eastern kings to medieval religious authorities have attempted to occupy this space relying on varied modes of imposition and interpretation to aggrandize authoritarian power.[379] In the 20th century, dreams became a tool of empire. Dreams were collected from across the British empire – from the Indian subcontinent, Nigeria, Uganda, Australia, the Solomon Islands and Jamaica – in studies by the chair of ethnography at the London School of Economics, sponsored by the British Colonial Office. These were an attempt to map the supposedly inscrutable 'native mind', to bring the single vision of scientific classification to imperialism.[380,381]

We know that today stress is a mediator of devastating physiological effects in low-income communities, but we pay little attention to its limiting effect on the imagination of the oppressed. We know that Black Americans are five times more likely than white Americans to get less than six hours of sleep per night but fail to consider the proportional loss of dreams.[382] Dr. Rubin Naiman, a clinician and sleep specialist, claims "we are at least as dream deprived as we are sleep deprived" and points to the impacts of commonly used antidepressants, abused alcohol, pre-sleep cannabis and stress on our sleep architecture.[74] If dreaming as an act is potentially liberatory imagination, we are being deprived of futures as we are being deprived of rest.

> *"The thinking of freedom can only be seized, surprised, and taken from elsewhere by the very thing it thinks."*
> Jean-Luc Nancy*, The Experience of Freedom* (1988) [383]

On Dreaming In Community

> *"dream-life can serve to reanimate a world that has been flattened by dark times. Dreams are a crucial resource for regaining a measure of freedom in our thought and speech, serving as a vital landscape to recover our fundamental human capacity to assign meaning to the world."*
> Sharon Sliwinksi, *Dreaming in Dark Times: Six Exercises in Political Thought* (2017)[374]

If we were to recognize dream deprivation and safeguard space for dreams in our communities, what could dreams in fact *do*? There is evidence that considering one's dreams increases moments of personal emotional insight over and above time-matched consideration of one's waking thoughts.[80] If dreams truly "reflect an attempt, on the part of the brain, to identify and evaluate novel cortical associations in the light of emotions mediated by limbic structures activated during REM," then we can expect important novel associations to arise in dreams whether the issue is mathematics, politics or one's love life.[384] We can expect to see ourselves more clearly as we consider our dream content.

Yet dreaming need not bring us back only to ourselves. In many traditions we see dreams are a means to discover and reaffirm one's relation to oneself *and* to the world. One of the sharpest critiques of psychoanalysis, which does indeed ask dreamers to look deeper into themselves, comes from Brazilian philosopher Roberto Unger. In his piece *Passion: An Essay on Personality*, Unger writes that "psychoanalytic theory offers opportunities to replicate, but not to transform, individual and social contexts."[385] Psychoanalysis takes a difficult dream we have and asks us to use it to unpack ourselves. A psychoanalytic reading of Algerian dreams of fleeing might deconstruct the running metaphor; Unger asks us instead to deconstruct the empire that begot the dream. This kind of imaginative work insists that our internal world is continuous with the world around us, and that changing one's mind must be an act involving our social and political environment.

There is a storied history of people using dreams to change not just themselves but their communities. We can look to the sciences, where evidence shows dream sharing increases empathy over and above the sharing of our waking thoughts, suggesting a group bonding function.[217] A positive correlation exists between dream sharing frequency in couples and perceived relationship intimacy; An interventional study indicated that regular dream sharing increased marital intimacy and satisfaction. [386,387] Or we can look to ethnography and religious studies, where we find that many of the world's cultures have elaborate and varied protocols by which dreams are enacted in the waking world. The Dane-zaa, a First Nations people living in British Columbia, must hunt in dreams before they can take an animal in waking life.[388] Before bed, the Ongees of the Andaman Islands narrated their dreams from the preceding night and experiences from the ending day to one another, and would then *negotiate* the content of their dreams so that everyone's dreams became gradually aligned.[388] Among the Wayuu of Colombia and Venezuela, a dream is altered by being retold in waking life, in turn changing coming dreams and waking life.[388] Practices of dream sharing permit the negotiation and transmission of individual unseen worlds into the public sphere, externalizing what the society holds in common and what must be realigned.

> *"Dreaming and dream sharing, in other words, provide for a continuous back-and-forth between an agreed-upon communal reality and an individual's experience of the real…This process, in turn, influences future dreams, creating a living system of circulation between discourse and lived experience, like blood going to and from the heart."*
> Matthew Spellberg, *Prisoners of the Dream* (2022)

If hunting animals in dreams feels irrelevant to your experience, consider instead the recent surge in COVID-19 related dreams as a model for dream sharing. A study design outlined by our collaborator Professor Paul Seli examined the links between COVID-19 dreams and prosocial behaviors His hypothesis is that individuals who experienced higher negative dreams regarding infection would be more motivated upon awakening to seek out vaccination and engage in masking.[389] Would pre-sleep dream sharing traditions applied today align our internal concerns and allow for a more coherent communal response to threats? We pay so much attention these days to the visible tides of our societal spending, votes, or vaccine behaviors; We pay so little attention to each of our internal worlds, which invisibly *drive* and divide our communal waking behavior.

Data in the Sleep and Dreams Database show that out of 11,000 people surveyed, 30% of males report never in their life having shared a dream with someone; 42% of females and 43% of males share a dream less than once a month. [390] In a 1998 study of 1,000 Austrians, 32% reported dreaming less than once per month.[391] In light of all the potential uses of dreams we've seen so far, what would change if these individuals started to keep a dream journal, a simple way to boost dream recall? [392] What would change if sleep science shifted their viewpoints and suddenly they recognised their daydreams as waking dreaming, and saw dreaming as their default state?[84] What would change if tools like TDI made dreaming more accessible and tangible? As we consider how to promulgate TDI we have to keep in mind questions like these which consider ripple effects far beyond the laboratory into the introspective and interpersonal spheres.

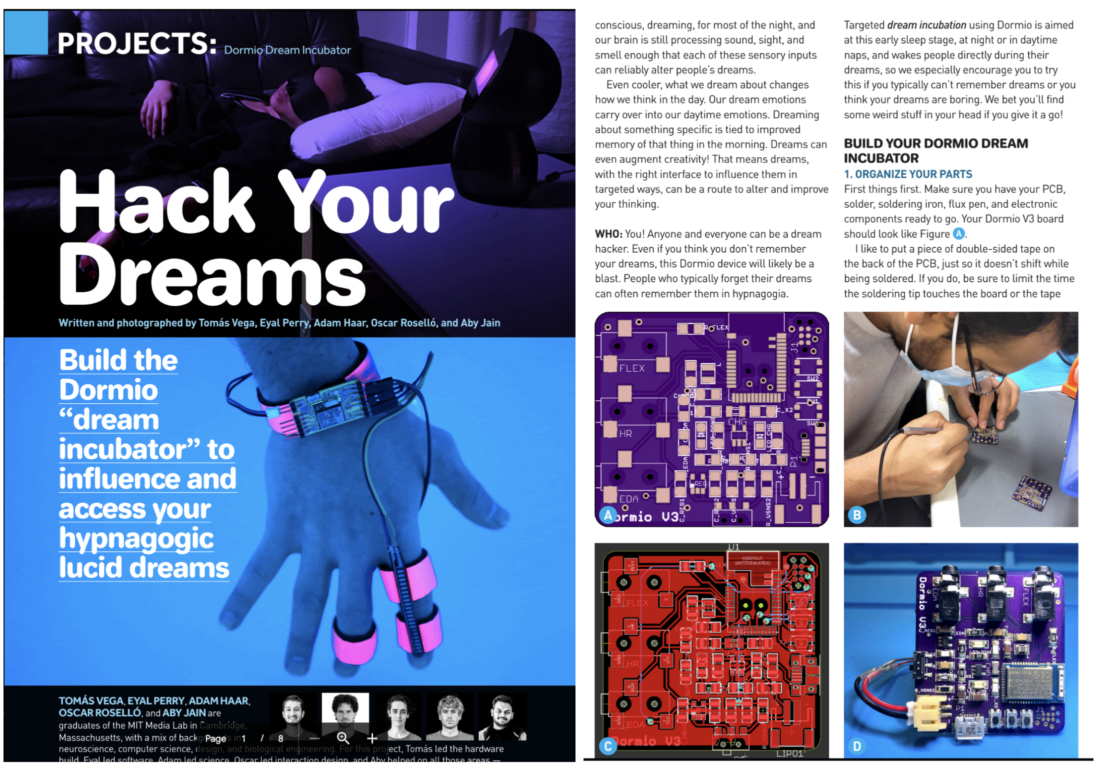
> *"The discourses a society has for sharing its deepest mental phenomena are as important as the phenomena themselves. Here I mean not only sleep dreams, but also the many other forms of mental life that are associated with them, and that have been grouped under rubrics like the unconscious, primary consciousness, or the voice of the gods. Dreams often stand as the emblem for all of these because they present a limit case for the radical privacy and radical intensity of individual experience."*
> Matthew Spellberg, *Prisoners of the Dream* (2022)

Into the Engineering and Brain Science Communities

To build accessible tools for dream research which can impact us both within and beyond the laboratory, it's crucial to build bridges between the engineers who construct novel technologies and the scientists who scope and test them. With these communities in mind, Dr. Michelle Carr reached out to me about the Dormio project and the larger Dream Engineering initiative ongoing in the Fluid Interfaces Group. She proposed that the momentum behind these dream technology projects could serve as a convener for the spread scientific community of dream researchers. To bridge and help build that community, we conceived the first *Dream Engineering Symposium*, held at the MIT Media Lab on January 28th, 2019. The workshop brought together 50 top researchers studying sleep and dreams (including many cited in this thesis, Ken Paller and Björn Rasch and Dierdre Barrett and Francesca Siclari and Stephen LaBerge and more) with engineers who develop novel technologies for studying, recording and influencing dreams. Researcher panels covered themes of nightmares, lucid dreaming, memory replay and sensory stimulation while technology talks, demos, and posters showed new devices and techniques for incubation of dream content and dream lucidity. All this work, and the collective brainstorming sessions which occurred afterwards, centered on the theme of Dream Engineering - how technological innovation and scientific expertise can be applied to record or influence dreaming, further dream research, and translate scientific advancement into boosts in health and cognition outside of the laboratory. This conference was the first of its kind, and convened a powerful group of builders and brain scientists to further the field of dream and sleep science. Since this original 2019 Dream Engineering Symposium we have hosted 7 gatherings, bringing researchers together from more than 20 countries and discussing dreams from the vantage point of anthropology, technology design, religious studies, ethics, neuroscience and more. One amongst many products of this community has been a *Special Issue on Dream Engineering*[393] published in the journal *Consciousness and Cognition*, a collection of papers on new tools and techniques for dream research – the first of its kind.

Figure 48 Researchers joined our seven Dream Engineering Seminar Series gatherings from more than 20 countries.

Many researchers at the Dream Engineering seminar series asked for a Dormio device of their own to run experiments. To further enable the dissemination of Dream Incubation devices, we have made our circuit board design Open Source, as well as the software enabling the Dormio Web App and iOS App, and published an in-depth tutorial in *Make Magazine.* [394] This article covers everything from soldering to circuit programming, and can be found at: https://makezine.com/projects/dormio-dream-incubator/



PROJECTS: Dormio Dream Incubator

Hack Your Dreams

Written and photographed by Tomás Vega, Eyal Perry, Adam Haar, Oscar Roselló, and Aby Jain

Build the Dormio "dream incubator" to influence and access your hypnagogic lucid dreams

TOMÁS VEGA, EYAL PERRY, ADAM HAAR, OSCAR ROSELLÓ, and ABY JAIN are graduates of the MIT Media Lab in Cambridge, Massachusetts, with a mix of back[illegible] in neuroscience, computer science, design, and biological engineering. For this project, Tomás led the hardware build, Eyal led software, Adam led science, Oscar led interaction design, and Aby helped on all those areas —

conscious, dreaming, for most of the night, and our brain is still processing sound, sight, and smell enough that each of these sensory inputs can reliably alter people's dreams.

Even cooler, what we dream about changes how we think in the day. Our dream emotions carry over into our daytime emotions. Dreaming about something specific is tied to improved memory of that thing in the morning. Dreams can even augment creativity! That means dreams, with the right interface to influence them in targeted ways, can be a route to alter and improve your thinking.

WHO: You! Anyone and everyone can be a dream hacker. Even if you think you don't remember your dreams, this Dormio device will likely be a blast. People who typically forget their dreams can often remember them in hypnagogia.

Targeted ***dream incubation*** using Dormio is aimed at this early sleep stage, at night or in daytime naps, and wakes people directly during their dreams, so we especially encourage you to try this if you typically can't remember dreams or you think your dreams are boring. We bet you'll find some weird stuff in your head if you give it a go!

BUILD YOUR DORMIO DREAM INCUBATOR

1. ORGANIZE YOUR PARTS

First things first. Make sure you have your PCB, solder, soldering iron, flux pen, and electronic components ready to go. Your Dormio V3 board should look like Figure A.

I like to put a piece of double-sided tape on the back of the PCB, just so it doesn't shift while being soldered. If you do, be sure to limit the time the soldering tip touches the board or the tape

Figure 49 Images from the *Make Magazine* article covering how to make a DIY dream incubation device. Written in collaboration with Tomás Vega, Eyal Perry, Oscar Rosello and Abhinandan Jain.

Our class: MAS.S63, Engineering Sleep and Dreams

One of the clearest ways to build an interdisciplinary research community is to teach a multifaceted class. Together with Dr. Pattie Maes, Dr. Robert Stickgold, Dr. Michelle Carr, Abhinandan Jain and Eyal Perry, I had the chance to create a class on sleep and dreams for a collection of MIT, Harvard, MassArt and RISD graduate and undergraduate students. Our student body was mixed, with backgrounds in neuroscience, computer science, device design, architecture, art, fashion and beyond. Invited speakers ranged from practitioners of clinical psychiatry, history of science, and ethnography to experts in social determinants of health and biomedical devices. Speakers helped us understand what *a dream* could mean from so many perspectives: A dream as a relevant clinical marker (Dr. Azizi Seixas), as intensified mind wandering (Dr. Thomas Andrillon), as memories evolving in real time (Dr. Bob Stickgold), as cultural symbols and carriers of intergenerational stories (Dr. Matthew Spellberg), as intervention opportunities for trauma (Dr. Judith Amores and Dr. Michelle Carr), as bridges to communicate across levels of consciousness (Karen Konkoly), as unusually personal traces of medical history (Dario Robleto).

Each weekly assignment for the course included both reading about an experiment, and *experiencing* it. In a week where Karen Konkoly came to speak about her 2021 lucid dreaming paper, *Real-time dialogue between experimenters and dreamers during REM sleep*, students spent the previous night listening to a lucid dream induction recorded by pioneering scientist Stephen LaBerge.[151] The curriculum emphasized both knowledge of the brain systems involved in dream generation *and* the language necessary to grapple with and make public the personal experience of the dream. It was, in this sense, as much an apprenticeship in looking as a course in brain mechanisms of dreaming.

The course ended with a final project, which asked students to propose new ways to understand, represent or alter dreams. Projects included novel dream experiments (influencing dream content with whole body hot or cold temperature applied during REM), dream-enacting environments (a public sleeping space covered entirely in oneirogenic plants and herbs), dream-representations (sculptures automatically generated by one's sleeping brainwaves) and more. The hope of this course was community building, and our hope is that the wide range of speakers and many faces of projects produced makes it clear that no background bars someone from deepening our knowledge of dreaming. The course is documented online at https://dreaming.media.mit.edu/, and I am hopeful readers would like to reproduce it at their institutions, so please do get in touch.

Figure 50 A final project by students Sahil Mohan, Kathleen Esfahany and Hyemin Gu creating a sleeping space with flowers that have classically been used for dream incubation

Writing Outside the Institutional Lines

“My most central idea is simple. It’s the primacy of fictions, that to understand the world you need to take stories seriously. The story in which you believe shapes the society that you create.”
Yuval Harari, *Interview*, NYT Magazine (2021)

One of the key takeaways from the experience of teaching was the success of bringing personal experience into the classroom. Dream sharing is a great equalizer; We are all vulnerable when we’re honest about our dream content. Sometimes shared dreams are disarming, and laughter breaks out. Sometimes they are more serious and powerfully personal than any waking thought we might expect shared in the university classroom. What is the responsibility of those involved to create a vessel for these stories, a set of practices that make altering, capturing, and sharing one’s dreams feel safe? What advantages and disadvantages does a school setting have for this kind of personal and communal exploration? How do we save ourselves from story limbo, wherein we re-encounter our dreams and do not know what to do with these strange voices inside us?

One answer is simply allowing as many perspectives as possible to enter the space. This is, admittedly, a beginning. In place of inventing ritual and assigning meaning, a road that we cannot really walk in the sciences, we can only offer many potential framings for people to place their stories in, offer intersubjectivity in the form of open dream sharing, and hope they find a fine fit.

To extend the potential for exploratory, social play with TDI outside of academic settings we composed two artistic written pieces. The first, *A Dream Is,* commissioned a series of disparate definitions and artworks expressing what a ‘dream’ is to individuals. Collectively the work suggests the equal, interdisciplinary authority to define experience inherent to all who are conscious. These submissions are from students in our MAS.S63 class and from professional artists, scientists and dreamworkers. The second piece, *An Experience Cookbook,* is a DIY activity booklet that presents sleep studies which readers can try in community at home to experience dream science and make it their own.

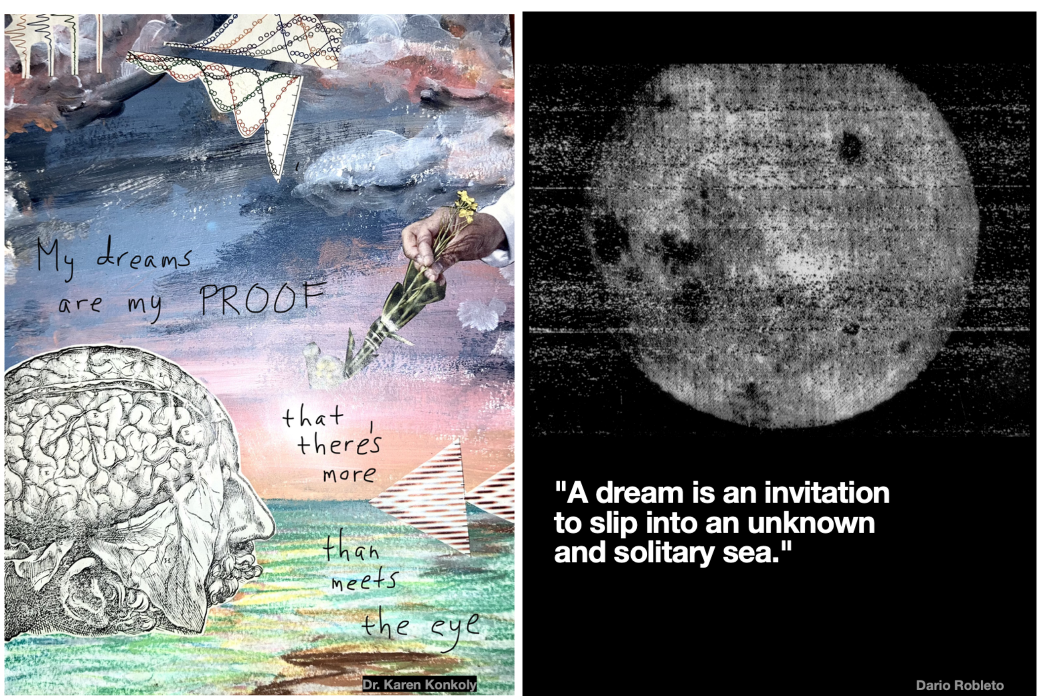


Figure 51 Submissions to *A Dream Is* booklet from dream scientist Karen Konkoly and artist Dario Robleto.

Figure 52 Excerpt from the *Experience Cookbook* which presents DIY instructions for dream studies which readers can try at home to experience dream science and make it their own.

Into the Artistic Community

> *"In a culture whose already classical dilemma is the hypertrophy of the intellect at the expense of energy and sensual capability, interpretation is the revenge of the intellect upon art."*
> Susan Sontag, *Against Interpretation and Other Essays* (1969)

It was inspiring to see seasoned and serious scientists send in expressive and personal artworks for their *A Dream Is* submissions. Inviting artwork in these two publications allowed for bridge-building definitions that were rooted in both the science and the self. At times it can feel like analytical investigation of the dream is a revenge of intellect upon the dreamscape, a single vision forcing multidimensional stories onto flat microscope slides. This thesis proposes scientific methods which hope to understand without undermining, but the scientific method is prone to atomizing. Meaning-making can suffer in the laboratory, and sensitivity towards subjectivity can get lost along the way. What can the arts offer as an antidote to this sort of atomization? Even as the sciences have struggled to work with subjectivity, the arts have successfully kept in contact with dreams as a means of rediscovery of the imaginative impulse. "Every act of imagination points implicitly to the dream. The dream is not a modality of the imagination, the dream is the first condition of its possibility," writes Michel Foucault as a doctoral student in *Dream, Imagination, and Existence'* (1954). Artwork and the artistic community are veins for dream science to maintain contact with the subjective content and imaginative capacity of dreams. The following section details one particular art project interwoven with this thesis work.

> *"The ultimate, hidden truth of the world is that it is something that we make, and could just as easily make differently."*
> David Graeber, The Utopia of Rules (2015)

The Höller *Hotel* project

> *"Our culture has beheld with suspicion unproductive time, things not utilitarian, and daydreaming in general, but we live in a time when it is especially challenging to articulate the importance of experiences that don't produce anything obvious, aren't easily quantifiable, resist measurement, aren't easily named, are categorically in-between."*
> Ann Hamilton, *Making Not Knowing*, (2005)[395]

Artwork is especially apt at repositioning what we accept as necessary or normal (i.e. repeated nightmares in veterans) but need not be either. Carsten Höller is a contemporary artist whose work often repositions the scientific method itself. Höller, with a doctorate in entomology, calls attention to the gaps, subjectivities and strangeness ever-present in the supposedly dry practice of experimentation. He writes, "the real material I work with is people's experience […] I think of life as an experiment on oneself. Subjective personal experience in science is a no-no. In starting to make art, I wanted to bring in what had been forbidden."[396]

Höller uses sleep and dreams in his exhibitions to enact the paradoxical, vulnerable control of the experimenter, the one who determines conditions but must wait desperately on outcomes only subjects can give. Working with the bidirectionality of observation in the scientific and artistic worlds, Höller puts museumgoers on display in *Two Roaming Beds* (2015) which travel the museum as visitors sleep in them. Höller, himself a frequent lucid dreamer, understands the porousness of the dream state, and the alternative visions that a moving bed might produce. Viewers at Höller's shows, in observing their own dreams and the sleep of others, are simultaneously scientists and the subjects of study (as Höller reminds us all scientists are). Another work, *Insensatus* (2013), is a toothpaste infused with plant extract activators meant to guide dreams, provoking excitement and fear in a normally mundane pre-sleep ritual. The toothpaste is aesthetically clinical, as much of Höller's work is, calling to mind a visit to the doctor or laboratory, and one cannot help but feel like a lab rat on a rollercoaster. Höller knows that this excitement and fear itself will alter dreams, as he has an ongoing interest in the placebo effect. Höller takes us through all of this disorientation to provoke active play with our own perception, in sleep and in wake, and to expose the ever present influences of observation and expectation on science.

As part of this thesis work, I've had the opportunity to work with Höller on a series of dream-altering prototypes which will form a series of rooms in a *Dream Hotel*. Each of these is a new possibility for dream science – inflatable pajamas which pneumatically guide dreams, immersive media which stimulates flying dreams, or a new version of the *Insensatus* toothpaste which is based in neurochemistry. As we consider bringing these tools for dream incubation into the museum setting, one of the key questions is the role of the 'scientist' label and its cultural cachet and placebo effect. Both Carsten and I know that my own name, MIT degree, the clinical aesthetic of the work, and the association with calculated control will all be present in the mind of anyone brushing their teeth with our concoction before bed. How would they dream differently if they thought of their experimenter in a new light? How have these beliefs influenced the subjects throughout this thesis? Working with the arts has served to center the aesthetic and framing of the dream experiment, something which has certainly had an invisible influence on my work all along. In light of this, as we think of the many people who might wield TDI in the future, how do we want to conceive the power dynamic in the dyad of dreamer and dream incubator? How do we want to structure this relationship, the expectations inherent and the pre-sleep practices they suggest?

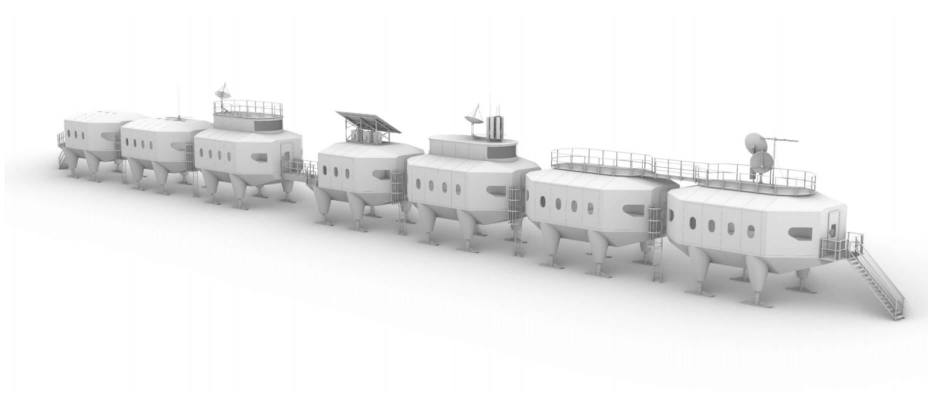


Figure 53 Above: The 7 distinct rooms of the *Dream Hotel* each house distinct scientific sleep experiments which visitors can participate in. Below: A room housing inflatable pajamas for visitors to receive pressure stimulation of limbs while asleep. Image credit Alejandro Medina, Carsten Höller

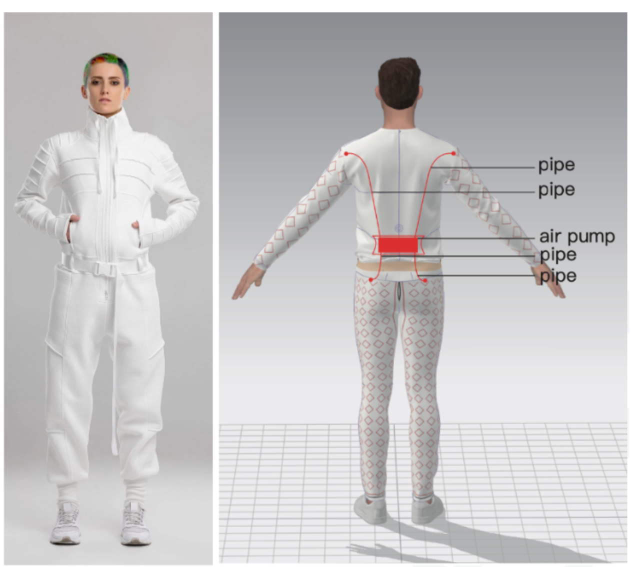


Figure 54 Inflatable pajamas designed for *Dream Hotel* visitors to receive pressure stimulation of limbs while asleep. Image credit Yechen Zhu (RISD)

Chapter 8: Ethics

> *"If something as private and seemingly interior as dreaming is now the object of advanced brain scanners and can be imagined in popular culture as downloadable media content, then there are few restraints on the objectification of those parts of individual life that can be more easily relocated to digital formats"*
> Jonathan Crary, *24/7, Late Capitalism and the Ends of Sleep* (2013)

The Xbox Dream Film project

Questions of power dynamics between dreamers and their dream incubators came into focus especially in one particular dream incubation project I participated in. I was open to proposals for the use of our TDI tools by artists, and was thrilled to receive a call for a project from Taika Waititi, a film director whose work I admire. He had read our *Dormio* paper in depth and was interested in using TDI for a film project. The concept of the short film Waititi would direct was simple; Actors would dream, and whatever they happened to dream would be the content of a short film they would act in. The project was at the whim of the dream.

The dreamers selected by the project lead were all professional video game players. This was interesting in particular because regular video game play is correlated with increased dream control and dream lucidity, and because the seminal study in contemporary dream science was done using pre-sleep video game play as an incubation stimulus.[384,397] This study demonstrated unambiguous incorporation of the game Tetris into sleep onset dreaming, even with amnesiac subjects, an effect dubbed the *Tetris Effect.* This study was taken up as a marketing opportunity by Playstation, who went on to create a hugely popular game of the same name.[398]

In our project with Waititi, the plan was for each sleeper to play their favorite video game before a nap and hold that gameplay in mind as a dream incubation as they fell asleep. The gamers expressed hopes to create a version of their favorite games which was entirely their own, altered and interior. My task was to awaken them during late stage NREM1 sleep, collect dream reports, and suggest they go back to sleep while maintaining focus on their dream incubation intentions. This was a simple dream incubation protocol, much like the Tetris dreams study above.

It was revealed to me over the course of the project that this short film was in fact *sponsored content*, a type of promotional media that is paid for by a brand but created and shared by another creator. Here, the gaming company Xbox was footing the bill while Waititi was creating the work. He was one of a few chosen 'creators' who would work to turn the collected dreams from different gamers into varied media. These creations ranged from fascinating to foolish; One blind video game player would have his dream turned into an immersive soundscape which could let him share an approximation of an imageless imagination. Another would take the dreams of a star football player and use it as inspiration to design a new pair of Nike Air Force One sneakers.

Figure 55 One participant, named MoonliteWolf, slept with her cat nearby. In this particular dream, the main character of the game Halo was a cat in disguise

Figure 56 Blind gamer Steve Saylor listened to his dream recreated in 3D audio. Steve Saylor referred to the creation of this audio as an artwork thet “made my dreams real.” [399]

Seeing these projects and products emerge from the collected dream reports I felt a combination of pride and apprehension. Watching Steve Saylor (the blind gamer) be reconnected to a dream in wake was so exciting. It’s vital that we create new media and methods for dream sharing, experimenting beyond the written and spoken word to find the form of dream sharing which can catch on today; Having a blind dreamer say this 3D audio faithfully recreates his dream experience is a step forward. Here is Steve; “That’s exactly my dream...To think that all this came from my subconscious brain and became this amazing 3D audio artwork…I am so honored and overwhelmed and emotional. This is literally the biggest thing I have ever worked on.” [400] Millions of people listened and watched; All communication about the project referenced and cited our paper clearly. I heard from huge numbers of people with new curiosity sparked about their dreams and TDI. Is this what science communication looks like in the 21st century? Is this a film, or art, or simply masked marketing? How different are these in an era where anything which grabs our attention is a profiteering opportunity? How much should we resist their blurring?

With both the Xbox sponsored content and marketing of the Tetris Effect, dreams are being put to use to sell a product. The marketing here relies on the stickiness of games in sleep, the notion that buyers can expect video game play to influence both their waking and dreaming consciousness. This, as far as the research suggests, is not false.[401] Association of the project with capitalism here is not damning in and of itself, yet this Xbox project is an invitation for corporate entry into the dreamscape – it suggests products can make promises (and in turn create desires) that reach into the sleeping mind. It in turn invites new projects which offer a shallow reading of the potential uses of dreams – i.e. a *starry* dream inspires *starry* Nike shoes – and in our society where scale and speed determine the success of any story, the shallowest reading and lowest hanging fruit often win out. This project with Xbox is not crossing lines which debase dreaming, but it is approaching them. TDI is a simple key for complicated doors; It offers a modicum of control which can be used in humble and personal ways, which can have potent clinical and practical impact. Yet this tool presents itself to all actors, and I can imagine misuse of TDI truly cheapening the dreamscape. And it is difficult to imagine that, especially when profit is possible, it will take other companies very long to throw us down that slippery slope. These important questions lead us into the following chapters, which discuss some of the ethical issues currently raised by TDI.

> *“It matters what matters we use to think other matters with; it matters what stories we tell to tell other stories with; it matters what knots knot knots, what thoughts think thoughts, what descriptions describe descriptions, what ties tie ties. It matters what stories make worlds, what worlds make stories.”*
> Donna J. Haraway, *Staying With the Trouble* (2016)

Coors And Dream Based Advertising

Another call came a few weeks after Waititi released his short film for Xbox. A representative of Molson Coors announced on the phone that they wanted to use TDI to make Superbowl viewers dream of Coors beer, in tandem with incubated positive themes of cleanliness and refreshment, to increase their daytime drinking. Their aim was not seeing naturally occurring relationships between a behavior (i.e. playing video games) and subsequent dreams; Instead, it sought to create *new* associations in sleep (Coors = clean) to engineer increased waking consumption. I was stunned by how quickly our work on Targeted Dream Incubation had been co-opted.

The potential implications of this project are as clear as they are sinister. We know that targeted delivery of odors during sleep can help combat addiction; participants exposed during their sleep to the smells of cigarettes along with those of rotten eggs smoke 30% fewer cigarettes over the following week.[402] Participants in this cigarette study did not remember their sleep stimulation in the morning, and moreover the same smell stimulus failed to change behavior if it was administered in wakefulness. We are *specifically* vulnerable in sleep to this sort of manipulation, in terms of both increased malleability and failures of memory. A recent paper demonstrates that playing audio recordings of product names during sleep, but *not* during wakefulness, could shift snack preferences toward either M&Ms or Skittles; The researchers concluded that "sleep likely represents a unique period during which preferences and choices that are otherwise stable can be selectively modified by external cues."[403] We know subjects who have numerous using dreams and relapse dreams are more likely to have greater drug and alcohol cravings and to return to active substance use.[404,405] Researchers have not yet tested whether incubating dreams can intentionally worsen addiction but this Coors design seemed like exactly the way to do it. The Coors project amounts to a completely uncontrolled pseudo-experiment on incubating addictive dreams in a way that can destabilize existing waking desires without even a plan to follow-up on the effects on potentially millions of superbowl viewers.

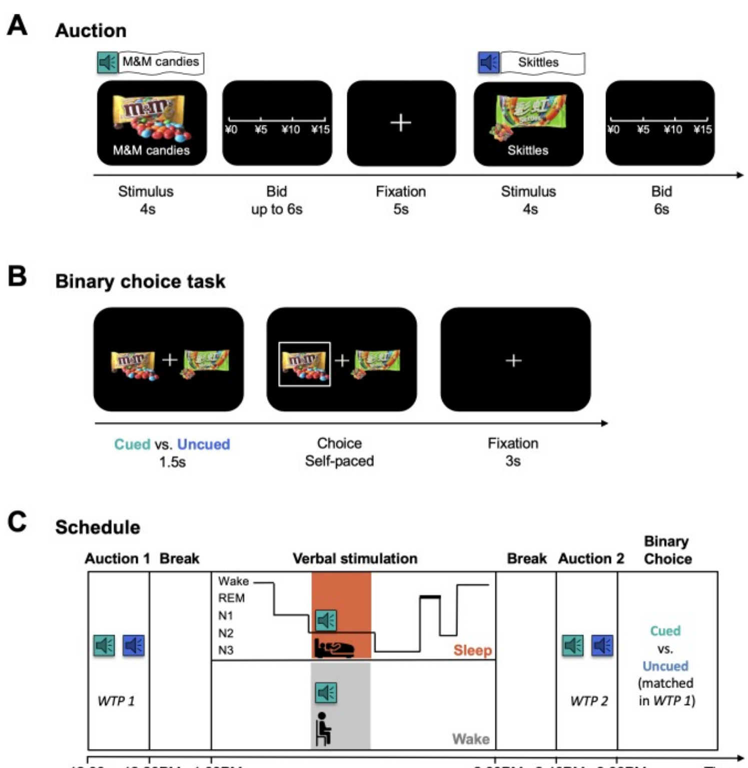


Figure 57 Study design for shifting people's purchasing preferences amongst candies while they sleep.[403]

Objections raised to Coors on moral grounds were ineffective. Coors thanked me for my thoughts and for publishing on TDI, and then went down the road to Harvard where they contracted Dr. Deirdre Barrett to create a beer dream incubation protocol. Coors released a promotion promising participants in 'the world's largest dream study' would get half off on a 12 pack of Coors; if they sent the link to a friend who also incubated their dreams, the 12 pack was free. All people had to do was watch a video before bed and play an 8 hour soundtrack while they slept, called the *Coors Beer Big Game Commercial of Your Dreams*. It was released on social media and the web and, just like that, Coors had proudly pioneered a new form of intrusive marketing. "Targeted Dream Incubation (TDI) is a never-before-seen form of advertising," says Marcelo Pascoa, Vice President of Marketing at Molson Coors.[406]

Dr. Barrett—a prominent and otherwise compelling researcher—apparently ran a scientific study on Coors dreams with 18 people before releasing her stimulus to the public, but data remain unpublished. In promotional footage the science aesthetic and clips of Harvard are prominent, subjects are admitted to a sleep lab, watch a Coors video in bed, and then are woken up in the night to describe their beer dreams. A dream incubation participant wrote about her experience with Coors after the ad emerged, saying that she responded to a strange Craigslist ad claiming that a 'big brand' was willing to pay $1,000 for "willing sleepers." She responded to the ad and was directed to a warehouse in Los Angeles where more than a dozen other volunteers were hooked up to brain monitoring equipment as marketers from Molson Coors looked on. She and the other subjects were directed to watch a video that featured Coors products amid waterfalls and jungle landscapes, and instructed to try to doze off while listening to audio from the video they'd just watched. For the next eight hours, she said she did, in fact, have a series of Coors related dreams; "I had one where I was on a pogo stick jumping around with Coors products. In another one, I was on a plane dropping Coors cans on people and they were cheering for me…They were trying to implant Coors into our brains. It just didn't really sit right." [407]

The Coors beer project culminated with a cameo from One Direction pop star Zayn Malik. Malik also watched the beer incubation video made by Barrett before sleeping on Instagram Live, a platform where he has 46,000,000 followers. When Malik woke up he described the dream he had to thousands watching: "I seen like this huge robot, and it was like a metal robot but he was made of Coors cans, and he was like walking over the hills. … I was quite skeptical, but actually it worked." Then, with absolutely lukewarm insincerity, "I've told you my dream. Now you can tell me yours." The campaign received 1.4 billion media impressions and, according to Coors, was tied to thousands of reports of Coors dreams and an 8% increase in sales, marking the highest market share in the brand's history. [408]

It's truly difficult to come up with a more cheapened dream sharing experience than light beer on Instagram live. The whole project is unprincipled, but perhaps even more disturbing it's unimaginative. The dream is reduced to an enhanced environment for inculcating pre-programmed associations. The equation Coors = clean is all that matters, and all that is at stake is the loss or gain of capital. The ethical quandaries raised here are the least interesting ways to engage with dreams, exactly because they are created by people whose shallow estimation of dreams brought about such a project. There is no dream in this dreaming.

Figure 58 Stills from the Coors Beer *Big Game Commercial of Your Dreams* and Coors marketing report[409]

This ad piggybacks on a history of intimate links between the study of dreams and the US advertising industry. Sigmund Freud's nephew Edward Bernays is credited with pioneering the US public relations and advertising industries, in part through influential books such as Propaganda (1928). It was Freud's theories that Bernays took as inspiration for his approaches to influencing the public, with a focus on the creation of unconscious desires and associations. In a series of hugely successful advertising campaigns, Bernays demonstrated that the irrational forces that drive human behavior could be harnessed to 'engineer consent' and manipulate people's behavior without their realizing it.[410] It is psychoanalysis that gave advertising the idea to sell by association, linking cars and masculinity or cigarettes and freedom, just as the Coors dream-incubation project linked beer with positive, refreshing experiences.[410]

Bernays inspired a wave of advertising industry leaders in the ensuing decades to hire 'motivational analysts' and 'depth manipulators', who sought to uncover and redirect the unconscious desires of consumers. The use of subliminal stimuli, first explored in perception and attention laboratories, seemed well suited to their purposes. Research suggested subliminal stimuli might be able to deliver messaging below a person's perceptual threshold, allowing for the undetected insertion of new motivations and meaningful associations in vulnerable viewers. The use of our dreamscape as advertising space is essentially what people feared subliminal marketing might be. Stimuli delivered during sleep can influence people without their being able to assess those stimuli. And it is far easier to deliver such information during sleep than during the milliseconds-long windows that subliminal stimuli must fit into. It's very likely that advertising in dreams would change behavior, even in unknowing listeners and those who remember only some of their dreams.[411]

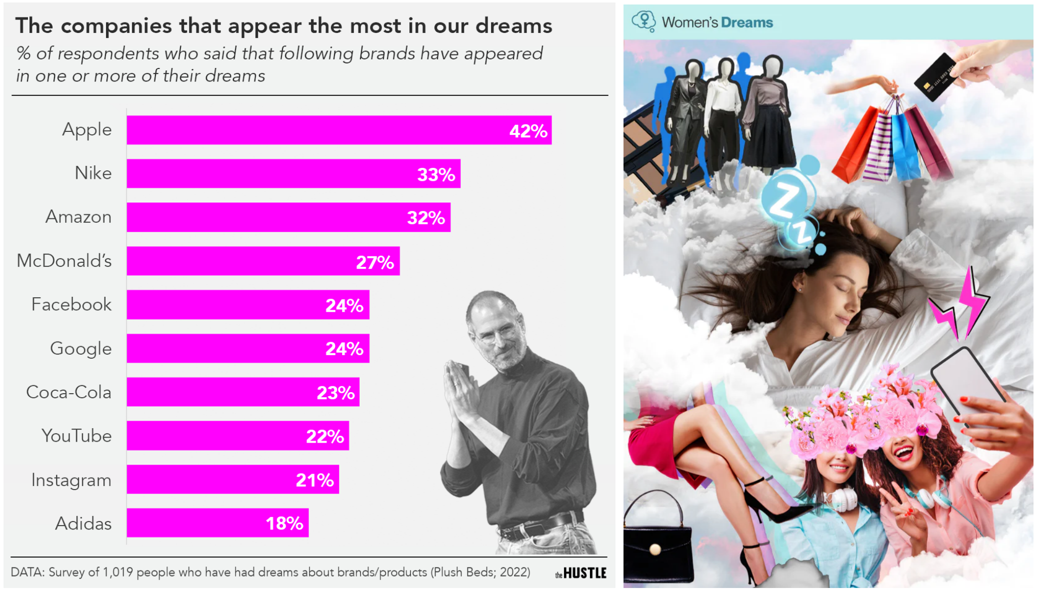


Figure 59 Left: A recent survey by a mattress company found that 7 in 10 people have had a dream about a brand as a result of interacting with regular ads, and more than half said those dreams made them want to interact with those brands even more while awake. Right: Illustration of "women's dreams" from this study [407]

A Community Responds

There was an unsettling absence of outrage in response to the Coors campaign. Other than some concerns – occasionally tinged with humor – expressed in the comments section that accompanied the Coors promotional video, the questions it raises received little attention. After the Coors campaign introduced the possibility of TDI creating new associations between product and emotions, the 2021 Future of Marketing study from the American Marketing Association asked advertisers and consumers whether they would welcome such promotion. Surveys of more than 400 marketers across firms found that 77% indicated they would deploy dream-tech in the next three years – more than would advertise on smart speakers or IoT devices. Of more than 500 consumers surveyed, only 32% were opposed to the use of dream incubation by advertisers, while about three in 10 were unsure.[412] What have we lost when we become so collectively inured to invasions of our privacy and to exploitative economic practice that we would happily accept a 12-pack for the placement of beer advertising into our dreams? Among other things, we certainly seem to have a diminished awareness of just how important sleep and dreams are – how they play a crucial, constructive role in our wellbeing and daytime behavior.

This is in part a problem of effectively communicating science, and so I organized our community of dream researchers to respond to this Coors promotion as a collective. We published a *Dream Engineering Ethic* as a community; This is why you gather after all, to potentiate communal ethics and collective voice when the time comes to speak. We wrote a longform piece in *Aeon* outlining the dangers presented by the Coors piece, and calling for policy protections. We wrote a policy demand, calling for a clearer conversation on the ethics of advertising in dreams, and 40 dream science leaders from different universities signed on. This piece was picked up by *The National Law Review,* and then by *Science*, by *NPR All Things Considered*, by local radio across the US and then by papers as far flung as India's *Hindustan Times* and Australia's *New Daily*.

Figure 60 Varied news articles covering our collective piece on TDI, advertising and policy demands

Our strategy for raising the alarm was outlining a clear, damning world-picture that was made possible by the lack of public outcry. If people permitted this incursion by Coors, they had to understand what was becoming possible. The creation of prospective, as opposed to retrospective, legislation is rare in our country. Our task was then a kind of dreaming we had to do on behalf of a lay public. Our bad dream was composed of past scientific knowledge stored in memory, mixed with current emotional context from Coors, projected into a future scenario which readers could feel and respond to. This Coors advertisement was a first step towards a nightmare scenario where every Amazon Alexa in a bedroom was a conduit for capitalizing on dreams. Yet like any dream, this future could be redirected and these feelings avoided if we took waking action.

Our communal outcry of dream scientists stirred enough of an emotional reaction to cause a public response to Coors, but it's doubtful it reached 1,400,000,000 people like their campaign did. This will be an ongoing conversation, as it should be. Around fifty percent of people under the age of 35 wake up to check their phone at least once per night, while hundreds of millions sleep with a smart speaker in their bedroom. [413,414] The digital world has already arrived at sleep's doorstep. And the case regarding what to allow into sleep is not entirely clear. Who is to say that Duolingo should not incorporate dream incubation into their language learning teaching practices and outreach? And what about Marvel giving children *Ironman* dreams?

It's not evident that the ethical authority here should be the individuals who know the science best. Our responsibility is not to delimit use cases for dreaming, but instead to keep the conversation alive because, frankly, those 77% of marketers won't need the help of scientists to do dream advertising if they simply read our papers; dialogue is the only way forward. The FCC in 2021 has stated that: "Regardless of whether it is effective, the broadcast of subliminal material is inconsistent with a station's obligation to serve the public interest because it is designed to be deceptive." In the view of the regulatory body, a message that seeks to circumvent the awareness of a listener to influence them without their being able to assess it is, by nature, deceptive. We were thrilled to see that the latest Open Commission meeting of the FTC (4.28.22) in fact involved a discussion of TDI and advertising in dreams.[415] Nevertheless, there is no regulation specific to dream advertising, and until a Policy Enforcement Statement by the FCC or FTC directly references dream advertising there is no legal barrier. Advertising companies know this well, but they also are keeping an eye on our community of vocal researchers. The 2022 trend forecasting report from advertising giant Wunderman Thompson (20,000 employees) identified 'Dreamvertising' as rising trend #39/100, but cited our calls for regulation and warned colleagues:

> *"The commercial exploitation of dreams is becoming a reality, but not without eliciting concern from the scientific community. Calls for regulation are placing early adopters of dream incubation advertising in the spotlight. While possibilities still run wild, the next wave of subliminal marketing is uncertain. While there are no prohibitive regulations in place, some consumers could perceive such techniques as dystopian. Until we have a deeper scientific understanding, it's perhaps best that brands approach "dreamvertising" with caution."* [416]

Figure 61 We were thrilled to see that the latest Open Commission meeting of the FTC (4.28.22) involved a discussion of TDI and advertising in dreams.[415]

Chapter 9: Conclusion

This thesis offers varied data suggesting our technique of Targeted Dream Incubation can be used to direct and capture content of N1 dreams, daydreams and REM dreams; to augment creative performance and advance sense of creative self-efficacy; to increase dream related locus of control, and lessen concerns and feelings of helplessness related to nightmares. This work offers a cheap and reliable dream incubation technique; experimental evidence for a *causal* relationship between incubation of dreams and post-sleep performance; a content-controlled comparison between daydreams and night dreams; a novel route for nightmare treatment via alteration of dream-related beliefs; and a framework for understanding the relative propensity for incubation across subjects. We demonstrate the efficacy of our TDI technique at varied levels of complexity and cost (with Dormio, with EEG and without devices) and offer our software and hardware open source, free of charge. We show inter-institutional validation wherein TDI is effective in use by labs other than our own (Duke University), and offer an online curriculum should collaborators want to teach their own course on building tools for dream science. Our TDI tools are not without their risks and unknowns, and so we offer a series of art and policy projects which look to the evolving implications of dream incubation; We publish a communal code of ethics, gather a diverse community of experts for dialogue on steering the burgeoning field of dream science, call for policy changes where we can. Over many years, and with many hands, we've assembled a toolkit and created a context for a deepened understanding of the 24-hour mind which we hope can help people see, heal and explore themselves and one another.

The experiments in this thesis are an endorsement of the non-deficiency view of dreaming, and a rejection of eliminative materialism, the idea that the mental vocabulary of psychology is fated to be replaced by the material physiology of neuroscience. Taking subjective reports from sleep seriously is the only way to a full dream science, yet studies linking sleep physiology, phenomenology, and post-sleep performance are exceedingly rare.[179,417] The braids that bind the experiencing mind and sleeping brain call for work which sees both signals and selves. For scientific readers, I hope that the experiments offered here, creating dialogue across levels of consciousness while grounded in physiological data and neurally motivated hypotheses, serve as a binding thread and inspire broader examination of the brain. For non-scientist readers, I hope that the joy and newfound curiosity that subjects exhibit after TDI, evident in their reports throughout this thesis, inspires you to explore incubation on your own terms.

> *"The lines of communication between the conscious zones and unconscious zones of the human psyche have all been cut, and we have split in two."*
> Joseph Campbell, *The Hero with a Thousand Faces* (1949) [418]

These TDI experiments raise a series of tantalizing scientific questions. Does dreaming about something specific increase related memory in the morning, or do dreams instead play a role in active forgetting as Francis Crick theorized?[419] If we can now incubate specific content in dreams, we can ask about the relationship between TDI and overnight consolidation of cued versus uncued information. By allowing content-controlled comparison of dreams and waking thought, we also enable research into differences in neural activation underlying imagining, remembering or dreaming of a specific subject. What about the ties between anxious rumination in daydreams, mentation at sleep onset and content of dreams? We know that the intensity of the negative effects of daytime events on dream content predicts—in addition to emotional intensity of the dream—the effect of that dream on daytime mood.[420] TDI could enable experiments on anxiety interventions over periods of 24 hours, targeting sleep onset, dreams and daydreams. If we can cue a single word as a dream prompt, what about a sentence, what about a story that reorients perspectives? We can also imagine intervention opportunities regarding addiction: if dreams of using drugs indeed predict relapse, can TDI perhaps alter this course? [421]

There is no end to the potential directions dream incubation may take us, because the boundaries of dreams are as expansive as the minds they form within, and in turn form. Establishing specific uses for dream incubation –i.e. augmenting creativity– is necessary as it legitimizes the research, opens up avenues for granting and grounds dream science concretely. Yet asking about the utility of dreams may already overly narrow our scope of possibility. We would not, after all, ask the parallel question in wake, i.e. what use is thinking? There are questions that remain unanswered and should precede seeking utility. What is a dream, after all? And if we make it *for* something will we diminish it, and diminish ourselves? And do we need to sleep to dream? To dream to sleep? What about to imagine, to daydream, to surprise ourselves? Are dreams effective, insofar as they help us create our futures? And if so, whose effective dream are we living in now, can we practice dream incubation to collectively reimagine?

We might engage in dream incubation not necessarily to *use* our creative associations, but as a kind of exposure therapy that could lessen our fear of the mind's unpredictability and strangeness. Dream science has in the past been instrumental in pathologizing bizarreness: Allan Hobson tells us "the study of dreams is the study of a model of mental illness," and later "dreaming is not a model of a psychosis. It is a psychosis. It's just a healthy one." [422,423] To reorient this perspective, the first step is encouraging open encounters with the dreamscape, the least cognitively constrained part of our psyches. In a sense these transient, inverted worlds are best understood by being *felt*. In simply reorienting our attention towards dreams we are setting the stage for increased dream recall the following day. In that dream you may find an experience you can't quite explain, but you nevertheless created. This is an encounter with something internal, inherent and inexplicable. Resisting identifying the inexplicable with the psychotic may be an important introspective step in seeing oneself more clearly.

My hope is that readers end this thesis with renewed respect for the contributions of the dreaming mind to their wellbeing and waking cognition. The stage is set for much of established scientific knowledge about dreams to be reoriented in the coming years, i.e. suppositions that "dreaming is phenomenality pure and simple, untouched by external physical stimulation."[12] Some of these changes in the science of dreams may change popular conceptions of the self, inspiring cultural shifts in the arts and philosophy as psychoanalysis once did; the evidence, for instance, that daydreaming is neurally akin to dreaming while awake and that we daydream for the majority of our day suggests that we are *primarily* imaginative beings.[16,84] Other discoveries in sleep and dream science will inspire dialogue on ethics and agency; if stimulation in sleep can in fact alter our smoking behavior and food preferences even when we cannot recall the intervention, how should we redefine what it means to 'consciously' choose to smoke and then create necessary consumer protections? As a reader faced with these emerging possibilities and imminent questions, you now have knowledge of the relevant science, affiliated dream community, novel tools and paradigms, and a sense of what is at stake. I hope this thesis inspires you to orient your attention more fully to the night and the day.

References:

1. Kuboyama, T. *et al.* Changes in cerebral blood flow velocity in healthy young men during overnight sleep and while awake. *Electroencephalography and Clinical Neurophysiology* vol. 102 125–131 (1997).
2. Jewett, M. E. *et al.* Time course of sleep inertia dissipation in human performance and alertness. *J. Sleep Res.* **8**, 1–8 (1999).
3. Reznik, D. *et al.* Oneiric synesthesia: Preliminary evidence for the occurrence of synesthetic-like experiences during sleep-inertia. *Psychology of Consciousness: Theory, Research, and Practice* **5**, 374–383 (2018).
4. Lacaux, C. *et al.* Increased creative thinking in narcolepsy. *Brain* **142**, 1988–1999 (2019).
5. Walker, M. P., Liston, C., Hobson, J. A. & Stickgold, R. Cognitive flexibility across the sleep–wake cycle: REM-sleep enhancement of anagram problem solving. *Cognitive Brain Research* **14**, 317–324 (2002).
6. Kahan, T. L. & LaBerge, S. Lucid Dreaming as Metacognition: Implications for Cognitive Science. *Conscious. Cogn.* **3**, 246–264 (1994).
7. Revonsuo, A. The reinterpretation of dreams: an evolutionary hypothesis of the function of dreaming. *Behav. Brain Sci.* **23**, 877–901; discussion 904–1121 (2000).
8. Flanagan, O. Deconstructing Dreams: The Spandrels of Sleep. *J. Philos.* **92**, 5–27 (1995).
9. Solms. The interpretation of dreams and the neurosciences. *Developmental Science and Psychoanalysis* doi:10.4324/9780429473654-10/interpretation-dreams-neurosciences-mark-solms.
10. Organization List & Senior Management. Scientists break through the wall of sleep to the untapped world of dreams. *Beta site for NSF - National Science Foundation* https://beta.nsf.gov/science-matters/scientists-break-through-wall-sleep-untapped-world-dreams.
11. Lewis, J. R. & Oliver, E. D. *The Dream Encyclopedia*. (Visible Ink Press, 2009).
12. Windt, J. M. *Dreaming: A Conceptual Framework for Philosophy of Mind and Empirical Research*. (MIT Press, 2015).
13. Mota, N. B., Furtado, R., Maia, P. P. C., Copelli, M. & Ribeiro, S. Graph analysis of dream reports is especially informative about psychosis. *Sci. Rep.* **4**, 3691 (2014).
14. Carr, M. *et al.* Dream engineering: Simulating worlds through sensory stimulation. *Conscious. Cogn.* **83**, 102955 (2020).
15. Stickgold, R., Malia, A., Maguire, D., Roddenberry, D. & O'Connor, M. Replaying the game: hypnagogic images in normals and amnesics. *Science* **290**, 350–353 (2000).
16. Fox, K. C. R., Nijeboer, S., Solomonova, E., Domhoff, G. W. & Christoff, K. Dreaming as mind wandering: evidence from functional neuroimaging and first-person content reports. *Front. Hum. Neurosci.* **7**, 412 (2013).
17. Haskell, R. E. Cognitive Psychology and Dream Research: Historical, Conceptual, and Epistemological Considerations. *The Journal of Mind and Behavior* **7**, 131–159 (1986).
18. Giacobbe, B., Bologna, M. & Colin, G. *Visionary dictionary: Beppe Giacobbe from A to Z*. (Lazy Dog Press, 2013).
19. Roberts, J. *Dario Robleto Unknown and Solitary Seas: Dreams and Emotions of the 19th Century*. (2019).
20. Gutta percha, the untold story. *Forest Research Institute Malaysia (FRIM)* https://www.frim.gov.my/gutta-percha-the-untold-story/.

21. Mosso, A. *Fear*. (Alpha Edition, 2022).
22. Sonolet, J. *Etienne Jules Marey (1830-1904) : the graphic method and cardiovascular research*. (1980).
23. Grafman, J. Conceptualizing functional neuroplasticity. *J. Commun. Disord.* **33**, 345–55; quiz 355–6 (2000).
24. Rule, M. E., O'Leary, T. & Harvey, C. D. Causes and consequences of representational drift. *Curr. Opin. Neurobiol.* **58**, 141–147 (2019).
25. Klink, P. C. *et al.* Combining Brain Perturbation and Neuroimaging in Non-human Primates. doi:10.31219/osf.io/z4x89.
26. Lakoff, G. How Metaphor Structures Dreams. in *Dreams: A Reader on Religious, Cultural, and Psychological Dimensions of Dreaming* (ed. Bulkeley, K.) 265–284 (Palgrave Macmillan US, 2001).
27. Simon, S. S., Tusch, E. S., Holcomb, P. J. & Daffner, K. R. Increasing Working Memory Load Reduces Processing of Cross-Modal Task-Irrelevant Stimuli Even after Controlling for Task Difficulty and Executive Capacity. *Front. Hum. Neurosci.* **0**, (2016).
28. Nir, Y. & Tononi, G. Dreaming and the brain: from phenomenology to neurophysiology. *Trends in Cognitive Sciences* vol. 14 88–100 (2010).
29. Irwin, L. *The Dream Seekers: Native American Visionary Traditions of the Great Plains*. (University of Oklahoma Press, 1996).
30. Jarvis, B. Did Covid Change How We Dream? *The New York Times* (2021).
31. Patton, K. C. 'A Great and Strange Correction': Intentionality, Locality, and Epiphany in the Category of Dream Incubation. *History of Religions* vol. 43 194–223 (2004).
32. Nielsen, T. & Powell, R. A. Dreams of the Rarebit Fiend: food and diet as instigators of bizarre and disturbing dreams. *Frontiers in Psychology* vol. 6 (2015).
33. Szpakowska, K. *Behind Closed Eyes: Dreams and Nightmares in Ancient Egypt*. (ISD LLC, 2003).
34. Rees, B. R. Chester Beatty Papyri. Papyri from Panopolis in the Chester Beatty Library, Dublin. Ed. T. C. Skeat (Chester Beatty Monographs, No. 10). Dublin: The Chester Beatty Library, 1964. Pp. xliv 194, 3 plates. £6. *Journal of Roman Studies* vol. 56 257–258 (1966).
35. Bulkeley, K. *Dreaming in the World's Religions*. (New York University Press, 2008).
36. Abrahamson, E. L. Euripides' Tragedy of Hecuba. *Trans. Proc. Am. Philol. Assoc.* **83**, 120–129 (1952).
37. Homer. *The Iliad of Homer*. (University of Chicago Press, 2011).
38. Houtman, C. What Did Jacob See in His Dream at Bethel?: Some Remarks on Genesis XXVIII 10-22. *Vetus Testamentum* **27**, 337–351 (1977).
39. Martínez, F. G. & García Martínez, F. Correnti culturali e movimenti religiosi del giudaismo. Atti del V Congresso internazionale dell'AISG. S. Miniato, 12-15 novembre 1984. B. CHIESA (ed.) (Associazione italiana per lo studio del giudaismo. Testi e studi 5), Carucci editore, Roma 1987, 336 pp., paper L. 40.000. *Journal for the Study of Judaism* vol. 19 98–99 (1988).
40. Heschel, A. J. *Prophetic Inspiration After the Prophets: Maimonides and Other Medieval Authorities*. (KTAV Publishing House, Inc., 1996).
41. Edgar, I. & Henig, D. Istikhara: The Guidance and Practice of Islamic Dream Incubation Through Ethnographic Comparison. *Hist. Anthropol. Chur.* **21**, 251–262 (2010).

42. Bulkeley, K. *Dreams: A Reader on Religious, Cultural and Psychological Dimensions of Dreaming*. (Springer, 2016).

43. Butler. A few rules for predicting the future. *Essence* .

44. Brill, A. A. & Freud, S. THE INTERPRETATION OF DREAMS. *J. Nerv. Ment. Dis.* **79**, 223 (1934).

45. Offord, C. Scientists engineer dreams to understand the sleeping brain. *The Scientist Magazine®* https://www.the-scientist.com/features/scientists-engineer-dreams-to-understand-the-sleeping-brain-68170.

46. Maury, A. *Le sommeil et les rêves: études psychologiques sur ces phénomènes et les divers états qui s'y rattachent*. (Didier, 1878).

47. Foulkes, D. & Rechtschaffen, A. Presleep determinants of dream content: Effects of two films. *Percept. Mot. Skills* (1964).

48. Cartwright, R. D. *Night Life: Explorations in Dreaming*. (Prentice Hall, 1977).

49. Koulack, D. *To Catch A Dream: Explorations of Dreaming*. (SUNY Press).

50. Breger, L., Hunter, I. & Lane, R. W. The effect of stress on dreams. *Psychol. Issues* **7**, 1–213 (1971).

51. Rechtschaffen, A. & Foulkes, D. EFFECT OF VISUAL STIMULI ON DREAM CONTENT. *Percept. Mot. Skills* **20**, SUPPL:1149–60 (1965).

52. Dement, W. C., Kahn, E. & Roffwarg, H. P. THE INFLUENCE OF THE LABORATORY SITUATION ON THE DREAMS OF THE EXPERIMENTAL SUBJECT. *J. Nerv. Ment. Dis.* **140**, 119–131 (1965).

53. Solomonova & Carr. Incorporation of external stimuli into dream content. *Dreams: understanding biology*.

54. Stevenson, A. *Oxford Dictionary of English*. (OUP Oxford, 2010).

55. Wamsley, E. J. Dreaming and Offline Memory Consolidation. *Current Neurology and Neuroscience Reports* vol. 14 (2014).

56. Berry, R. B. *et al.* Darien, IL: American Academy of Sleep Medicine; 2012. The AASM manual for the scoring of sleep and associated events: rules, terminology and technical specifications, version 2.0. (2012).

57. Berry, R. B. Central Sleep Apnea. *Clinical Sleep Disorders* 331 (2012).

58. McKELLAR, P. & Simpson, L. BETWEEN WAKEFULNESS AND SLEEP: HYPNAGOGIC IMAGERY. *British Journal of Psychology. General Section* vol. 45 266–276 (1954).

59. Nielsen, T. Microdream neurophenomenology. *Neurosci Conscious* **2017**, nix001 (2017).

60. Tanaka, H., Hayashi, M. & Hori, T. Statistical features of hypnagogic EEG measured by a new scoring system. *Sleep* **19**, 731–738 (1996).

61. Hori, T., Hayashi, M. & Morikawa, T. Topographical EEG changes and the hypnagogic experience. in *Sleep onset: Normal and abnormal processes , (pp* (ed. Ogilvie, R. D.) vol. 397 237–253 (American Psychological Association, xxviii, 1994).

62. Berry, R. B. Sleep Architecture Parameters, Normal Sleep, and Sleep Loss. *Fundamentals of Sleep Medicine* 79–90 (2012) doi:10.1016/b978-1-4377-0326-9.00006-3.

63. Speth, J., Schloerscheidt, A. M. & Speth, C. Mental time travel to the future might be reduced in sleep. *Consciousness and Cognition* vol. 48 180–189 (2017).

64. Wamsley, E. J. *et al.* Reduced sleep spindles and spindle coherence in schizophrenia: mechanisms of impaired memory consolidation? *Biol. Psychiatry* **71**, 154–161 (2012).

65. Nielsen, T. *et al.* NREM sleep spindles are associated with dream recall. *Sleep spindl. cortical states* **1**, 27–41 (2017).

66. Cavallero, C., Cicogna, P., Natale, V., Occhionero, M. & Zito, A. Slow Wave Sleep Dreaming. *Sleep* vol. 15 562–566 (1992).

67. Tononi, G. & Cirelli, C. Sleep function and synaptic homeostasis. *Sleep Med. Rev.* **10**, 49–62 (2006).

68. Siclari, F. & Tononi, G. Local aspects of sleep and wakefulness. *Curr. Opin. Neurobiol.* **44**, 222–227 (2017).

69. Gujar, N., McDonald, S. A., Nishida, M. & Walker, M. P. A role for REM sleep in recalibrating the sensitivity of the human brain to specific emotions. *Cereb. Cortex* **21**, 115–123 (2011).

70. Nielsen, T. & Carr, M. Nightmares and Nightmare Function. *Principles and Practice of Sleep Medicine* 546–554.e5 (2017) doi:10.1016/b978-0-323-24288-2.00053-2.

71. Lee, Y. J., Lee, J. Y., Cho, J. H. & Choi, J. H. Interrater reliability of sleep stage scoring: a meta-analysis. *J. Clin. Sleep Med.* **18**, 193–202 (2022).

72. Solms, M. *The Feeling Brain: Selected Papers on Neuropsychoanalysis*. (Routledge, 2018).

73. Suni, E. Sleep quality: How to determine if you're getting poor sleep. *Sleep Foundation* https://www.sleepfoundation.org/sleep-hygiene/how-to-determine-poor-quality-sleep (2020).

74. Naiman, R. Dreamless: the silent epidemic of REM sleep loss. *Ann. N. Y. Acad. Sci.* **1406**, 77–85 (2017).

75. Stickgold, R. Inclusive versus exclusive approaches to sleep and dream research. *Behav. Brain Sci.* **23**, 1011–1013 (2000).

76. Voss, U., Holzmann, R., Tuin, I. & Hobson, J. A. Lucid dreaming: a state of consciousness with features of both waking and non-lucid dreaming. *Sleep* **32**, 1191–1200 (2009).

77. Christoff, K., Irving, Z. C., Fox, K. C. R., Spreng, R. N. & Andrews-Hanna, J. R. Mind-wandering as spontaneous thought: a dynamic framework. *Nat. Rev. Neurosci.* **17**, 718–731 (2016).

78. Kam, J. W. Y. & Handy, T. C. The neurocognitive consequences of the wandering mind: a mechanistic account of sensory-motor decoupling. *Front. Psychol.* **4**, 725 (2013).

79. Moran, J. M., Kelley, W. M. & Heatherton, T. F. What Can the Organization of the Brain's Default Mode Network Tell us About Self-Knowledge? *Frontiers in Human Neuroscience* vol. 7 (2013).

80. Edwards, C. L. *et al.* Comparing personal insight gains due to consideration of a recent dream and consideration of a recent event using the Ullman and Schredl dream group methods. *Front. Psychol.* **6**, 831 (2015).

81. Quercia, A., Zappasodi, F., Committeri, G. & Ferrara, M. Local Use-Dependent Sleep in Wakefulness Links Performance Errors to Learning. *Front. Hum. Neurosci.* **12**, 122 (2018).

82. Perogamvros, L. *et al.* The Phenomenal Contents and Neural Correlates of Spontaneous Thoughts across Wakefulness, NREM Sleep, and REM Sleep. *J. Cogn. Neurosci.* **29**, 1766–1777 (2017).

83. Freud, S. I. Creative Writers and Daydreaming. in *Literature and Psychoanalysis* 19–28 (Columbia University Press, 1983).

84. Killingsworth, M. A. & Gilbert, D. T. A wandering mind is an unhappy mind. *Science* **330**, 932 (2010).

85. Reichle, E. D., Reineberg, A. E. & Schooler, J. W. Eye movements during mindless reading. *Psychol. Sci.* **21**, 1300–1310 (2010).

86. Baird, B., Smallwood, J. & Schooler, J. W. Back to the future: Autobiographical planning and the functionality of mind-wandering. *Consciousness and Cognition* vol. 20 1604–1611 (2011).

87. Dobson, C. & Christoff, K. Chapter 12 - Productive mind wandering in design practice. in *Creativity and the Wandering Mind*

(eds. Preiss, D. D., Cosmelli, D. & Kaufman, J. C.) 271–281 (Academic Press, 2020).

88. Seli, P., Risko, E. F., Smilek, D. & Schacter, D. L. Mind-Wandering With and Without Intention. *Trends Cogn. Sci.* **20**, 605–617 (2016).

89. Wei, S. L. The Absence of Sin in Sexual Dreams in the Writings of Augustine and Cassian. *Vigiliae Christianae* **66**, 362–378 (2012).

90. Fox, K. C. R. & Christoff, K. *The Oxford Handbook of Spontaneous Thought: Mind-wandering, Creativity, and Dreaming*. (Oxford University Press, 2018).

91. van Rijn, E. *et al.* The dream-lag effect: Selective processing of personally significant events during Rapid Eye Movement sleep, but not during Slow Wave Sleep. *Neurobiology of Learning and Memory* vol. 122 98–109 (2015).

92. Spellberg, M. Wittgenstein's dream, 13 January 1922. https://www.cabinetmagazine.org/issues/67/spellberg2.php.

93. Bailey, C. Remembering the Lotus-Born: Padmasambhava in the History of Tibet's Golden Age, by Daniel A. Hirshberg. *International Journal of Buddhist Thought and Culture* vol. 28 217–222 (2018).

94. Windt & Voss. Spontaneous thought, insight, and control in lucid dreams. *The Oxford handbook of spontaneous thought*.

95. Malcolm, N. Stern's Dreaming. *Analysis* **20**, 47–47 (1959).

96. Dement, W. & Wolpert, E. A. Relationships in the manifest content of dreams occurring on the same night. *J. Nerv. Ment. Dis.* **126**, 568–578 (1958).

97. Price, R. F. & Cohen, D. B. Lucid Dream Induction. in *Conscious Mind, Sleeping Brain: Perspectives on Lucid Dreaming* (eds. Gackenbach, J. & LaBerge, S.) 105–134 (Springer New York, 1988).

98. Hearne, K. M. T. Lucid dreams : an elecro-physiological and psychological study. (Liverpool University, 1978).

99. Zadra, A. What dream characters reveal about the astonishing dreaming brain. *Psyche* https://psyche.co/ideas/what-dream-characters-reveal-about-the-astonishing-dreaming-brain (2021).

100. Kahn, D. & Hobson, J. A. State-dependent thinking: a comparison of waking and dreaming thought. *Conscious. Cogn.* **14**, 429–438 (2005).

101. Kahan, T., Worsley, A. & Blagrove, M. What You Cannot Do in a Lucid Dream. *Self & Society* **23**, 10–13 (1995).

102. Schredl, M., Fuchs, C. & Mallett, R. Differences between lucid and nonlucid dream reports: A within-subjects design. in *No Pagination Specified* (ed. Dreaming, A.) (2022).

103. Dresler, M. *et al.* Dreamed movement elicits activation in the sensorimotor cortex. *Curr. Biol.* **21**, 1833–1837 (2011).

104. Schultes, R. E. & Hofmann, A. Plants of the gods: their sacred, healing, and hallucinogenic powers. https://agris.fao.org/agris-search/search.do?recordID=US19930094591.

105. Preller, K. H. *et al.* The Fabric of Meaning and Subjective Effects in LSD-Induced States Depend on Serotonin 2A Receptor Activation. *Curr. Biol.* **27**, 451–457 (2017).

106. Green, W. J. LSD and the sleep-dream cycle. *Exp. Med. Surg.* **27**, 138–144 (1969).

107. Strassman, R. *DMT: The Spirit Molecule: A Doctor's Revolutionary Research into the Biology of Near-Death and Mystical Experiences*. (Simon and Schuster, 2000).

108. Carhart-Harris, R. L. *et al.* Neural correlates of the psychedelic state as determined by fMRI studies with psilocybin. *Proc. Natl.*

Acad. Sci. U. S. A. **109**, 2138–2143 (2012).

109. Shulgin. The new psychotherapy: MDMA and the shadow. *Eleusis*.

110. Sanz, C., Zamberlan, F., Erowid, E., Erowid, F. & Tagliazucchi, E. The Experience Elicited by Hallucinogens Presents the Highest Similarity to Dreaming within a Large Database of Psychoactive Substance Reports. *Frontiers in Neuroscience* vol. 12 (2018).

111. Carhart-Harris, R. & Nutt, D. Was it a vision or a waking dream? *Front. Psychol.* **5**, 255 (2014).

112. Cicogna, P. C. & Bosinelli, M. Consciousness during dreams. *Conscious. Cogn.* **10**, 26–41 (2001).

113. Dresler, M. *et al.* Neural correlates of insight in dreaming and psychosis. *Sleep Med. Rev.* **20**, 92–99 (2015).

114. Allan Hobson, J. *The Dream Drugstore: Chemically Altered States of Consciousness*. (MIT Press, 2002).

115. Zheng, Y., Wang, D., Zhang, Y. & Xu, W. Detecting Mind Wandering: An Objective Method via Simultaneous Control of Respiration and Fingertip Pressure. *Front. Psychol.* **10**, 216 (2019).

116. Sfetcu, N. *The distinction between falsification and refutation in the demarcation problem of Karl Popper*. (MultiMedia Publishing, 2019).

117. Popper. Science as falsification. *Conjectures and refutations*.

118. Thornton, S. Karl Popper. *The Stanford Encyclopedia of Philosophy* (2021).

119. Colby, K. M. & Stoller, R. J. *Cognitive Science and Psychoanalysis*. (Routledge, 2013).

120. Grünbaum, A. Is Psychoanalysis a Pseudo-Science? Karl Popper versus Sigmund Freud. *Z. Philos. Forsch.* **31**, 333–353 (1977).

121. Freud, S. A case of paranoia running counter to the psycho-analytic theory of the disease (1915). *PsycEXTRA Dataset* (1971) doi:10.1037/e417472005-353.

122. Menand. Why Freud Survives. *New Yorker*.

123. Kroker, K. *The Sleep of Others and the Transformation of Sleep Research*. (University of Toronto Press, 2015).

124. Plato. *Plato: 'The Republic'*. (Cambridge University Press, 2000).

125. Panksepp, J., Siviy, S. M. & Normansell, L. A. Brain Opioids and Social Emotions. *The Psychobiology of Attachment and Separation* 3–49 (1985) doi:10.1016/b978-0-12-586780-1.50006-9.

126. Nielsen, T. A. THE NEUROPSYCHOLOGY OF DREAMS. 1997. By: Mark Solms. Published by Lawrence Erlbaum Associates. 292 pages. $C78.00. *Canadian Journal of Neurological Sciences / Journal Canadien des Sciences Neurologiques* vol. 25 346–347 (1998).

127. Szentgyorgyi & Hyp. The History of Hypnosis. *urmstonhypnotherapy.com*.

128. Janik, A. Karl Popper — The Formative Years, 1902-1945: Politics and Philosophy in Interwar Vienna. By Malachi Haim Hacohen. Cambridge, UK: Cambridge University Press. 2000. Pp. xiv 610. $54.95. ISBN 0-521-47053-6. *Central European History* vol. 35 613–616 (2002).

129. Bloom. FREUD, THE GREATEST MODERN WRITER+ LEGACY OF HIS WORK. *N. Y. times book rev.*

130. Baars, B. J. Global workspace theory of consciousness: toward a cognitive neuroscience of human experience. *Prog. Brain Res.* **150**, 45–53 (2005).

131. Wagman, M. *Historical Dictionary of Quotations in Cognitive Science: A Treasury of Quotations in Psychology, Philosophy, and Artificial Intelligence*. (Greenwood Publishing Group, 2000).

132. Howard. Sweet dreams are made of this: why dream analysis is flourishing. *The guardian*.

133. Hobson, J. A. & McCarley, R. W. The brain as a dream state generator: an activation-synthesis hypothesis of the dream process. *Am. J. Psychiatry* **134**, 1335–1348 (1977).

134. Rosenberg, A. E. by J. *Harvard Magazine: May - June 1998, Volume 100, Number 5*. (The Harvard Advocate, 1998).

135. Allan Hobson, J. *The Dreaming Brain*. (Basic Books, 1988).

136. Malinowski, J., Carr, M. & Edwards, C. The effects of dream rebound: evidence for emotion processing theories of dreaming. *J. Sleep Res.* (2019).

137. Rasch, B. & Born, J. About sleep's role in memory. *Physiol. Rev.* **93**, 681–766 (2013).

138. Peigneux, P. *et al.* Learned material content and acquisition level modulate cerebral reactivation during posttraining rapid-eye-movements sleep. *Neuroimage* **20**, 125–134 (2003).

139. Antony, Lurie, Brooks & Paller. Targeted memory reactivation during sleep elicits neural signals related to learning content. *J. At. Mol. Phys.*

140. Oudiette, D. & Paller, K. A. Upgrading the sleeping brain with targeted memory reactivation. *Trends Cogn. Sci.* **17**, 142–149 (2013).

141. Schoch, S. F., Cordi, M. J., Schredl, M. & Rasch, B. The effect of dream report collection and dream incorporation on memory consolidation during sleep. *J. Sleep Res.* **28**, e12754 (2019).

142. Miller, G. A. The cognitive revolution: a historical perspective. *Trends Cogn. Sci.* **7**, 141–144 (2003).

143. Windt, J. M. Reporting dream experience: Why (not) to be skeptical about dream reports. *Front. Hum. Neurosci.* **7**, 708 (2013).

144. LeDoux, J., Brown, R., Pine, D. & Hofmann, S. Know thyself: well-being and subjective experience. in *Cerebrum: the Dana Forum on Brain Science* vol. 2018 (Dana Foundation, 2018).

145. Fanselow, M. S. & Pennington, Z. T. A return to the psychiatric dark ages with a two-system framework for fear. *Behav. Res. Ther.* **100**, 24–29 (2018).

146. Cygan, F., Oudiette, D., Leclair-Visonneau, L., Leu-Semenescu, S. & Arnulf, I. Night-to-Night Variability of Muscle Tone, Movements, and Vocalizations in Patients with REM Sleep Behavior Disorder. *Journal of Clinical Sleep Medicine* vol. 06 551–555 (2010).

147. Nagel, T. Dreaming. *Analysis* **19**, 112–116 (1959).

148. Godin, I., Montplaisir, J. & Nielsen, T. Dreaming and nightmares in REM sleep behavior disorder. *Dreaming* **25**, 257–273 (2015).

149. Horikawa, T., Tamaki, M., Miyawaki, Y. & Kamitani, Y. Neural decoding of visual imagery during sleep. *Science* **340**, 639–642 (2013).

150. Lucid dreaming verified by volitional communication during REM sleep. in *Essential Sources in the Scientific Study of Consciousness* (The MIT Press, 2003).

151. Konkoly, K. R. *et al.* Real-time dialogue between experimenters and dreamers during REM sleep. *Curr. Biol.* **31**, 1417–1427.e6 (2021).

152.Siclari, F., Valli, K. & Arnulf, I. Dreams and nightmares in healthy adults and in patients with sleep and neurological disorders. *Lancet Neurol.* **19**, 849–859 (2020).

153.Rechtschaffen, A. The Psychophysiology of Mental Activity during Sleep. *The Psychophysiology of Thinking* 153–205 (1973) doi:10.1016/b978-0-12-484050-8.50011-x.

154.Rechtschaffen. Scientific method in the study of altered states of consciousness with illustrations from sleep and dream research. *Altered States of.*

155.Hurlburt, R. & Schwitzgebel, E. *Describing Inner Experience?: Proponent Meets Skeptic*. (MIT Press, 2011).

156.Soffer-Dudek, N. Arousal in Nocturnal Consciousness: How Dream- and Sleep-Experiences May Inform Us of Poor Sleep Quality, Stress, and Psychopathology. *Frontiers in Psychology* vol. 8 (2017).

157.Barrett, D. *Trauma and Dreams*. (Harvard University Press, 2001).

158.Brückl, T. M. *et al.* The biological classification of mental disorders (BeCOME) study: a protocol for an observational deep-phenotyping study for the identification of biological subtypes. *BMC Psychiatry* vol. 20 (2020).

159.Bergner, D. *The Mind and the Moon: My Brother's Story, the Science of Our Brains, and the Search for Our Psyches*. (HarperCollins, 2022).

160.Ribeiro, S. & Hahn, D. *The Oracle of Night: The History and Science of Dreams*. (Knopf Doubleday Publishing Group, 2021).

161.Ford, D. E. & Kamerow, D. B. Epidemiologic study of sleep disturbances and psychiatric disorders. An opportunity for prevention? *JAMA* **262**, 1479–1484 (1989).

162.Manber, R. *et al.* Cognitive Behavioral Therapy for Insomnia Enhances Depression Outcome in Patients with Comorbid Major Depressive Disorder and Insomnia. *Sleep* vol. 31 489–495 (2008).

163.Bernert, R. A. & Nadorff, M. R. Sleep Disturbances and Suicide Risk. *Sleep Med. Clin.* **10**, 35–39 (2015).

164.Study reports significant link between nightmares and suicidal behavior. *American Academy of Sleep Medicine – Association for Sleep Clinicians and Researchers* https://aasm.org/study-reports-significant-link-between-nightmares-and-suicidal-behavior/ (2016).

165.Tribl, G. G., Wetter, T. C. & Schredl, M. Dreaming under antidepressants: a systematic review on evidence in depressive patients and healthy volunteers. *Sleep Med. Rev.* **17**, 133–142 (2013).

166.Christo, G. & Franey, C. Addicts Drug-Related Dreams: Their Frequency and Relationship to Six-Month Outcomes. *Subst. Use Misuse* **31**, 1–15 (1996).

167.Colace. Dreams in abstinent heroin addicts: four case reports. *Sleep Hypn.*

168.Fuchs, X., Flor, H. & Bekrater-Bodmann, R. Psychological factors associated with phantom limb pain: A review of recent findings. *Pain Res. Manag.* **2018**, 5080123 (2018).

169.Tong, X. *et al.* 'I Dreamed of My Hands and Arms Moving Again': A Case Series Investigating the Effect of Immersive Virtual Reality on Phantom Limb Pain Alleviation. *Front. Neurol.* **11**, 876 (2020).

170.Otaiku, A. I. Dream Content Predicts Motor and Cognitive Decline in Parkinson's Disease. *Mov Disord Clin Pract* **8**, 1041–1051 (2021).

171.Kandel, E. *The Age of Insight: The Quest to Understand the Unconscious in Art, Mind, and Brain, from Vienna 1900 to the*

Present. (Random House Publishing Group, 2012).

172. Damasio, A. R. *The Feeling of what Happens: Body and Emotion in the Making of Consciousness*. (Houghton Mifflin Harcourt, 1999).

173. Zadra, A. & Stickgold, R. *When Brains Dream: Understanding the Science and Mystery of Our Dreaming Minds*. (W. W. Norton & Company, 2021).

174. Fosse, M. J., Fosse, R., Hobson, J. A. & Stickgold, R. J. Dreaming and episodic memory: a functional dissociation? *J. Cogn. Neurosci.* **15**, 1–9 (2003).

175. Stenstrom, P. *The Role of Sleep and Dreaming in the Processing of Episodic Memory*. (Université de Montréal (Faculté des arts et des sciences), 2010).

176. Horovitz, S. G. *et al.* Decoupling of the brain's default mode network during deep sleep. *Proc. Natl. Acad. Sci. U. S. A.* **106**, 11376–11381 (2009).

177. Wamsley, E. J. & Stickgold, R. Dreaming of a learning task is associated with enhanced memory consolidation: Replication in an overnight sleep study. *J. Sleep Res.* **28**, e12749 (2019).

178. Fogel, S. M., Ray, L. B., Sergeeva, V., De Koninck, J. & Owen, A. M. A Novel Approach to Dream Content Analysis Reveals Links Between Learning-Related Dream Incorporation and Cognitive Abilities. *Front. Psychol.* **9**, 1398 (2018).

179. Wamsley, E. J. & Stickgold, R. Memory, Sleep and Dreaming: Experiencing Consolidation. *Sleep Med. Clin.* **6**, 97–108 (2011).

180. de Koninck, J., Christ, G., Hébert, G. & Rinfret, N. Language learning efficiency, dreams and REM sleep. *Psychiatr. J. Univ. Ott.* **15**, 91–92.

181. Wamsley, E. J., Tucker, M., Payne, J. D., Benavides, J. A. & Stickgold, R. Dreaming of a learning task is associated with enhanced sleep-dependent memory consolidation. *Curr. Biol.* **20**, 850–855 (2010).

182. Nielsen, T. A., Deslauriers, D. & Baylor, G. W. Emotions in dream and waking event reports. *Dreaming* **1**, 287–300 (1991).

183. Mallett, R. *et al.* The relationship between dreams and subsequent morning mood using self-reports and text analysis. *Affec Sci* **3**, 400–405 (2022).

184. Walker, M. P. & van der Helm, E. Overnight therapy? The role of sleep in emotional brain processing. *Psychol. Bull.* **135**, 731–748 (2009).

185. Sterpenich, V., Perogamvros, L., Tononi, G. & Schwartz, S. Fear in dreams and in wakefulness: Evidence for day/night affective homeostasis. *Hum. Brain Mapp.* **41**, 840–850 (2020).

186. Cartwright, R. D. Dreams that work: The relation of dream incorporation to adaptation to stressful events. *Dreaming* **1**, 3–9 (1991).

187. Germain, A. Sleep disturbances as the hallmark of PTSD: where are we now? *Am. J. Psychiatry* **170**, 372–382 (2013).

188. Yücel, D. E., van Emmerik, A. A. P., Souama, C. & Lancee, J. Comparative efficacy of imagery rehearsal therapy and prazosin in the treatment of trauma-related nightmares in adults: A meta-analysis of randomized controlled trials. *Sleep Medicine Reviews* vol. 50 101248 (2020).

189. Titus, C. E. *et al.* What role do nightmares play in suicide? A brief exploration. *Current Opinion in Psychology* **22**, 59–62 (2018).

190. Black, J., Murkar, A. & Black, J. Examining the healing process through dreams in bereavement. *Sleep Hypn.* **16**, 10–17 (2014).

191. Edwards, C. L., Ruby, P. M., Malinowski, J. E., Bennett, P. D. & Blagrove, M. T. Dreaming and insight. *Front. Psychol.* **4**, 979 (2013).
192. Oliver, M. *A Poetry Handbook*. (Houghton Mifflin Harcourt, 1994).
193. Schredl, M. & Erlacher, D. Self-reported effects of dreams on waking-life creativity: an empirical study. *J. Psychol.* **141**, 35–46 (2007).
194. Meyer, M. L., Hershfield, H. E., Waytz, A. G., Mildner, J. N. & Tamir, D. I. Creative expertise is associated with transcending the here and now. *J. Pers. Soc. Psychol.* **116**, 483–494 (2019).
195. Lacaux, C. *et al.* Sleep onset is a creative sweet spot. *Sci Adv* **7**, eabj5866 (2021).
196. Rugg, H. Imagination. **361**, (1963).
197. Woodworth, R. S. & Schlosberg, H. *Experimental Psychology*. (Holt, 1954).
198. Jones, R. & Langley, P. *A theory of scientific problem solving*. https://apps.dtic.mil/sti/citations/ADA201437 (1988).
199. Kohn, N. W. & Smith, S. M. Collaborative fixation: Effects of others' ideas on brainstorming. *Appl. Cogn. Psychol.* **25**, 359–371 (2011).
200. Schooler, J. W. & Melcher, J. The ineffability of insight. in *The creative cognition approach , (pp* (ed. Smith, S. M.) vol. 351 97–133 (The MIT Press, viii, 1995).
201. Barrett, D. & Burguete, M. The committee of sleep: Dreams and creative problem solving. https://scimat-2015.webnode.pt/_files/200000309-775b878560/All%20Abstracts%20Invited%20Speakers.pdf.
202. Horowitz, H. & Jedidiah, A. Incubating dreams : awakening creativity. (Massachusetts Institute of Technology, 2019).
203. Haar Horowitz, A., Grover, I., Reynolds-Cuéllar, P., Breazeal, C. & Maes, P. Dormio: Interfacing with Dreams. in *Extended Abstracts of the 2018 CHI Conference on Human Factors in Computing Systems* 1–10 (Association for Computing Machinery, 2018).
204. Baird, B. *et al.* Inspired by distraction: mind wandering facilitates creative incubation. *Psychol. Sci.* **23**, 1117–1122 (2012).
205. Sio, U. N. & Ormerod, T. C. Does incubation enhance problem solving? A meta-analytic review. *Psychol. Bull.* **135**, 94–120 (2009).
206. Healy, C. J. The acute effects of classic psychedelics on memory in humans. *Psychopharmacology* **238**, 639–653 (2021).
207. Cartwright, R. D. *The Twenty-four Hour Mind: The Role of Sleep and Dreaming in Our Emotional Lives*. (Oxford University Press, 2012).
208. Sikka, P., Pesonen, H. & Revonsuo, A. Peace of mind and anxiety in the waking state are related to the affective content of dreams. *Scientific Reports* vol. 8 (2018).
209. Walker, M. P. Sleep, memory and emotion. *Prog. Brain Res.* **185**, 49–68 (2010).
210. Pace-Schott, E. F., Germain, A. & Milad, M. R. Effects of sleep on memory for conditioned fear and fear extinction. *Psychol. Bull.* **141**, 835–857 (2015).
211. Faccini, J., Joshi, V., Graziani, P. & Del-Monte, J. Non-Constructive Ruminations, Insomnia and Nightmares: Trio of Vulnerabilities to Suicide Risk. *Nat. Sci. Sleep* **14**, 433–441 (2022).
212. Kraehenmann, R. Dreams and Psychedelics: Neurophenomenological Comparison and Therapeutic Implications. *Curr.*

Neuropharmacol. **15**, 1032–1042 (2017).

213.Perdomo, V. L., Hofman, W. F. & Talamini, L. M. Sleep Fosters Insight Into Real-Life Problems. *Arch. Ital. Biol.* **156**, 87–98 (2018).

214.Thomas, K. S., Bower, J., Hoyt, M. A. & Sepah, S. Disrupted sleep in breast and prostate cancer patients undergoing radiation therapy: the role of coping processes. *Psychooncology* **19**, 767–776 (2010).

215.Zalta, A. K. *et al.* Sleep quality predicts treatment outcome in CBT for social anxiety disorder. *Depress. Anxiety* **30**, 1114–1120 (2013).

216.Yaden, D. B. & Griffiths, R. R. The Subjective Effects of Psychedelics Are Necessary for Their Enduring Therapeutic Effects. *ACS Pharmacol Transl Sci* **4**, 568–572 (2021).

217.Blagrove, M. *et al.* Dream sharing and the enhancement of empathy: Theoretical and applied implications. *Dreaming* **31**, 128–139.

218.Guadagni, V., Burles, F., Ferrara, M. & Iaria, G. The effects of sleep deprivation on emotional empathy. *J. Sleep Res.* **23**, 657–663 (2014).

219.Holze, F., Avedisian, I., Varghese, N., Eckert, A. & Liechti, M. E. Role of the 5-HT2A Receptor in Acute Effects of LSD on Empathy and Circulating Oxytocin. *Front. Pharmacol.* **12**, 711255 (2021).

220.Schofield, D. Lucid dreamers are using unproven tech to hack their sleep. *WIRED UK* https://www.wired.co.uk/article/lucid-dreaming-tech (2021).

221.Kouider, S., Andrillon, T., Barbosa, L. S., Goupil, L. & Bekinschtein, T. A. Inducing task-relevant responses to speech in the sleeping brain. *Curr. Biol.* **24**, 2208–2214 (2014).

222.Fogel, S. *et al.* While you were sleeping: Evidence for high-level executive processing of an auditory narrative during sleep. *Conscious. Cogn.* **100**, 103306 (2022).

223.Bokert, E. G. THE EFFECTS OF THIRST AND A RELATED VERBAL STIMULUS ON DREAM REPORTS. (1967).

224.De Koninck, J. M. & Koulack, D. Dream content and adaptation to a stressful situation. *J. Abnorm. Psychol.* **84**, 250–260 (1975).

225.Haar Horowitz, A., Cunningham, T. J., Maes, P. & Stickgold, R. Dormio: A targeted dream incubation device. *Conscious. Cogn.* **83**, 102938 (2020).

226.Nielsen & Zadra. Nightmares and other common dream disturbances. *Principles and practice of sleep medicine*.

227.Sauvageau, A., Nielsen, T. A. & Montplaisir, J. Effects of Somatosensory Stimulation on Dream Content in Gymnasts and Control Participants: Evidence of Vestibulomotor Adaptation in REM Sleep. *Dreaming* **8**, 125–134 (1998).

228.Koulack, D. Effects of somatosensory stimulation on dream content. *Arch. Gen. Psychiatry* **20**, 718–725 (1969).

229.Noreika, V. *et al.* Modulating dream experience: Noninvasive brain stimulation over the sensorimotor cortex reduces dream movement. *Sci. Rep.* **10**, 6735 (2020).

230.Schredl, M. & Erlacher, D. Fever Dreams: An Online Study. *Front. Psychol.* **11**, 53 (2020).

231.O'Nell, C. W. A Cross-Cultural Study of Hunger and Thirst Motivation Manifested in Dreams. *Hum. Dev.* **8**, 181–193 (1965).

232.Rozen, N. & Soffer-Dudek, N. Dreams of Teeth Falling Out: An Empirical Investigation of Physiological and Psychological

Correlates. *Front. Psychol.* **9**, 1812 (2018).

233.Yu, C. K.-C. Recurrence of typical dreams and the instinctual and delusional predispositions of dreams. *Dreaming* **20**, 254–279 (2010).

234.Nielsen, T. A. Changes in the kinesthetic content of dreams following somatosensory stimulation of leg muscles during REM sleep. *Dreaming* **3**, 99–113 (1993).

235.Schredl, M. *et al.* Information processing during sleep: the effect of olfactory stimuli on dream content and dream emotions. *J. Sleep Res.* **18**, 285–290 (2009).

236.LaBerge, S. & Levitan, L. Validity established of DreamLight cues for eliciting lucid dreaming. *Dreaming* vol. 5 159–168 (1995).

237.Stocks, A. *et al.* Dream lucidity is associated with positive waking mood. *Conscious. Cogn.* **83**, 102971 (2020).

238.Carr, M. *et al.* Combining presleep cognitive training and REM-sleep stimulation in a laboratory morning nap for lucid dream induction. *Psychology of Consciousness: Theory, Research, and Practice* (2020) doi:10.1037/cns0000227.

239.Kitson, A., DiPaola, S. & Riecke, B. E. Lucid Loop: A Virtual Deep Learning Biofeedback System for Lucid Dreaming Practice. in *Extended Abstracts of the 2019 CHI Conference on Human Factors in Computing Systems* 1–6 (Association for Computing Machinery, 2019).

240.Nielsen, T. The COVID-19 Pandemic Is Changing Our Dreams. *Scientific American* doi:10.1038/scientificamerican1020-30.

241.Barrett, D. The ‘committee of sleep’: A study of dream incubation for problem solving. *Dreaming* **3**, 115–122 (1993).

242.Ngo, H.-V. V., Seibold, M., Boche, D. C., Mölle, M. & Born, J. Insights on auditory closed-loop stimulation targeting sleep spindles in slow oscillation up-states. *J. Neurosci. Methods* **316**, 117–124 (2019).

243.Hu, X., Cheng, L. Y., Chiu, M. H. & Paller, K. A. Promoting memory consolidation during sleep: A meta-analysis of targeted memory reactivation. *Psychol. Bull.* **146**, 218–244 (2020).

244.Cacioppo, J. T. & Tassinary, L. G. Inferring psychological significance from physiological signals. *Am. Psychol.* **45**, 16–28 (1990).

245.Gerne & Strauch. Psychophysiological indicators of affect patterns and conversational signals during sleep. *Sleep*.

246.Krys, K. *et al.* Be Careful Where You Smile: Culture Shapes Judgments of Intelligence and Honesty of Smiling Individuals. *J. Nonverbal Behav.* **40**, 101–116 (2016).

247.Lehmann, M., Schreiner, T., Seifritz, E. & Rasch, B. Emotional arousal modulates oscillatory correlates of targeted memory reactivation during NREM, but not REM sleep. *Sci. Rep.* **6**, 39229 (2016).

248.Kisley, M. A., Olincy, A. & Freedman, R. The effect of state on sensory gating: comparison of waking, REM and non-REM sleep. *Clin. Neurophysiol.* **112**, 1154–1165 (2001).

249.Noreika, V., Valli, K., Lahtela, H. & Revonsuo, A. Early-night serial awakenings as a new paradigm for studies on NREM dreaming. *Int. J. Psychophysiol.* **74**, 14–18 (2009).

250.Ogilvie, R. D. The process of falling asleep. *Sleep Med. Rev.* **5**, 247–270 (2001).

251.Andr�s, C.-J. *et al.* Induced gamma-band activity signals awareness of change in a bistable percept during wakefulness but changes dynamics with sleep onset. *Front. Hum. Neurosci.* **9**, (2015).

252.Prerau, M. J. *et al.* Tracking the sleep onset process: an empirical model of behavioral and physiological dynamics. *PLoS*

Comput. Biol. **10**, e1003866 (2014).

253.Penzel, T., Kantelhardt, J. W., Lo, C.-C., Voigt, K. & Vogelmeier, C. Dynamics of heart rate and sleep stages in normals and patients with sleep apnea. *Neuropsychopharmacology* **28 Suppl 1**, S48–53 (2003).

254.Carskadon & Dement. Normal human sleep: an overview. *and practice of …*.

255.LeBoutillier, N. & Marks, D. F. Mental imagery and creativity: a meta-analytic review study. *Br. J. Psychol.* **94**, 29–44 (2003).

256.Horowitz, A., Esfahany, K., Gálvez, T. V., Maes, P. & Stickgold, R. Targeted Dreaming Increases Waking Creativity. (2022) doi:10.2139/ssrn.4088893.

257.Weitzman, E. D. & Kremen, H. AUDITORY EVOKED RESPONSES DURING DIFFERENT STAGES OF SLEEP IN MAN. *Electroencephalogr. Clin. Neurophysiol.* **18**, 65–70 (1965).

258.Oudiette, D., Antony, J. W., Creery, J. D. & Paller, K. A. The role of memory reactivation during wakefulness and sleep in determining which memories endure. *J. Neurosci.* **33**, 6672–6678 (2013).

259.Shimizu, R. E. *et al.* Closed-Loop Targeted Memory Reactivation during Sleep Improves Spatial Navigation. *Front. Hum. Neurosci.* **12**, 28 (2018).

260.Vargas, I. M., Schechtman, E. & Paller, K. A. Targeted memory reactivation during sleep to strengthen memory for arbitrary pairings. *Neuropsychologia* **124**, 144–150 (2019).

261.Ritter, S. M., Strick, M., Bos, M. W., van Baaren, R. B. & Dijksterhuis, A. Good morning creativity: task reactivation during sleep enhances beneficial effect of sleep on creative performance. *J. Sleep Res.* **21**, 643–647 (2012).

262.Stickgold, R. & Walker, M. To sleep, perchance to gain creative insight? *Trends Cogn. Sci.* **8**, 191–192 (2004).

263.Mavromatis, A. *Hypnagogia: The Unique State of Consciousness Between Wakefulness and Sleep*. (2010).

264.Chow, H. M. *et al.* Rhythmic alternating patterns of brain activity distinguish rapid eye movement sleep from other states of consciousness. *Proc. Natl. Acad. Sci. U. S. A.* **110**, 10300–10305 (2013).

265.Stickgold, R., Scott, L., Rittenhouse, C. & Hobson, J. A. Sleep-induced changes in associative memory. *J. Cogn. Neurosci.* **11**, 182–193 (1999).

266.Guilford, J. P. Creativity: Yesterday, today and tomorrow. *J. Creat. Behav.* **1**, 3–14 (1967).

267.Antrobus, J. S. & Wamsley, E. J. Sleep Mentation in REM and NREM: A Cognitive Neuroscience Perspective☆. *Reference Module in Neuroscience and Biobehavioral Psychology* (2017) doi:10.1016/b978-0-12-809324-5.02859-5.

268.De Koninck, J., Christ, G., Hébert, G. & Rinfret, N. Language learning efficiency, dreams and REM sleep. *Psychiatr. J. Univ. Ott.* **15**, 91–92 (1990).

269.Stickgold, R. & Wamsley, E. J. Why We Dream. *Principles and Practice of Sleep Medicine* 628–637 (2011) doi:10.1016/b978-1-4160-6645-3.00055-4.

270.Arnulf, I. *et al.* Will students pass a competitive exam that they failed in their dreams? *Conscious. Cogn.* **29**, 36–47 (2014).

271.Schredl, M., Frauscher, S. & Shendi, A. Dream recall and visual memory. *Percept. Mot. Skills* **81**, 256–258 (1995).

272.Barrett, D. *The New Science of Dreaming: Content, recall, and personality correlates*. (2007).

273.Sladeczek, I. & Domino, G. Creativity, Sleep and Primary Process Thinking in Dreams. *The Journal of Creative Behavior* vol. 19 38–46 (1985).

274. Barrett, D. *The Committee of Sleep: How Artists, Scientists, and Athletes Use Dreams for Creative Problem-solving-- and how You Can, Too*. (Crown, 2001).

275. Barrett, D. Dreams and creative problem-solving. *Ann. N. Y. Acad. Sci.* **1406**, (2017).

276. Nir, Y. & Tononi, G. Dreaming and the brain: from phenomenology to neurophysiology. *Trends Cogn. Sci.* **14**, 88–100 (2010).

277. Horowitz, A. J. H. *Incubating Dreams: Awakening Creativity*. (2019).

278. Horowitz, A. H., Grover, I., Reynolds-Cuéllar, P., Breazeal, C. & Maes, P. Dormio. *Extended Abstracts of the 2018 CHI Conference on Human Factors in Computing Systems - CHI '18* (2018) doi:10.1145/3170427.3188403.

279. Zadra, A. & Stickgold, R. *When Brains Dream: Exploring the Science and Mystery of Sleep*. (W. W. Norton & Company, 2021).

280. Wamsley, E. J., Perry, K., Djonlagic, I., Reaven, L. B. & Stickgold, R. Cognitive replay of visuomotor learning at sleep onset: temporal dynamics and relationship to task performance. *Sleep* **33**, 59–68 (2010).

281. Beghetto, R. A. Creative Self-efficacy Scale. *PsycTESTS Dataset* (2017) doi:10.1037/t61972-000.

282. Martindale, C., Hines, D., Mitchell, L. & Covello, E. EEG alpha asymmetry and creativity. *Personality and Individual Differences* vol. 5 77–86 (1984).

283. Howard-Jones, P. A., Blakemore, S.-J., Samuel, E. A., Summers, I. R. & Claxton, G. Semantic divergence and creative story generation: an fMRI investigation. *Brain Res. Cogn. Brain Res.* **25**, 240–250 (2005).

284. Carroll, J. B. & Guilford, J. P. The Nature of Human Intelligence. *American Educational Research Journal* vol. 5 249 (1968).

285. Fink, A., Benedek, M., Grabner, R. H., Staudt, B. & Neubauer, A. C. Creativity meets neuroscience: experimental tasks for the neuroscientific study of creative thinking. *Methods* **42**, 68–76 (2007).

286. Heinen, D. J. P. & Johnson, D. R. Semantic distance: An automated measure of creativity that is novel and appropriate. *Psychology of Aesthetics, Creativity, and the Arts* vol. 12 144–156 (2018).

287. Ritter, S. M. & Mostert, N. Enhancement of Creative Thinking Skills Using a Cognitive-Based Creativity Training. *Journal of Cognitive Enhancement* vol. 1 243–253 (2017).

288. Prabhakaran, R., Green, A. E. & Gray, J. R. Thin slices of creativity: using single-word utterances to assess creative cognition. *Behav. Res. Methods* **46**, 641–659 (2014).

289. Zedelius, C. M., Mills, C. & Schooler, J. W. Beyond subjective judgments: Predicting evaluations of creative writing from computational linguistic features. *Behav. Res. Methods* **51**, 879–894 (2019).

290. Kenett, Y. N. What can quantitative measures of semantic distance tell us about creativity? *Current Opinion in Behavioral Sciences* vol. 27 11–16 (2019).

291. Torrance, E. P. *Predictive Validity of the Torrance Tests of Creative Thinking*. (1972).

292. Baer, J. & McKool, S. S. Assessing Creativity Using the Consensual Assessment Technique. *Handbook of Research on Assessment Technologies, Methods, and Applications in Higher Education* 65–77 (2009) doi:10.4018/978-1-60566-667-9.ch004.

293. Kovas, Y. Assessing Creative Expressiveness In Children's Written Stories Using The Consensual Assessment Technique. (2018) doi:10.15405/epsbs.2018.11.02.80.

294. Pennington, J., Socher, R. & Manning, C. D. GloVe: Global Vectors for Word Representation. in *Proceedings of the 2014*

Conference on Empirical Methods in Natural Language Processing (EMNLP) 1532–1543 (2014).

295. O'Neill, R. T. Secondary endpoints cannot be validly analyzed if the primary endpoint does not demonstrate clear statistical significance. *Control. Clin. Trials* **18**, 550–6; discussion 561–7 (1997).

296. Nardo, Saisana, Saltelli & Tarantola. Hoffman a., Giovannini E. Handbook on Constructing Composite Indicators: Methodology and User Guide. *Methodology* .

297. Song, M.-K., Lin, F.-C., Ward, S. E. & Fine, J. P. Composite variables: when and how. *Nurs. Res.* **62**, 45–49 (2013).

298. Rubin, M. When to adjust alpha during multiple testing: a consideration of disjunction, conjunction, and individual testing. *Synthese* **199**, 10969–11000 (2021).

299. Wobbrock, J. O., Findlater, L., Gergle, D. & Higgins, J. J. The aligned rank transform for nonparametric factorial analyses using only anova procedures. in *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* 143–146 (Association for Computing Machinery, 2011).

300. Elkin, L. A., Kay, M., Higgins, J. J. & Wobbrock, J. O. An Aligned Rank Transform Procedure for Multifactor Contrast Tests. in *The 34th Annual ACM Symposium on User Interface Software and Technology* 754–768 (Association for Computing Machinery, 2021).

301. Hsu, J. *Multiple Comparisons: Theory and Methods*. (CRC Press, 1996).

302. Allen, M., Poggiali, D., Whitaker, K., Marshall, T. R. & Kievit, R. A. Raincloud plots: a multi-platform tool for robust data visualization. *Wellcome Open Res* **4**, 63 (2019).

303. Seli, P. *On the Theoretical Importance of Distinguishing Between Intentional and Unintentional Types of Mind Wandering*. (2015).

304. Preiss, D. D., Cosmelli, D. & Kaufman, J. C. *Creativity and the Wandering Mind: Spontaneous and Controlled Cognition*. (Academic Press, 2020).

305. Dumpert, J. *Liminal Dreaming: Exploring Consciousness at the Edges of Sleep*. (North Atlantic Books, 2019).

306. Crawford, J. R. & Garthwaite, P. H. Single-case research in neuropsychology: a comparison of five forms of t-test for comparing a case to controls. *Cortex* **48**, 1009–1016 (2012).

307. Crawford, J. R. & Howell, D. C. Comparing an Individual's Test Score Against Norms Derived from Small Samples. *Clin. Neuropsychol.* **12**, 482–486 (1998).

308. Dietrich, A. Functional neuroanatomy of altered states of consciousness: the transient hypofrontality hypothesis. *Conscious. Cogn.* **12**, 231–256 (2003).

309. Simonton, D. K. Creativity and Discovery as Blind Variation: Campbell's (1960) BVSR Model after the Half-Century Mark. *Review of General Psychology* vol. 15 158–174 (2011).

310. Bizarreness in dreams and fantasies: Implications for the activation-synthesis hypothesis. *Conscious. Cogn.* **1**, 172–185 (1992).

311. Stenstrom, P., Fox, K., Solomonova, E. & Nielsen, T. *Mentation during sleep onset theta bursts in a trained participant: A role for NREM stage 1 sleep in memory processing?* (Citeseer, 2012).

312. Speth, J., Schloerscheidt, A. M. & Speth, C. As we fall asleep we forget about the future: A quantitative linguistic analysis of mentation reports from hypnagogia. *Conscious. Cogn.* **45**, 235–244 (2016).

313. Starker, S. Daydreaming styles and nocturnal dreaming. *J. Abnorm. Psychol.* **83**, 52–55 (1974).

314. Strauch, I. & Lederbogen, S. The Home Dreams and Waking Fantasies of Boys and Girls Between Ages 9 and 15: A Longitudinal Study. *Dreaming* **9**, 153–161 (1999).

315. Bizarreness in dreams and waking fantasy: Ruth reinsel, John Antrobus, and Miriam Wollman. in *The Neuropsychology of Sleep and Dreaming* 162–189 (Psychology Press, 2013).

316. Jordano, M. L. & Touron, D. R. Priming performance-related concerns induces task-related mind-wandering. *Conscious. Cogn.* **55**, 126–135 (2017).

317. Carr, M., Blanchette-Carrière, C., Solomonova, E., Paquette, T. & Nielsen, T. Intensified daydreams and nap dreams in frequent nightmare sufferers. *Dreaming* **26**, 119–131.

318. Smallwood, J. *et al.* Representing Representation: Integration between the Temporal Lobe and the Posterior Cingulate Influences the Content and Form of Spontaneous Thought. *PLoS One* **11**, e0152272 (2016).

319. Vrana, S. R., Bono, R. S., Konig, A. & Scalzo, G. C. Assessing the coherence of narratives of traumatic events with latent semantic analysis. *Psychol. Trauma* **11**, 521–524 (2019).

320. Cer, D. *et al.* Universal Sentence Encoder. *arXiv [cs.CL]* (2018).

321. Morris, P. E. & Fritz, C. O. Effect sizes in memory research. *Memory* **21**, 832–842 (2013).

322. Cohen, L., Manion, L. & Morrison, K. Statistical significance, effect size and statistical power. *Research Methods in Education* 739–752 (2017) doi:10.4324/9781315456539-39.

323. Green, G. H. & Diggle, P. J. On the operational characteristics of the Benjamini and Hochberg False Discovery Rate procedure. *Stat. Appl. Genet. Mol. Biol.* **6**, Article27 (2007).

324. Piccione, C., Hilgard, E. R. & Zimbardo, P. G. On the degree of stability of measured hypnotizability over a 25-year period. *J. Pers. Soc. Psychol.* **56**, 289–295 (1989).

325. Broadbent, D. E. Failures of attention in selective listening. *J. Exp. Psychol.* **44**, 428–433 (1952).

326. Hammond, M. M., Neff, N. L., Farr, J. L., Schwall, A. R. & Zhao, X. Predictors of individual-level innovation at work: A meta-analysis. *Psychology of Aesthetics, Creativity, and the Arts* **5**, 90–105 (2011).

327. Tierney, P. & Farmer, S. M. Creative Self-Efficacy: Its Potential Antecedents and Relationship to Creative Performance. *Academy of Management Journal* vol. 45 1137–1148 (2002).

328. Waggoner, R. & McCready, C. *Lucid Dreaming, Plain and Simple: Tips and Techniques for Insight, Creativity, and Personal Growth*. (Conari Press, 2015).

329. Krakow, B. & Zadra, A. Imagery Rehearsal Therapy: Principles and Practice. *Sleep Medicine Clinics* vol. 5 289–298 (2010).

330. Balliett, N. E., Davis, J. L. & Miller, K. E. Efficacy of a brief treatment for nightmares and sleep disturbances for veterans. *Psychol. Trauma* **7**, 507–515 (2015).

331. Harb, G. C. *et al.* Randomized Controlled Trial of Imagery Rehearsal for Posttraumatic Nightmares in Combat Veterans. *J. Clin. Sleep Med.* **15**, 757–767 (2019).

332. Cook, J. M., Thompson, R., Harb, G. C. & Ross, R. J. Cognitive−behavioral treatment for posttraumatic nightmares: An investigation of predictors of dropout and outcome. *Psychological Trauma: Theory, Research, Practice, and Policy* vol. 5

545–553 (2013).

333. Taylor, S. Outcome Predictors for Three PTSD Treatments: Exposure Therapy, EMDR, and Relaxation Training. *Journal of Cognitive Psychotherapy* vol. 17 149–162 (2003).

334. Pruiksma, K. E. *et al.* A pilot randomized controlled trial of cognitive behavioral treatment for trauma-related nightmares in active duty military personnel. *Journal of Clinical Sleep Medicine* vol. 16 29–40 (2020).

335. Edinger, J. D., Wohlgemuth, W. K., Radtke, R. A., Marsh, G. R. & Quillian, R. E. Does cognitive-behavioral insomnia therapy alter dysfunctional beliefs about sleep? *Sleep* **24**, 591–599 (2001).

336. Song, Y. *et al.* Change in Dysfunctional Sleep-Related Beliefs is Associated with Changes in Sleep and Other Health Outcomes Among Older Veterans With Insomnia: Findings From a Randomized Controlled Trial. *Ann. Behav. Med.* (2021) doi:10.1093/abm/kaab030.

337. Bandura, A. Self-efficacy: toward a unifying theory of behavioral change. *Psychol. Rev.* **84**, 191–215 (1977).

338. Rousseau, A., Dubé-Frenette, M. & Belleville, G. Self-efficacy as a Mechanism of Action of Imagery Rehearsal Therapy's Effectiveness: An Exploratory Mediation Analysis. *J. Nerv. Ment. Dis.* **206**, 749–756 (2018).

339. Wooldridge, K. L., Wallston, K. A., Graber, A. L., Brown, A. W. & Davidson, P. The relationship between health beliefs, adherence, and metabolic control of diabetes. *Diabetes Educ.* **18**, 495–500 (1992).

340. Kemp, S. Learned Helplessness, Locus of Control, Self-Efficacy. *Was Communism Doomed?* 195–214 (2016) doi:10.1007/978-3-319-32780-8_9.

341. Hiroto, D. S. Locus of control and learned helplessness. *Journal of Experimental Psychology* vol. 102 187–193 (1974).

342. Logsdon, S. A., Bourgeois, A. E. & Levenson, H. Locus of Control, Learned Helplessness, and Control of heart Rate Using Biofeedback. *Journal of Personality Assessment* vol. 42 538–544 (1978).

343. Wagner, Bourgeois & Levenson. Multidimensional locus of control and voluntary control of GSR. *Percept. Mot. Skills*.

344. Rutledge, C. M., La Guardia, A. C. & Bluestein, D. Predictors of self-efficacy for sleep in primary care. *Journal of Clinical Nursing* vol. 22 1254–1261 (2013).

345. Johnson, R. & Hlaing, E. E. Predictors of sleep quality: Depression, anxiety, and sleep self-efficacy. *Modern Psychological Studies* **25**, 4 (2020).

346. Morin, C. M., Vallières, A. & Ivers, H. Dysfunctional beliefs and attitudes about sleep (DBAS): validation of a brief version (DBAS-16). *Sleep* **30**, 1547–1554 (2007).

347. Halliday. Clinical utility seen in lucid dreaming ability. *Lucidity Letter*.

348. UpToDate. https://www.uptodate.com/contents/nightmares-and-nightmare-disorder-in-adults/print.

349. Miller, K. E., Davis, J. L. & Balliett, N. E. Taking Control: Examining the Influence of Locus of Control on the Treatment of Nightmares and Sleep Impairment in Veterans. *Military Behavioral Health* **2**, 337–342 (2014).

350. Beaulieu-Prévost, D., Simard, C. C. & Zadra, A. Making sense of dream experiences: A multidimensional approach to beliefs about dreams. *Dreaming* vol. 19 119–134 (2009).

351. Devilly, G. J. & Borkovec, T. D. Psychometric properties of the credibility/expectancy questionnaire. *J. Behav. Ther. Exp. Psychiatry* **31**, 73–86 (2000).

352. Solms, M. Dreaming and REM sleep are controlled by different brain mechanisms. *Behav. Brain Sci.* **23**, 843–50; discussion 904–1121 (2000).

353. Labruzza, A. L. The activation-synthesis hypothesis of dreams: a theoretical note. *Am. J. Psychiatry* **135**, 1536–1538 (1978).

354. Jus, K. Sleep EEG Studies in Untreated, Long-Term Schizophrenic Patients. *Archives of General Psychiatry* vol. 29 386 (1973).

355. Hartmann, E. Sleep Disorders. *The Journal of Nervous and Mental Disease* vol. 168 508–509 (1980).

356. Foulkes, D. & Schmidt, M. Temporal sequence and unit composition in dream reports from different stages of sleep. *Sleep* **6**, 265–280 (1983).

357. Nielsen, T. A. A review of mentation in REM and NREM sleep: 'Covert' REM sleep as a possible reconciliation of two opposing models. *Behav. Brain Sci.* **23**, 851–866 (2000).

358. Berry, R. B. *et al.* Rules for scoring respiratory events in sleep: update of the 2007 AASM Manual for the Scoring of Sleep and Associated Events. Deliberations of the Sleep Apnea Definitions Task Force of the American Academy of Sleep Medicine. *J. Clin. Sleep Med.* **8**, 597–619 (2012).

359. Hartmann, E. & Kunzendorf, R. Thymophor in Dreams, Poetry, Art and Memory: Emotion Translated into Imagery as a Basic Element of Human Creativity. *Imagin. Cogn. Pers.* **33**, 165–191 (2013).

360. van der Helm, E. *et al.* REM Sleep Depotentiates Amygdala Activity to Previous Emotional Experiences. *Curr. Biol.* **21**, 2029–2032 (2011).

361. Kramer, M. & Kinney, L. Vigilance and avoidance during sleep in US Vietnam War veterans with posttraumatic stress disorder. *J. Nerv. Ment. Dis.* **191**, 685–687 (2003).

362. Hutchison, I. C. *et al.* Targeted memory reactivation in REM but not SWS selectively reduces arousal responses. *Commun Biol* **4**, 404 (2021).

363. Foulkes, D. A cognitive-psychological model of REM dream production. *Sleep* **5**, 169–187 (1982).

364. Vogel, G. W. An alternative view of the neurobiology of dreaming. *Am. J. Psychiatry* **135**, 1531–1535 (1978).

365. Penttila. Sleep's Dark and Silent. *Dana Foundation*.

366. Klinger, E., Barta, S. G. & Maxeiner, M. E. Current Concerns: Assessing Therapeutically Relevant Motivation. *Assessment Strategies for Cognitive–Behavioral Interventions* 161–196 (1981) doi:10.1016/b978-0-12-404460-9.50012-4.

367. Saredi, R., Baylor, G. W., Meier, B. & Strauch, I. Current concerns and REM-dreams: A laboratory study of dream incubation. *Dreaming* **7**, 195–208 (1997).

368. Griffin, M. L. & Foulkes, D. Deliberate Presleep Control of Dream Content: An Experimental Study. *Perceptual and Motor Skills* vol. 45 660–662 (1977).

369. Nielsen, T. A. *et al.* The Typical Dreams of Canadian University Students. *Dreaming* **13**, 211–235 (2003).

370. Morrison, T. *The Source of Self-regard: Selected Essays, Speeches, and Meditations*. (Vintage International, 2020).

371. Addis, D. R., Wong, A. T. & Schacter, D. L. Remembering the past and imagining the future: common and distinct neural substrates during event construction and elaboration. *Neuropsychologia* **45**, 1363–1377 (2007).

372. Spellberg, M. Prisoners of the dream. https://cabinetmagazine.org/kiosk/spellberg_matthew_8_february_2022.php.

373. Mandela, N. *Long walk to freedom: The autobiography of Nelson Mandela*. (Hachette UK, 2008).

374. Sliwinski, S. *Dreaming in Dark Times: Six Exercises in Political Thought*. (U of Minnesota Press, 2017).

375. Kelley, R. D. G. *Freedom Dreams: The Black Radical Imagination*. (Beacon Press, 2002).

376. Feng, X. & Wang, J. Presleep Ruminating on Intrusive Thoughts Increased the Possibility of Dreaming of Threatening Events. *Front. Psychol.* **13**, 809131 (2022).

377. Lafrenière, A., Lortie-Lussier, M., Dale, A., Robidoux, R. & De Koninck, J. Autobiographical memory sources of threats in dreams. *Conscious. Cogn.* **58**, 124–135 (2018).

378. Fanon. Algeria unveiled. *Decolonization* doi:10.4324/9780203485521-9/algeria-unveiled-frantz-fanon.

379. Rogoff, S. *The Politics of the Dreamscape*. (Springer International Publishing).

380. Hartnack, C. Vishnu on Freud's Desk: Psychoanalysis in Colonial India. *Soc. Res.* **57**, 921–949 (1990).

381. Linstrum, E. Britain's imperial dream-catchers and the truths of empire. *Aeon* https://aeon.co/essays/britains-imperial-dream-catchers-and-the-truths-of-empire (2017).

382. Redline, S., Redline, B. & James, P. Sleep Epidemiology. *The Social Epidemiology of Sleep* 11–46 (2019) doi:10.1093/oso/9780190930448.003.0002.

383. Nancy, J.-L. *The Experience of Freedom*. (Stanford University Press, 1993).

384. Stickgold, R., Hobson, J. A., Fosse, R. & Fosse, M. Sleep, learning, and dreams: off-line memory reprocessing. *Science* **294**, 1052–1057 (2001).

385. Unger, R. M. *Passion: An Essay on Personality*. (Simon and Schuster, 1986).

386. Olsen, M. R., Schredl, M. & Carlsson, I. Sharing dreams: Frequency, motivations, and relationship intimacy. *Dreaming* **23**, 245–255 (2013).

387. Duffey, T. H., Wooten, H. R., Lumadue, C. A. & Comstock, D. C. The Effects of Dream Sharing on Marital Intimacy and Satisfaction. *J. Couple Relatsh. Ther.* **3**, 53–68 (2004).

388. Spellberg, M. On dream sharing and its purpose. https://www.cabinetmagazine.org/issues/67/spellberg1.php.

389. The good that comes from bad dreams (2020-2021). *Bass Connections* https://bassconnections.duke.edu/project-teams/good-comes-bad-dreams-2020-2021.

390. Empathy and Dream-Sharing: New Research Shows a Connection. *Psychology Today*.

391. Stepansky, R. *et al.* Austrian Dream Behavior: Results of a Representative Population Survey. *Dreaming* **8**, 23–30 (1998).

392. Aspy, D. J., Delfabbro, P. & Proeve, M. Is dream recall underestimated by retrospective measures and enhanced by keeping a logbook? A review. *Consciousness and Cognition* vol. 33 364–374 (2015).

393. Carr, M., Horowitz, A. H., Amores, J. & Maes, P. Towards engineering dreams. *Consciousness and Cognition* vol. 85 103006 (2020).

394. Vega, T., Perry, E., Haar, A., Rosello, O. & Jain, A. Dormio dream incubator. *Make: DIY Projects and Ideas for Makers* https://makezine.com/projects/dormio-dream-incubator/ (2022).

395. Popova, M. Acts that amplify: Ann Hamilton on art, the creative value of unproductive time, and the power of not knowing. *The Marginalian* https://www.themarginalian.org/2016/12/12/making-not-knowing-ann-hamilton/ (2016).

396. Lindblad, J. BOMB magazine. *BOMB Magazine*

https://bombmagazine.org/articles/the-phenomenological-experience-of-carsten-h%C3%B6ller/ (2012).

397. Gackenbach, J. Video game play and lucid dreams: Implications for the development of consciousness. *Dreaming* **16**, 96–110.

398. Wikipedia contributors. Tetris Effect. *Wikipedia, The Free Encyclopedia* https://en.wikipedia.org/w/index.php?title=Tetris_Effect&oldid=1101603507 (2022).

399. Fetch! Xbox - power your dreams. *big-orange-nuxt* https://www.big-orange.nl/projects/30-xbox-power-your-dreams.

400. Saylor, S. @Xbox made my dreams REAL! https://www.youtube.com/watch?v=_z4-VB741Yc (2020).

401. Gackenbach, J. Video game play and dreams. *Video game play and consciousness.* **352**, 173–189 (2012).

402. Arzi, A. *et al.* Olfactory aversive conditioning during sleep reduces cigarette-smoking behavior. *J. Neurosci.* **34**, 15382–15393 (2014).

403. Ai, S. *et al.* Promoting subjective preferences in simple economic choices during nap. *Elife* **7**, (2018).

404. Karch, S. B. & FFFLM. *Drug Abuse Handbook*. (CRC Press, 2019).

405. Kelly, J. F. & Claire Greene, M. The reality of drinking and drug using dreams: A study of the prevalence, predictors, and decay with time in recovery in a national sample of U.S. adults. *J. Subst. Abuse Treat.* **96**, 12–17 (2019).

406. Coors light and Coors seltzer are creating the first Big Game ad that runs in your dreams. https://www.businesswire.com/news/home/20210127005208/en/Coors-Light-and-Coors-Seltzer-Are-Creating-the-First-Big-Game-Ad-That-Runs-in-Your-Dreams (2021).

407. Crockett, Z. Are advertisers going to infiltrate our dreams? *The Hustle* https://thehustle.co/are-advertisers-going-to-infiltrate-our-dreams/ (2022).

408. Li, E. Coors Big Game Dream - Case Study. https://vimeo.com/655247852 (2021).

409. Big game dream. https://www.dandad.org/awards/professional/2021/234412/big-game-dream/.

410. Bernays, E. L. *Propaganda*. (Ig Publishing, 2005).

411. Horowitz, A. H., Stickgold, R. & Zadra, A. Dreams are a precious resource. Don’t let advertisers hack them. *Aeon* https://aeon.co/essays/dreams-are-a-precious-resource-dont-let-advertisers-hack-them (2021).

412. To sleep, perchance to dream of Coors beer and halo 2. *The National Law Review* https://www.natlawreview.com/article/to-sleep-perchance-to-dream-coors-beer-and-halo-2.

413. Exelmans, L. & Van den Bulck, J. Bedtime mobile phone use and sleep in adults. *Soc. Sci. Med.* **148**, 93–101 (2016).

414. Godsell, S. & White, J. Adolescent perceptions of sleep and influences on sleep behaviour: A qualitative study. *J. Adolesc.* **73**, 18–25 (2019).

415. FTC announces tentative agenda for April 28 open Commission meeting. *Federal Trade Commission* https://www.ftc.gov/news-events/news/press-releases/2022/04/ftc-announces-tentative-agenda-april-28-open-commission-meeting (2022).

416. The future 100: 2022. *Wunderman Thompson* https://www.wundermanthompson.com/insight/the-future-100-2022.

417. Wamsley, E. J. Dreaming, waking conscious experience, and the resting brain: report of subjective experience as a tool in the cognitive neurosciences. *Front. Psychol.* **4**, 637 (2013).

418. Campbell, J. *The Hero with a Thousand Faces*. (New World Library, 2008).

419. Poe, G. R. Sleep Is for Forgetting. *J. Neurosci.* **37**, 464–473 (2017).

420. Schredl, M. & Reinhard, I. The Continuity between Waking Mood and Dream Emotions: Direct and Second-Order Effects. *Imagin. Cogn. Pers.* **29**, 271–282 (2010).

421. Flowers, L. K. & Zweben, J. E. The Changing Role of 'Using' Dreams in Addiction Recovery. *J. Subst. Abuse Treat.* **15**, 193–200 (1998).

422. Rogoff. J. Allan Hobson's Dreamstage in Context. *The Politics of the Dreamscape* doi:10.1007/978-3-030-74796-1_7.

423. Windt, J. M., Harkness, D. L. & Lenggenhager, B. Tickle me, I think I might be dreaming! Sensory attenuation, self-other distinction, and predictive processing in lucid dreams. *Front. Hum. Neurosci.* **8**, 717 (2014).