LuciEntry: Towards Understanding the Design of Lucid Dream Induction

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Figure 1: LuciEntry, our interactive lucid dream induction prototype, presents well-time visual (red flashing LED light) and auditory (*"This is a dream"*) cues to induce lucid dreaming.

Abstract

Lucid dreaming, a state in which people become aware that they are dreaming, is known for its many mental and physical health benefits. However, most lucid dream induction techniques, such as reality testing, require significant time and effort to master, creating a barrier for people seeking these experiences. We designed LuciEntry, a portable interactive prototype aimed at helping people induce lucid dreaming through well-timed visual and auditory cues. We conducted a lab and a field study to understand LuciEntry's user experience. The interview data allowed us to identify three themes. Building on these findings and our design practice, we derived seven considerations to guide the design of future lucid dream systems. Ultimately, this work aims to inspire further research into interactive technologies for altered states of consciousness.

CCS Concepts

• **Human-centered computing → Systems and tools for interaction design**; **Empirical studies in interaction design**.

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1 Introduction

Lucid dreaming is "the phenomenon of becoming aware of the fact that one is dreaming during ongoing sleep" [7]. During lucid dreaming, people experience vivid hallucinations (i.e., dream content), much like in typical dreams. However, unlike with typical dreams, lucid dreamers can manipulate their dream content, offering the potential to experience desired content. Lucid dreaming has not only been shown to be enjoyable, but it can alleviate recurrent nightmares, aid problem-solving, develop skills, inspire creativity, fulfill wishes, and heal both physically and mentally [43, 80, 86]. These various benefits suggest that helping people to experience lucid dreaming could be valuable.

Unfortunately, lucid dreams rarely occur naturally [47, 65, 66]. To help people experience lucid dreaming, prior work has devised cognitive techniques that need to be practiced outside of sleep, such as mnemonic induction of lucid dreams (MILD) [48] and reality testing (which requires asking oneself: *"Am I dreaming?"* at least ten times every day [1]). However, practicing these cognitive techniques demands considerable time and effort [2, 89]. Another approach to help induce lucid dreaming is delivering external stimulation during sleep. For example, researchers monitored participants' sleep and triggered red flashing lights as cues when the participants entered the rapid-eye-movement (REM) stage—when lucid dreams are most likely to occur—in order to make the participants aware that they are dreaming [46]. However, such studies require researchers to monitor the participants throughout the night, leading to long periods of vigilance. This human-in-the-loop approach (visually inspecting polysomnographic data and reactively triggering cues) is an established method of inducing lucid dreaming in research settings [16, 46, 73, 76, 87], but the requirement for sustained researcher attention at late hours makes the approach cumbersome, costly, and prone to fatigue hence error [62].

We see an opportunity for interactive technology to aid lucid dream induction. Specifically, we propose that lucid dreaming could be induced without the need for long training or a researcher's presence if a system could detect sleep stages in real-time and identify the most optimal moment to trigger cues. We hence designed LuciEntry. LuciEntry monitors a user's brain and eye signals with electroencephalography (EEG) and electrooculography (EOG) sensors to determine their sleep stage. When LuciEntry detects that the user has entered the most favorable sleep stage for lucid dreaming (REM stage), it triggers visual and auditory cues to help induce lucid dreaming.

We investigated the user experiences in both the lab and field studies with 13 participants. Through a thematic analysis of interviews, we identified 3 themes: facilitating lucidity, challenges around system usability, and trade-offs of the analog lucid dream induction techniques. Based on these findings and our practical experience of designing LuciEntry, we propose 7 design considerations for future lucid dream systems and, more broadly, systems for altered states of consciousness.

1.1 Contributions

This work offers the following contributions and benefits:

- We provide a description of a prototype we designed that aims to help users induce lucid dreaming. This prototype might inspire developers who are interested in designing systems beyond the ordinary waking state of the user.
- We present implementation details of our LuciEntry prototype, including the open-source software. This enables design researchers to replicate and conduct lucid dream research without needing a costly sleep lab or extensive staffing. Moreover, design researchers might use this as a foundation to create other altered states of consciousness systems, extending the reach of HCI design.
- We provide insights into participants' user experiences from a study involving LuciEntry, explicated through three themes. These themes can be useful for user experience researchers studying interactive experiences around altered states of consciousness.
- We propose seven design considerations drawn from the above themes and our reflections on designing LuciEntry. These considerations aim to provide guidance for practitioners interested in creating interactive systems that engage with altered states of consciousness.

With our work, we hope to extend the field of dream engineering [15] so that more people can reap the benefits of lucid dreaming. Building on this, we aspire for our work to inspire further exploration of interactive technologies that facilitate and enhance altered states of consciousness.

2 Related work

We learned from prior works on lucid dream induction (which are often categorized into four main approaches: (1) cognitive techniques, (2) substance intervention, (3) cortical stimulation, and (4) external stimulation [88]). We focus on cognitive techniques (described as analog lucid dream induction techniques) and external stimulation (described as digital lucid dream induction techniques) since they mostly inform our work. We then discuss prior HCI dream research that explored various approaches to detecting, modulating, and inducing dream states through interactive systems.

2.1 Analog and digital lucid dream induction techniques

Most analog lucid dream induction techniques involve training the brain to enhance awareness during the dream state [24]. This training utilizes prospective memory—i.e., the ability to remember certain information or tasks for the future—so that the dreamer can recognize when they are dreaming and become lucid. For example, mnemonic induction of lucid dreaming (MILD) involves a dreamer recalling previous dreams, while actively thinking about becoming lucid before sleep [48]. Similarly, reality testing aims to induce lucidity by prompting a person to ask, *"Am I in a dream?"* and carefully examining their surroundings [49]. This process needs to be repeated at least 10 times per day [1]. These analog lucid dream induction techniques require substantial training, costing time and effort, hence are difficult to integrate into modern lifestyles.

An alternative, less costly and effortful technique is wake-back-to-bed (WBTB), in which people use an alarm to wake up in the middle of the night, remain awake for 30 minutes, and then return to sleep [28]. Waking up increases awareness (supporting lucid dream induction), while returning to sleep in the early morning enhances the likelihood of dreaming [28]. Interestingly, while waking up in the middle of the night may appear to disrupt people's sleep, prior work has suggested that the WBTB technique does not negatively affect sleep quality [3]. We hypothesize that incorporating the WBTB technique into our design could enhance the likelihood of inducing lucid dreams without requiring extensive user training or effort.

Digital lucid dream induction techniques refers to presenting external stimuli to dreamers as cues to remind them that they are dreaming. Visual [46], auditory [73], and tactile stimulations [76] appear to be effective cues, as they can be easily incorporated into a participant's dreams, helping them to remember to question their cognitive state. Hence, we decided to utilize visual and auditory cues (and leave tactile cues as future work), but unlike prior work that manually triggered them, we automate this process.

Furthermore, researchers have explored combining analog and digital lucid dream induction techniques, demonstrating a reduction in the difficulty of entering a lucid dream. For instance, Carr et al. developed the targeted lucidity reactivation (TLR) technique [16], which uses visual and auditory cues in conjunction with a cognitive training stage before sleep to help participants associate their awareness with the cues. Inspired by this approach, we combine analog (WBTB and TLR) and digital lucid dream induction techniques (visual and auditory cues).

We note that in most of these prior works, a sleep laboratory was required, where researchers had to manually monitor the data and trigger the external cues. We aim to go beyond and support lucid dream induction even outside sleep labs which might contribute positively to the overall user experience. Hence, we consider the user experience of lucid dream induction in our work, which is often neglected in prior works. We also note that several commercial products claim to induce lucid dreaming; however, many lack scientific validation or are unavailable [67].

2.2 HCI dream research

We also drew insights from prior HCI dream research, such as Dormio [34], an interactive sleep interface that primes people to think or dream about certain things during hypnagogia (the transitional state between wakefulness and sleep); Dozer [81], a system that automatically aids sleep onset through auditory and electrical brain stimulation after detecting drowsiness in EEG signals; and Lucid Loop [42], a closed-loop lucid dream simulation in virtual reality (VR). These works demonstrate how a lucid dream system could leverage EEG data to trigger external cues. However, because these prior works primarily addressed other sleep stages but not specific lucid dream stages or only simulate lucid dreaming (without showing that simulations confer the same benefits as actual lucid dreaming) a gap remains that our work aims to fill.

Prior research highlights the usefulness of interactive technologies in the enrichment of the dream experience. For instance, Virtual Dream Reliving is a generative AI-driven immersive experience designed to help users relive and reflect on dreams [56]. Furthermore, Personal Dream Informatics is a self-information system that supports dream tracking, dream recall, and dreamwork to help users learn about themselves [35]. These projects illustrated that interactive technology can enrich the dream experience; however, they focused on dream reflection upon waking. In contrast, we aim to increase the probability of lucid dreaming.

Existing works have attempted to recreate dream experiences in VR environments. For example, Virtual Transcendent Dream[57] provides an immersive VR experience of flying dreams by using the orientation of a head-mounted display (HMD) for locomotion control. Similarly, Picard-Deland et al. [77] investigated a flying dream induction task using VR. The associated studies suggest that exposure to a VR flying task can lead to more flying- and gravity-related themes in subsequent dreams. Furthermore, Diushekeeva et al. [22] indicated that exposure to visual media before sleep may influence the content of non-lucid dreams. Learning from their work, we noted the importance of pre-sleep exposure in shaping the dream state, which motivated our use of cognitive training (elaborated in Section 4.2.3). However, the effect of pre-sleep exposure on lucid dreamers still remains underexplored.

Dreamento [29] is a modular toolbox that enables sleep data monitoring, real-time stimulation, and post-processing via a graphical user interface (GUI). We learned from their work that a modular system can be beneficial for dream researchers. However, their current system lacks a reliable real-time sleep staging model, still requiring a researcher to monitor the sleep data throughout the night.

Wang et al. have also explored prototypes for lucid dream induction [95–97] and lucid dream manipulation [98], further validating the potential of interactive systems for guiding dream states. However, these investigations lack comprehensive insights into user experiences and detailed design documentation. We extend their work with our prototype, which is portable, allowing for deployments in diverse settings and enabling studies with higher ecological validity [55]. In other words, participants can attempt to induce lucid dreaming in their own beds, rather than only in a laboratory environment.

In summary, prior research on lucid dreaming has shown that various approaches to lucid dream induction are possible, but much of this work focuses on the feasibility of creating such systems rather than the user experience. Meanwhile, HCI research on dreaming has explored digital dream experiences, but has not yet specifically focused on lucid dreaming. As a result, how to design an automatic lucid dream induction system—and understand the user experience associated with it—remains an open question. Our work addresses this gap through the design of LuciEntry, a novel automatic lucid dream induction prototype, and an investigation into the associated user experiences.

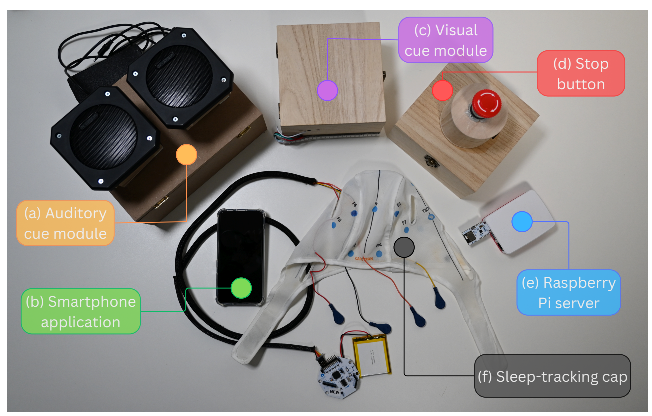

Figure 2: LuciEntry's design includes (a) an auditory cue module to provide sound cues (*"This is a dream"*), (b) a smartphone application to guide the user into the experience, (c) a visual cue module to provide visual cues (red flashing light), (d) a stop button to cease the cues if the user feels uncomfortable, (e) a Raspberry Pi server as the back-end, and (f) a sleep-tracking cap to read the user's sleep stages and their eye movements.

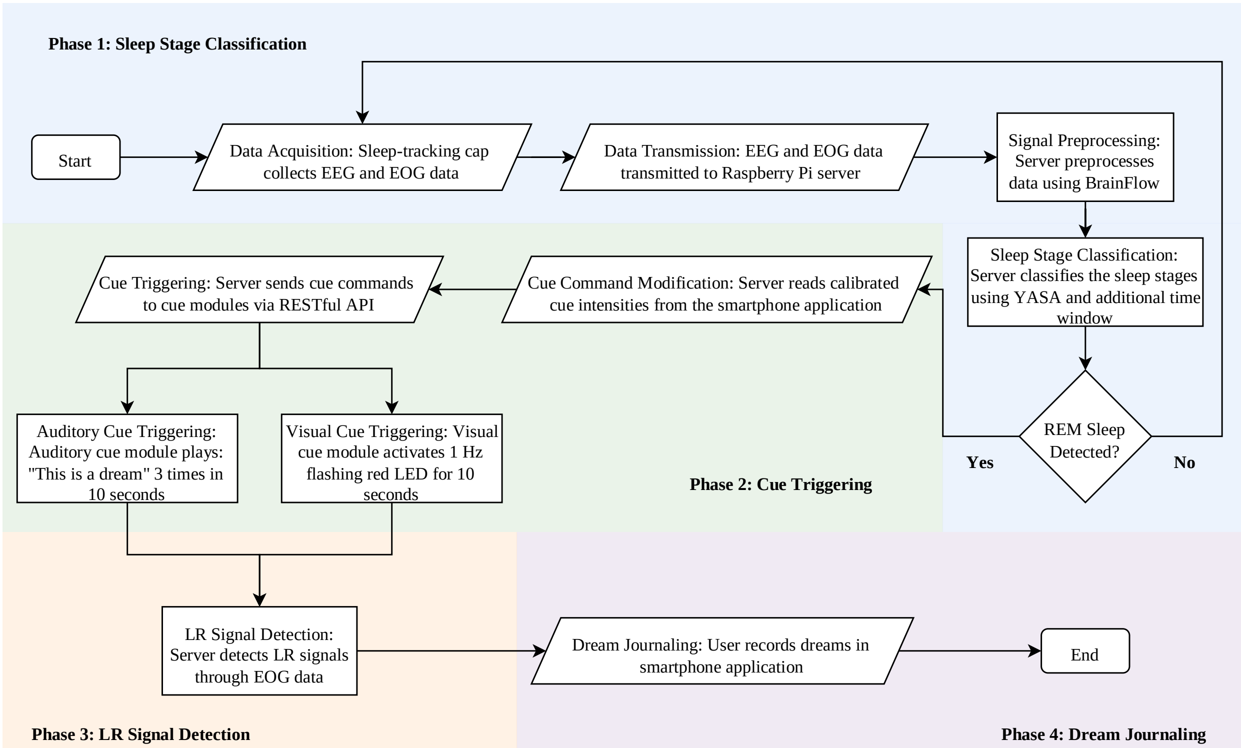

Figure 3: The flowchart of LuciEntry detailing a multi-phase process: from sleep data acquisition and classification to cue triggering, LR signal detection and dream journaling, integrating EEG/EOG data, BrainFlow, YASA, and cue modules.

3 Designing LuciEntry

LuciEntry is a portable, modular, automatic prototype designed to facilitate lucid dream induction by triggering timely cues during the REM stage, when most of the dreams occur [6]. The prototype comprises four core components: (1) a sleep-tracking cap, (2) a server for sleep stage classification, (3) cue modules for triggering induction stimuli, and (4) a smartphone application to guide the user (Figure 2). Below, we detail the design and functionality of each component, with a flowchart provided in Figure 3 to enhance clarity.

3.1 Sleep-tracking cap

The sleep-tracking cap is a lightweight, wearable cap equipped with adhesive electrodes to monitor the electroencephalogram (EEG) and electrooculogram (EOG) data (Figure 2c). While there are other EEG recording systems exist, such as Zmax [92], we chose the OpenBCI Cyton board [70] since it is an customizable open-source system that enables us to track the user's eye movements. The cap has four electrodes: one on the forehead (Fpz) to sense EEG data, two on the side of the eyes (Horizontal [82]) to sense EOG data, and one behind the ear as a reference (Figure 4). Sacrificing accuracy, we decided to use adhesive electrodes instead of dry comb electrodes and minimized the number of electrodes to increase comfort, an approach suggested by prior work that investigated sleep technology for field studies [81]. The electrodes connect to the OpenBCI Cyton board through Dupont wires [20]. By keeping the OpenBCI Cyton board detached from the cap, we reduce head weight for increased comfort (which prior work has identified as key for the user experience [81]).

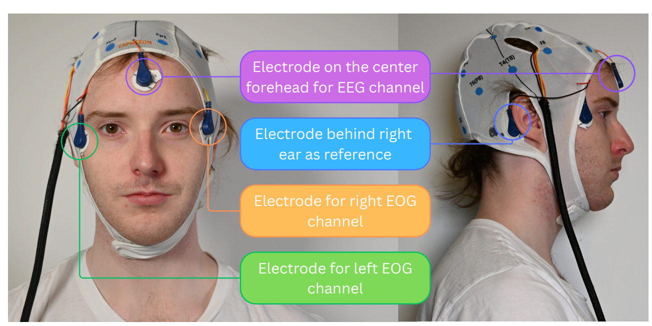

Figure 4: The placement of the sleep-tracking cap's four electrodes. (1) One electrode is placed on the forehead in the center (Fpz) to sense the EEG data. (2) Two electrodes are placed on the side of the eyes (horizontal) to sense the EOG data. (3) One electrode is placed behind the right ear as the reference.

3.2 Server: sleep stage classification

The EEG and EOG data are transmitted to a server running on a Raspberry Pi 4 Model B [59] that classifies the user's sleep stages (Figure 2e).

The server runs Python 3.11 for signal processing, mainly using BrainFlow [72] and a sleep staging classifier. We considered AttnSleep [26] and YASA [91] as the sleep classifier. In order to determine which one is preferable, one would usually evaluate the accuracy against manual polysomnography (PSG) [8]. However, manual PSG is expensive and requires experts in neuroscience. Therefore, we used the commercial Oura Ring (79% accuracy compared to PSG [4], while other commercial products are around 60-65% [71]) to determine which sleep staging classifier is most accurate. In a pilot study, we found that YASA's sleep stages aligned more with Oura Ring's results; hence, we chose YASA.

The EEG and EOG data, sampled at 250 Hz, was filtered through the BrainFlow detrend function to center the signal around zero, as is usual in signal processing analysis [53, 68]. The sleep staging classification is performed every 36 seconds, a length that supports the assumption of signal "stationarity", essential for accurate epoch-based analysis [17, 18]. This approach helps reduce the impact of artifacts, such as those generated by movement (e.g., when moving the head slightly during sleep). Each classification utilized data from the beginning of sleep until the current moment because YASA requires preceding sleep data for subsequent stage determinations, which was confirmed in our pilot study. In another pilot study, we noticed that there are some false positives of REM stage detection, which could be disturbing for the user if the prototype triggered the cues at the wrong time. To minimize the chance of falsely classifying REM sleep, we added another time window for REM sleep classification. Only when YASA classifies a segment as REM sleep for 60% of the time within the last 90 seconds do we flag it as REM sleep (the numbers were selected based on our experiences from a pilot study and finalized during the formal study).

During the study, the participant is asked to move their eyes from left to right four times (LR signal [16, 50]) once lucid dreaming. Such an LR signal usually serves as the objective reference of lucid dreaming [16, 50]. To detect eye movement, we analyzed the EOG data every 0.2 seconds. After applying the detrend filter mentioned above, we used a bandpass filter to remove noises. Prior work used a bandpass filter with 0.3 - 15 Hz [44] to remove the signal outside the bandwidth of eye movement; here, we applied the bandpass filter but adjusted it to 0.5 - 6 Hz for less noise. A rolling filter was applied to the signal to average and smooth the data stream of outliers. After pre-processing, we extract the maximum and minimum values within the last 0.2 seconds. By comparing the indices of both eyes' maximum and minimum values, we determine which side the user looks at.

3.3 Cue modules

Once the server classifies the user as being in the REM stage of sleep, it sends commands to the cue modules through Node.js using a RESTful API (using the RESTful API makes the commands easy to understand while offering extensibility). During setup, the cue modules are assigned a device ID, which supports extending the prototype with additional cue modules.

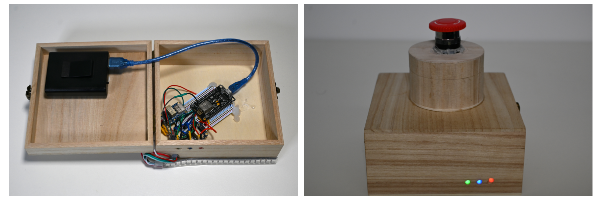

Figure 5: Left: the inside of a cue module. Each cue module runs on an ESP8266 microcontroller and is powered by a power bank. Right: There are three LEDs to show the cue module's current status: (1) green: whether the module is on; (2) blue: whether the module is connected to the Wi-Fi; and (3) red: whether the module is stopped for safety or unknown error.

Once the cue module receives the command, it triggers the cue accordingly, intended to make the user aware that they are dreaming [16]. Currently, we have two cue modules, visual and auditory. Vibration cues [76] could be added in the future. Electrical stimulation [94] also seemed promising; we removed it from the current design because we noticed that the electrical stimulation hindered our signal reading. Our cue modules, run by an ESP8266 microcontroller and powered by a power bank to ensure portability (Figure 5 left), communicate with the server through the HTTP protocol for universality and extensibility. Each cue module has an LED indicator (Figure 5 right) to show the module's status (On, Wi-Fi-connected, Stopped).

The auditory cue module (Figure 2a) consists of two FR 10 HM speakers [93]. The sound played is of a male person (first author's voice) saying in a soft tone: *"This is a dream"* repeated three times in ten seconds. According to prior work, hearing acoustic suggestions is effective because it triggers a cognitive process to perform reality testing [73].

The visual cue module (Figure 2c) consists of a WS2812B light-emitting diode (LED) strip of 18.7 cm, with a maximum luminous intensity of 720 mcd. Following prior works' suggestion [16, 46], we choose a 1 Hz red (R: 255; G: 0; B: 0) flashing light that illuminates for 10 seconds when the REM sleep stage is detected. Red is the most effective color penetrating the eyelids [5], while the flashing process is designed to attract people's attention [52]. A stop button is also included in the design for safety. If the user experiences discomfort, they can press the button to stop the cues.

3.4 User guide smartphone application

To support users in effectively utilizing LuciEntry, we developed a smartphone application that not only guides them through the entire lucid dreaming procedure but also enables dream recording (Figure 6). We developed this application using React Native [61] and Expo Go [30], with Flask [78] facilitating communication with the server. Recognizing that combining analog lucid dream induction techniques with digital techniques offers advantages over using digital techniques alone [45] while preserving sleep quality [3], we integrated WBTB [28] and targeted lucidity reactivation (TLR) [16] into our design. The smartphone application plays a key role in this process, introducing the user to the concept of lucid dreaming

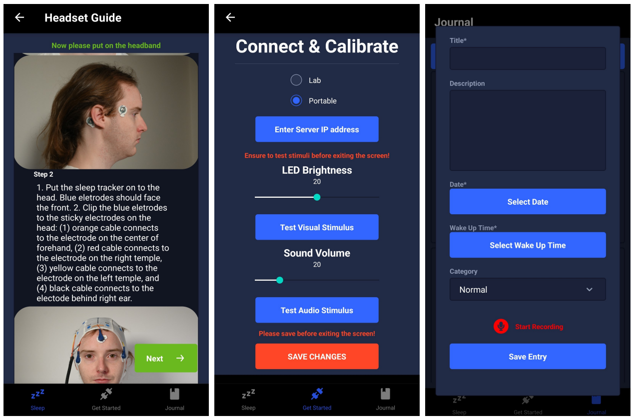

Figure 6: The smartphone application serves as a guide to help users navigate the use of LuciEntry. Left: The application guides the user in wearing the sleep-tracking cap. Middle: The application allows the user to adjust the intensity of each cue. Right: The application enables the user to report their dream content.

and providing step-by-step guidance on utilizing the components of LuciEntry. Additionally, it offers instructions on how to perform WBTB and TLR (discussed further in subsection 4.2). The application also allows the user to calibrate the intensities of cues (Figure 6 middle). The calibration instruction advises: "Imagine that you are already asleep, and adjust the intensity to a level that is just perceptible but not strong enough to fully wake you up." This aims to ensure the cues are effective without disrupting sleep. Furthermore, the application includes a dream journaling function, enabling the user to document their dreams and select appropriate dream categories (Figure 6 right). This feature is grounded in prior research that suggests that immediate dream journaling reduces memory distortion, helping to ensure that the dream report is trustworthy [101].

We acknowledge that using a smartphone before sleep may increase the time it takes to fall asleep [38]. To mitigate this, we incorporated several design elements:

- A voice-over feature for textual content to minimize screen use.
- A dark visual theme with reduced brightness to reduce visual strain.
- The option for the user to record their dream journals via voice input, further limiting screen interaction.

3.5 Portability and modularity

Overall, we designed our prototype with portability and modularity in mind. The portability enables the user to deploy the prototype at home and use it in a real-life scenario. The modularity allows the user and researchers to exchange and add input and output modules (for example, using Zmax to sense EEG data [92] or using haptic actuators as cues [76]), making LuciEntry an extendable lucid dream induction platform. Our code is available on GitHub[1].

[1] 1. smartphone application: https://github.com/Exertion-Games-Lab/LucidReality-UI; 2. server and cue modules: https://github.com/Exertion-Games-Lab/LuciEntry-Home

4 Methodology

To understand the experiences associated with LuciEntry, we conducted both a laboratory and a field study with 13 participants. Participants used LuciEntry during their sleep for one night and were interviewed the following day.

4.1 Participants

Thirteen participants were recruited via advertisements on our mailing list, social media posts, and word of mouth. The group comprised seven males, six females, and zero individuals identifying as non-binary or self-described. Their ages ranged from 22 to 31 years old ($M = 25.3, SD = 3.0$). The advertisement described our intention to support lucid dreaming with interactive technology, hence our participants had various dream experiences (Table 1). We excluded people with sleep disorders (e.g., sleep apnea, periodic limb movement disorder, narcolepsy, insomnia, and nightmare disorder) and chose to defer lucid dream induction for people with specific sleep challenges to future work.

The participants were screened with a pre-study questionnaire based on the sleep disorder questionnaire [23]. If participants' scores indicated a high probability of any of these disorders, we recommended that they consult their physicians and be excluded from the study.

Participants were given an explanatory statement and needed to sign a consent form. No compensation was given. The study received approval from our institution's ethics board.

4.2 Procedure

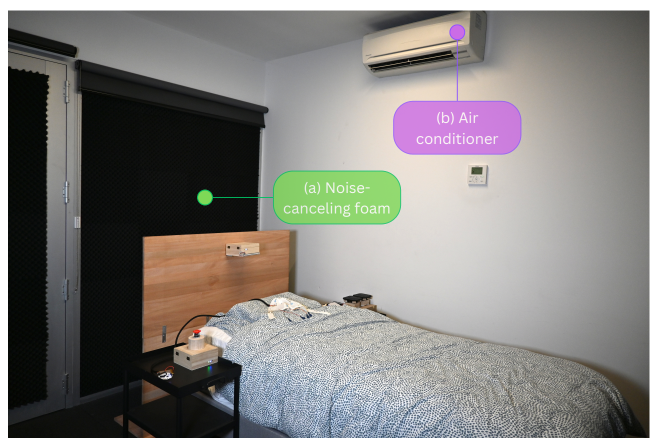

Figure 7: The lab environment. We installed noise-canceling foam boards to reduce noise and had an air conditioner to maintain a comfortable temperature for sleep.

Our investigation of LuciEntry involved both a lab study and a field study. Field studies [33] are characterized by research conducted outside laboratory environments, typically in naturalistic settings such as participants' homes, here, their bedrooms. While the lab study offered us a controlled environment, where we could clearly observe the interaction between the participant and LuciEntry, we anticipated that the field study could complement these insights

	Age	Gender	Typical dream frequency	Lucid dream frequency	Study type	Dream content
P1	22	Female	>2 a week	<1 per 6 months	Lab	Study procedure
P2	30	Female	>2 a week	<1 per 6 months	Lab	Cannot remember dreams
P3	22	Male	>2 a week	<1 per 6 months	Field	Study procedure
P4	22	Male	>1 a month	<1 per 6 months	Lab	Pre-sleep experience
P5	26	Male	Every day	<1 per 6 months	Field	Lucid dream
P6	27	Male	>2 a week	>1 per 6 months	Lab	Lucid dream
P7	24	Female	Every day	>2 a week	Field	Cue incorporated dream
P8	25	Male	Every day	Every day	Lab	Lucid dream
P9	27	Male	>1 a week	<1 per 6 months	Lab	Pre-sleep experience
P10	27	Female	>2 a week	<1 per 6 months	Lab	Study procedure
P11	23	Male	Every day	<1 per 6 months	Field	Pre-sleep experience and lucid dream
P12	23	Female	>2 a week	<1 per 6 months	Lab	Study procedure and cue incorporated dream
P13	31	Female	>1 a month	<1 per 6 months	Field	"Bizarre" dream content

Table 1: Participants' characteristics and study details. The table includes participants' age, gender, typical dream frequency, lucid dream frequency, study location, and the type of dream content.

by giving us a better understanding of how our prototype would perform in a context similar to real-life.

Participants could choose where they wanted to participate: in the lab or their home. Eight participants chose the lab. We then started the lab study with these participants, as the controlled setting alongside the researchers' presence facilitated continuous supervision of the prototype's performance and troubleshooting of any technical issues. (During a pilot study, we discovered that running studies for more than 8 hours can easily lead to technology glitches, unlike most interaction design studies that often last only minutes.)

To minimize sleep disruptions, we equipped the lab with sound-absorbing foam panels and an air conditioner, ensuring a quiet, temperature-controlled, and comfortable environment (Figure 7). We set up the server using the lab's Wi-Fi. Subsequently, we conducted the field study with the remaining five participants in their own homes. We did not install any additional sound-damping or heat-controlling materials in their homes to investigate the user experience in a real-life setting. We set up the server using their home Wi-Fi or a smartphone hotspot for those without stable Wi-Fi at home. The following describes the process of setting up Wi-Fi at a participant's home:

(1) Connect the server to the Wi-Fi network at the participant's home.
(2) Run `configure_wifi.py` on the server to update the Wi-Fi details for the code on each cue module.
(3) Plug each cue module into the server to apply the updated Wi-Fi details.
(4) Run `./start.sh` on the server to start the server.
(5) Enter the IP address of the server on the smartphone application to establish the communication between the server and the application.
(6) Position the cue modules around the participant's bed.

Our study comprised five stages: (1) prototype setup, (2) "normal" sleep, (3) cognitive training, (4) lucid dreaming, and (5) a semi-structured interview (Table 2). Overall, the study lasted about 11 hours, typically from evening to morning, depending on participants' normal sleep schedules. Participants were asked to refrain from consuming caffeinated food and beverages for 8 hours prior to the study.

Table 2: The summary of our study procedure, which includes 5 stages: prototype setup, normal sleeping, cognitive training, lucid dreaming, and a semi-structured interview.

Stage	Activities	Duration
Prototype setup	- The study procedure and prototype were introduced to the participants. - The prototype was set up by the researchers.	< 2 hours
Normal sleeping	- The participant slept without the prototype.	4 hours
Cognitive training	- The participant turned on the prototype. - The participant calibrated the intensity of cues. - The participant performed cognitive training.	0.5 hour
Lucid dreaming	- The participant slept with the prototype. - The participant is meant to perform the LR signal once they experienced lucid dreaming.	4 hours
Semi-structured interview	- Researchers interviewed the participants.	1 hour

4.2.1 Prototype setup. After setting up the Wi-Fi, we arranged the cue modules according to each participant's sleeping habits. For example, if the participants tended to sleep on their side, we placed the visual cue module on that side of the bed. We also introduced participants to lucid dreaming, explained the study, and showed them how to use the prototype (e.g., how to turn on and off the system) with the user guide provided in the smartphone application. To ensure proper use of the sleep-tracking cap, we demonstrated electrode placement (as shown in Figure 4) and how to wear the cap, accompanied by the smartphone application (Figure 6 left) and a printed instruction manual. For the field study, participants were asked to demonstrate their ability to operate the prototype independently before we left.

4.2.2 Normal sleep. The participants were asked to sleep for a while and wake up to perform WBTB [28]. Using the smartphone application, they set an alarm based on their sleep schedule, usually around 3 to 4 a.m, to wake up and stay awake for 30 minutes before going back to sleep. In this stage, participants did not wear the sleep-tracking cap, and none of the cues were activated.

4.2.3 Cognitive training. This stage required the participants to perform cognitive training (part of TLR) to associate their awareness with the cues. The stage began after participants woke up to the alarm from the smartphone application. Following the user guide on the application, participants turned on the cue modules and calibrated the intensities of each cue through the application to ensure the cues would be presented at the appropriate level of intensity [88]. The prototype then presented cues every 20 seconds for around 30 minutes. Every time when participants recognized the cues, they were asked to practice becoming lucid (while they were awake). The idea behind cognitive training is to utilize prospective memory; more simply, the training helps the user to remember to become lucid when they perceive the cues in the next stage [16]. After 30 minutes of cognitive training, participants set an alarm for the last stage using the smartphone app and returned to sleep with the prototype activated.

4.2.4 Lucid dreaming. In this stage, the participants slept for around four hours until the next alarm. When the prototype detected a REM period, it presented the cues for 10 seconds and repeated them every 20 seconds. It was intended for participants to recognize these cues and therefore help them realize that they were dreaming. We told participants during the setup that if they became aware of their dream, they should perform an LR signal (explained in section 3) as objective evidence of lucidity. After signaling, the participants could continue exploring their lucid dream world until they awoke. We also instructed the participants that immediately after waking up they should report their dreams in the application, noting whether they had a lucid dream and providing details of the experience if they felt comfortable doing so. After the report, participants could either continue the session by going back to sleep until the alarm went off or end the session if they were unable to go back to sleep.

4.2.5 Semi-structured interview. The participants took part in a semi-structured interview [11] to help us better understand their experiences with LuciEntry. We began by asking them about their overall experiences, followed by their experiences at each stage of the study (including how to they felt), and concluded with their reflections on the entire process. We also asked questions focusing on LuciEntry, e.g., which part of the prototype they liked the most and the least. When the participants reported interesting insights, we followed up with additional questions to gain a deeper understanding of their experiences (The complete list of interview questions is included in the supplementary materials). The interviews were conducted in person and on Zoom, the average length was approximately an hour ($Mean = 61.9mins, SD = 23.8mins$).

4.3 Data analysis

We conducted a thematic analysis following a six-step process [12], involving two independent coders (authors) and NVivo software [100]. Each participant's response was treated as a distinct data unit for analysis. To streamline the coding process, we created a master NVivo project file and performed two rounds of coding by two authors. In the first round, one coder generated 209 codes, while the other produced 49. To resolve any discrepancies, the coders discussed the issues with two additional authors. We then discovered that one of the reasons for the discrepancy in the number of codes between authors is due to differences in coding styles: Author 1 tends to record all minor details, whereas Author 2 focuses only on aspects related to the research question. after the discussion, the authors refined the coding schema within the master file. This refined schema was applied in a second round of coding. Following multiple discussions, all discrepancies were solved, resulting in a final coding scheme with 63 codes. The final codes were then grouped and visualized through Miro [63], an online co-editing workspace, to create themes. Ultimately, the coders synthesized 3 overarching themes by examining and cross-referencing these coded categories.

5 Results

This section presents themes from the thematic analysis of the interviews. The dream experiences are summarized in Table 1. Overall, participants found engaging with LuciEntry intriguing but also noted challenges. Notably, two out of eight lab study participants and two out of five field study participants reported experiencing lucid dreaming during the interview. P11 accidentally broke the sleep-tracking cap during the lucid dream stage. After fixing it, P11 repeated the study the following day.

5.1 Theme 1: Appreciating LuciEntry's help in inducing lucid dreaming

Four participants reported that LuciEntry, particularly the auditory cue, supported them in achieving lucid dreaming. However, they also reported having less control over their dreams than they had anticipated. Participants who did not experience lucid dreaming still appreciated LuciEntry, as it influenced and altered their dream experiences.

5.1.1 LuciEntry's cues helped with achieving lucidity. LuciEntry had a significant impact on participants' dreams, with 4 out of 13 participants (P5, P6, P8, and P11) reporting experiences of lucid dreaming. P5 dreamt about being watched in a luxury house and wanted to escape from the dream: *"I was aware I was dreaming, but it was in a different place, and there was a big window on the floor. [...] There were a lot of people outside looking at me, which made me nervous. But then I became aware I was in a dream, [...] I definitely couldn't have this very luxurious room. [...] So I tried to record the dream and wake up."* P6 could not recall specific dream details but described repeatedly transitioning between lucid and waking states: *"When I fell asleep, I generated my lucid dream. So your system is really good at detecting my brain signals, and it outputs, 'This is a dream, this is a dream.' Then I woke up for a moment and fell asleep again, and it generated another lucid dream in my mind, which is like a loop."* P8 did not recall vivid dream content but clearly recognized their inability to move, which made them realize they were dreaming: *"I tried to move my body [during sleep], as always. Suddenly, I realized I couldn't move my body, so I realized I was sleeping."* P11 dreamt about Victoria 3, a game they played before sleep, and described pausing the dream after becoming lucid: *"I was playing Victoria 3 at night. When I was asleep, I felt like I was buying weapons for the northern states to fight against the Confederate States of America.*

[...] I'm representing the country itself. [...] It was weird that you were not a person in a dream. It was not always the first person. [...] Then I heard the voice start, and I was half awake. 'Yeah, I am in the dream!' So I looked back to the dream, and I felt like I paused it! It was ridiculous. Why did I play this game in the dream again?" We highlight that P5 and P11 — who had little prior experience with lucid dreaming (less than once every six months) — still reported lucid dreams, suggesting LuciEntry's potential for facilitating lucid dream induction among novices.

The primary factor contributing to these experiences appeared to be the auditory cue, which participants (P5, P6, and P11) found to be effective at making them aware of their dream. P5 noted, *"After about an hour of sleep, I heard the sound. I clearly remember hearing the sound but not the light. The sounds made me subconsciously aware I was dreaming, allowing me to easily leave the dream."* Therefore, the inclusion of auditory cues appears to have played a notable role in helping participants achieve lucidity. This supports the idea that LuciEntry can effectively assist with lucid dream induction.

5.1.2 Participants expected full control over their lucid dream. During lucid dreaming, P11 expected to fully control their dream content. However, disembodiment in the dream prevented them from doing so, subverting their expectations. They said: *"I wondered why I was here and what this was. It wasn't exactly as I expected. [...] I thought I could realize I was dreaming and control everything, but I just paused the dream. [...] I felt like a representation of the country. [...] I had no hands, so I was just a spirit in my dream and couldn't control anything. [...] I had no mouth to make a sound. [...] I didn't even think I was human in that scenario."* P11's account suggests that people often expect complete control during lucid dreaming, whereas novice lucid dreamers can struggle to achieve it.

This notion of control was also informed by the external (study) context. For example, P5 dreamt of being watched and felt that their lack of control over the dream prevented them from escaping this situation: *"I could see everyone outside the window on the ground floor looking up at me, which was stressful."* P5 heard the auditory cue and tried to escape from the dream but remembered that they were instructed to record it as a dream: *"I realized it was a dream because the sound cue kept playing. I thought, 'I can't have this luxury room; it's not real.' I woke up but was still in a second dream. This one was more intense, with people outside trying to approach me. Because the sound was still playing, I knew it was a dream."*

However, all participants who experienced lucid dreaming were unable to control their bodies sufficiently to perform the LR signal.

- P5 focused on escaping their dream due to disliking its content.
- P6 said that they could not perform the LR signal because their lucid dreams were too brief.
- P8 forgot they were supposed to perform the LR signal until reminded during the interview.
- P11 was concerned that moving their eyes might cause them to wake up: *"I don't think I could move my eyes during that period; if I did, I would become more awake, and the dream would be ruined."*

5.1.3 Lucidity and awareness. While P11 lost awareness and *"went back to deep sleep,"* P5, P6, and P8 reported that their awareness increased when they woke up after lucid dreaming. P6 described: *"(After lucid dreaming) I would wake up briefly, then fall asleep again and generate another dream. Your voice would reappear, and I'd wake up, creating another lucid dream. It was like a loop."* Notably, P5, P6, and P11 experienced multiple short lucid dreams (*"less than 5 minutes"*) during the study, whereas P8 reported their lucid dreams were *"quite long, more than 30 minutes"*.

P11 described their experience as *"semi-awake"*, *"movie-like"*, and *"daydreaming"*. P8 described their experience as *"meditation-like"*, which made them *"relaxed"* and *"comfortable"*. P6 felt *"dizzy"* due to continuously swapping *"between the dream and the reality"*.

5.1.4 LuciEntry facilitated incorporating contextual information into the dreams. Although the remaining 9 participants did not explicitly express experiencing lucidity, we learned that the cues, study procedures, and pre-sleep experiences were incorporated into their dreams. For example, P7 and P12 dreamt about the visual cue as the flashing lights of a police car and a camera flash: *"I remembered seeing a flash. Wait, the flash might be from the light cue device. [...] I saw a friend with a camera taking a photo of me wearing an EEG for a sleep study. [...] Then there were more flashes from the room across from me"* (P12). P1, P3, P10, and P12 dreamt of being in a user study. As P3 stated, *"I dreamt that I finished the actual steps. I saw the stimuli, but I wasn't awake or lucid. When I woke up, I thought, wait, that didn't happen. It was really weird."* Similarly, P10 described, *"I was lying on the bed, and the LED was shining above my eye. My eyes were very sensitive, and I felt like whenever I closed them, I couldn't sleep. The lights kept shining, and I was anxious about not being able to sleep and complete the study. Then I woke up and realized it was a dream."* P4, P9, and P11 dreamt about their pre-sleep experiences. P9 noted, *"During the dream, I was on campus with friends, including you and two friends from China. I think you appeared in my dream because I played with those two friends before this test."*

5.2 Theme 2: Challenges around system usability and cue perception

Participants reported system usability challenges, including difficulties with cue calibration, cue perception, setting up the prototype while feeling sleepy, and sleep hindrance from the indicator light.

5.2.1 Individual differences affected the perception of the cues. Some participants preferred visual cues, whereas others found them disturbing. For instance, P11 reported that LuciEntry's light was too bright, and P10 found the visual cues more disturbing than the auditory cues. P9 experienced negative emotions and found the audio *"weird"*. P2 and P8 mentioned that the language of the auditory cues significantly affected the prototype's impact. P8 reported sometimes ignoring the auditory cues because it was not in their mother tongue. Similarly, P2, a non-native English speaker, said: *"I'm not a native English speaker, so I would like the reminder in Chinese. It would feel more familiar and help me notice it better."* Such individual differences were also reported for the visual cue. While most participants reported perceiving the color red, P2 and P9 reported seeing white and green lights, respectively. This variability might be due to individual physiological differences—P9 hypothesized that the perceived green color could be caused by blood vessels when the eyes are closed. Beyond color, the meaning and emotional associations of the light varied significantly among participants. P10, for instance, connected the red light to fear, suggesting that color choice could be linked to certain meanings and potentially influence dream content. P10 believed that changing the hue from red to yellow could make a *"huge difference"* in both perception and effect.

5.2.2 Cue calibration is challenging. Another frequently reported issue was that participants were awakened by the cues. P1, P10, P11, P12, and P13 reported that the cues disrupted their sleep *"I was almost asleep, but it (the stimuli) just woke me completely up"* (P1). Conversely, P2 and P9 said that they were unable to perceive the cues at all while sleeping. P11 echoed similar feelings: *"Maybe it was because I was too sleepy, I could not feel the light and sound."*. These varied perceptions of cues led to changes in the REM sleep classification threshold for cue triggering. At first, participants did not perceive cues, so we lowered the threshold to trigger the cues more often. However, later participants reported that they perceived the cues too frequently and were awakened by the cues. Another main reason for the participants to be awakened was the miscalibration of cues. P11 and P13 noted that the auditory cues were too loud: *"I should not amplify it [the volume]. It was too loud. [...] If I calibrate it to 20 or 30, then maybe I can have a deeper, lucid dream and control the dream"* (P11). P13 said *"I heard the sound cue, and then I woke up. This is because I set the voice in the largest volume. I just wanted to remind myself that was a dream because I could fall into a deep sleep"*. Meanwhile, P8 pointed out that the visual cues were too bright and *"strained"* their eyes. Although participants calibrated the intensities before entering the lucid dreaming stage, they still tended to miscalibrate the intensities, suggesting that it is difficult for participants to imagine how cues will be perceived during sleep. A longitudinal study, with more time for calibration, might address this issue.

5.2.3 Setup is challenging when sleepy. Three of the field study participants (P3, P5, and P13) reported that the prototype was too complicated to set up: *"There was a lot of equipment, a lot of different things that I had to look at and look out for"* (P3). P13 said *"For me, it was a lot of things to do for the setting, so I felt the prototype was a little bit complicated. There were too many boxes and procedures I needed to follow."* In contrast, P7, another field study participant, reported the setup was easy because each component was straightforward: *"I think it [the setup] is easy to understand. For example, the 'on' and 'off' button is quite clear. So, I did not need to worry about which button was which, because there was only one button. [...] That is a good sign for me, as it decreases my nervousness during the night."* Although our modular design led to multiple components, making the setup more difficult—especially for the participants in the field study—the simplicity of each component appeared to minimize some concerns.

5.2.4 The indicator lights hinder participants from falling asleep. P7, P11, and P13 stated that the indicator lights on our cue modules were too bright, preventing them from sleeping comfortably: *"I couldn't fall asleep because the [indicator] lights were too bright for me. [...] I put the light underneath my pillow; otherwise, it was too bright for me to sleep."* (P13)

5.3 Theme 3: Challenges and trade-offs of the analog lucid dream induction techniques

While the analog lucid dream induction techniques we adopted (WBTB and TRL) helped participants experience lucid dreaming, unexpected emotions — such as tiredness and annoyance — made them hesitant about using LuciEntry.

5.3.1 Supplementary cognitive training can have positive side effects but also be taxing. Participants found that cognitive training made them more confident in their lucid dreaming ability. Five participants (P5, P6, P9, P12, and P13) felt that the preparation they underwent before sleeping helped them focus their intent on recognizing their dream state. For example, P5 stated *"Because of the prior training [...] I could connect what was happening,"* referring to their ability to understand the meaning of cues in their dream through cognitive training. This suggests that the cognitive training can increase the likelihood of experiencing lucid dreams. P12 similarly remarked: *"The more I did it, the more I thought, 'This is cool.' I felt excited and thought it might help with lucid dreams. "* Similarly, P13 commented: *"I felt like I got confidence in myself; I got a feeling I would be successful in finishing this dream."* Beyond enhancing confidence, P2, P9, and P11 also reported feeling *"relaxed"* or *"resting"* during the cognitive training, noting that the auditory cues resembled *"ASMR"*.

In contrast, P5, P8, and P9 said they felt *"a bit annoyed"* by the cognitive training. P9 explained: *"It was a bit annoying; it felt like I was sleeping, but someone turned on the light."* P3 and P7 reported that the cognitive training stage was *"too long"*, keeping them awake for an extended period so that they were *"too awake to go back to sleep"*. P7 further described feeling confused when they heard the auditory cues while still awake: *"I felt very confused, as my brain and ears contradicted each other."* Overall, participants expressed mixed feelings about the cognitive training. Some felt relaxed and gained confidence for the future lucid dreaming stage, whereas others were irritated by having to train in the middle of the night.

5.3.2 WBTB is effective but tiring. Nothing that WBTB is one of the most effective lucid dream induction techniques [28, 88], almost one-third of our participants disliked this technique. While P5 found WBTB *"not too difficult"* because they usually wake up in the middle of the night, P2, P6, P8, P11, and P13 considered it *"annoying"* and felt *"tired"* after the study. P13 even expressed *"regrets to participate"* P11 elaborated: *"It felt annoying to wake up after just four hours [. . .] like you were sleeping normally and woke up by the alarm."* P13 added, *"I woke up in the morning feeling so tired [. . .] because I had to wake up in the middle. Disrupted sleep makes you tired."*

5.3.3 The study's dream recording requirement hindered falling asleep again. P7 noted feeling more awake when detailing their dream report, preventing them from falling back asleep: *"I was tired but not enough to sleep again, so I decided to record my dream. As I wrote in detail, I became more awake and couldn't get back to sleep."* P2, concerned about becoming too alert, chose not to record their dreams, which led to forgetting the content: *"I think I had some dreams, but after waking up, I forgot them. [. . .] Maybe I should have written them down, but I was worried about staying awake, so I didn't."* Although recording dreams was important for the study [101], the act of remembering and recording appeared to raise participants' consciousness, preventing them from falling back asleep.

6 Discussion

Our results suggest that our prototype, LuciEntry, can induce lucid dreaming in some participants, while others may only experience partial lucidity or fail to recall any lucid state. This finding aligns with Carr et al.'s work on TLR [16]. We now discuss our findings in more detail and present design considerations based on our results and our experience designing LuciEntry, with the goal of guiding future system designs.

6.1 Consider designing a safeguard to avoid overuse when designing altered states of consciousness systems

Although prior work suggested lucid dream induction does not compromise sleep quality [3, 32]— and therefore WBTB was adopted in our design—we observed that LuciEntry's design features can increase participants' lucidity but also have the potential to raise the level of consciousness, i.e., wake the user up or hinder them from falling asleep (again). This finding contrasts with prior work [3, 32] and highlights the double-edged nature of lucid dream induction that designers must carefully consider. We highlight that the pros and cons of lucid dream induction must be considered, therefore, we recommend that designers balance the desire to induce lucid dreaming with considerations of sleep depth. Prior HCI research [21, 58] has highlighted how challenging such balancing can be, particularly in body-centric experiences; we extend these findings to the design of systems for sleep. We suggest designers consider users' sleep quality when developing lucid dream induction systems. For instance, an application might provide a warning that advises against using the system during consecutive nights or analyze users' sleep data through biosignal wearables to determine whether they are fit enough to use the system. Ultimately, we advocate for incorporating a safeguard into the design to ensure that lucid dream induction technologies support — not disrupt — restorative sleep.

6.2 Consider prioritizing auditory cues over visual cues to influence altered states of consciousness

As shown in subsubsection 5.1.1, auditory cues were more effective than visual cues when used for lucid dream induction. This aligns with prior work around the Dormio system [34], which used sound to influence dream content during the hypnagogic state, and Dozer [81], which employed both electrical and auditory stimulation to induce sleep onset. Auditory cues are also often used in hypnosis [69, 90]. This "auditory dominance" appears unique to affecting altered states of consciousness and contrasts with HCI designs for the ordinary waking state, where visual dominance is more prevalent [19]. We therefore suggest designers apply auditory cues in the context of sleep. In particular, an auditory cue verbalizing the desired dream outcome (expressed as a single sentence) may be a useful starting point for designers [79]. While auditory cues appear to be more effective, we note that visual cues still have value, as several participants reported that these cues were incorporated into their dream content.

6.3 Consider complementing digital approaches with analog techniques, while leveraging digital systems to make analog techniques more engaging

Two participants reported that the cognitive training gave them the confidence to induce lucid dreaming, with one of them reporting that they experienced lucid dreaming during the study.

This finding aligns with the mnemonic induction of lucid dreams (MILD), in which people set the intention to become lucid before sleep [48]. Furthermore, our results confirm the approach of Carr et al. [16], who combined analog and digital lucid dream induction techniques to increase induction rates.

Although the analog techniques facilitated lucid dream induction, participants also expressed that they caused both annoyance and tiredness. One possible strategy to reduce negative emotional outcomes might be to augment analog techniques with digital approaches. For instance, Montoya et al. demonstrated that a playful water experience could reduce people's unexpected emotions such as fear of water [64]. Therefore, we suggest approaches such as gamification to make bodily training practices more engaging [41]. The application of gamification aligns with Jung et al.'s suggestion of utilizing games to facilitate altered states of consciousness since games are free from the spatial-temporal constraint of reality [40]. One gamification approach is to offer digital rewards, as in Pokémon Sleep [13]. In our case, we can imagine that analog lucid dream induction techniques could be integrated into Pokémon Sleep. If the user chooses to induce lucid dreams and follows the instructions to perform analog techniques properly, they will get a special Pokémon in the game, which might make the user feel more engaged. Another approach is to have the user practice analog techniques while engaging with other forms of digital entertainment. Peters et al., for instance, asked participants to practice reality testing, an analog lucid dream induction technique, while playing WII Fit [74]. With regard to cognitive training, we could design an app that allows for the delivery of visual and auditory cues while the user is simultaneously playing a mobile game. In sum, combining digital and analog techniques can help to both mitigate user fatigue and enhance motivation, making lucid dream induction more sustainable and enjoyable.

6.4 Consider using interactive technologies to create desired digital content in altered states of consciousness

A key finding from our study was that, while 4 participants reported having lucid dreams, they had less control over their dreams than they anticipated. Our findings align with Lemyre et al., suggesting that believing dream lucidity guarantees dream control is a misconception [54]. Mallett et al. further categorizes lucid dream control as an indicator of high lucidity, whereas they argue that the simple awareness of dreaming should be classified as a state of medium lucidity [60]. In our study, we also noticed that pre-sleep experiences, such as the study procedure, and cues were incorporated into participants' dreams; this is consistent with the findings of Salvesen, et al. [79] and Carr et al. [15]. We, therefore, see an opportunity to facilitate dream control through interactive technologies. For example, a system could prompt users to specify their desired dream narrative before sleep (which also utilizes their pre-sleep experiences). During lucid dreaming, the system could trigger narrative-related cues to help users exert control over their dreams. However, the relationship between cues and dream content requires further investigation.

6.5 Consider sensing the user's umwelt to allow for enhanced customization

While using cues to create digital content in altered states of consciousness is possible, our results suggest that the user's umwelt—how a person interprets the world, shaped not only by (1) the physiological factors but also (2) their past experiences [37]—can influence how the mind interprets cues to a greater extent than in designs targeted at wakefulness.

Firstly, we observed that physiological factors related to sleep—such as eyelid—can distort cue perception. For example, when their eyes were closed, P2 and P9 reported seeing the visual cue as "white" and "green" respectively. The color distortion might stem from partial light absorption by the eyelids [9]. Similarly, individuals with sleep apnea might have an altered perception of olfactory cues because pauses in breathing could prevent scent detection during apneic episodes [99]. We, therefore, recommend that designers account for such physiological factors during sleep to ensure that users can perceive the cues. For instance, Bierman et al. reviewed prior work on eyelid transmittance and found that red transmittance is 9%, green is 0.5%, and blue is 0.4% [10]. Accordingly, one could recode a visual cue by amplifying red by 11 times, green by 200 times, and blue by 250 times to achieve the initially intended color.

Second, the user's past experiences, such as their cultural background and daily experiences, influence their interpretation of the cues. For example, P2 and P5, whose first language was not English had trouble processing the English auditory cues at such a low level of consciousness, even though they understood English during wakefulness (such as in the interviews) very well.

Moreover, the visual cue was reinterpreted by the mind as the flashing lights of a police car, or the white light of a camera flash; it manifested in a way consistent with the narrative of the user's dream. This suggests that cues can influence dream content. However, participants only recognized that these were manifestations of the cues after waking up, which was elicited through the interviews. The interviews also suggested the difficulty in participants recognizing cues during a low level of consciousness. Hence, we can confirm States' prior theory that that dream has its own umwelt: "[D]reams create a world order, or umwelt, with its own distinct cognitive domain in which waking considerations of efficiency, logic, and common sense are only thematically relevant." [85] Furthermore, Salvesen et al. indicated that the mind would be more likely to incoporate and transform cues into the dream if they were relevant to the content of the dream [79], and vice versa. These suggestions, in combination with our findings, imply that when designing cues, the designer should consider not only past experiences of the user but also the content of the dream. Understanding the users' past experiences can be done through, for example, (1) collecting the user's data before sleep and (2) allowing for the customization of cues. Consequently, even if data on the user's cultural background is utilized (enabling the system to personalize cues), going further by allowing the user to customize the cues on their own could be beneficial.

It becomes more challenging with regard to sensing the dream's umwelt. In the current state of the art, dream decoding has only provably been performed using functional magnetic resonance imaging (fMRI). While Horkawa et al. decoded the dream content into categories [36], such as *"book"* and *"male"*, Fu et al. proposed a proof of concept to decode dream content into videos [31]. However, this proof of concept only works with fMRI, limiting the possibility of using it in everyday life. One approach of investigating dream content with accessible technology is to understand the user's daily life, as pre-sleep experiences influence the dream experience through a day-residue effect; people are more likely to dream of events that happened in their daily life during the previous two days [25]. Therefore, the designers could design cues by logging the user's daily life and analyzing its content with a large-language model to identify relevant cues. In the future, we imagine once the dream decoding becomes mature, the designers can alter cues based on the user's dream content in real-time.

In sum, the user's umwelt, not only the physiological factors but also their past experiences, creates a fog for the cue interpretation. To address this, we suggest the designers consider sensing the user's umwelt and allowing customization so that the user can interpret the cues properly.

6.6 Design space: Targeting the optimal range for transitioning to the lucid state

Despite the ability for users to calibrate cue intensities prior to sleep and automatic delivery of cues upon detection of the user's REM stages, five participants still reported waking up due to cues, and two participants were entirely unaware of them during sleep. This suggests that the thresholds for awakening and perceiving are not fixed but fluctuate during sleep, making it difficult to predefine cue parameters. In related prior work, Byrne et al. have described the need to find a "sweet spot" for effective stimulation when designing bodily HCI experiences [14]. Drawing inspiration from their work, we propose the following diagram for digital lucid dream induction experiences (Figure 8):

- If people perceive strong cues while awake, they might feel annoyed.
- If people perceive weak cues while awake, they might remain awake without interruption.
- If people perceive strong cues while asleep, they may wake up.
- If people perceive weak cues while asleep, they might continue sleeping without interruption.
- Only cues at the right intensities, presented at the right level of consciousness, can help people realize they are dreaming and thereby induce lucid dreaming.

The current prototype, LuciEntry, enabled participants to self-calibrate cue intensity, which influenced their perception of the

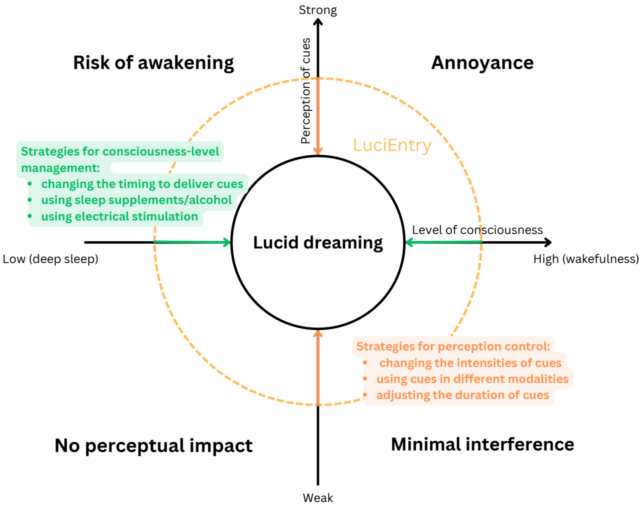

Figure 8: The digital lucid dream induction experience diagram. The diagram describes how people would react to cues at different levels of consciousness. The x-axis presents the level of consciousness (deep sleep → wakefulness), and the y-axis presents the perception of cues. Our goal is to guide users toward the center "sweet spot," where they are aware they are dreaming—thus inducing lucid dreaming. However, the current prototype, LuciEntry, elicited a range of experiences among participants. Based on these findings, we propose several strategies to help shift user experiences toward this ideal state.

cues. It also incorporated the WBTB technique, which elevated participants' consciousness to the ordinary waking state before allowing them to return to light sleep, thereby adjusting their level of consciousness. However, the techniques developed in LuciEntry elicited a range of experiences—more often the four other aforementioned types—rather than consistently inducing lucid dreams. This may be due to two key reasons: (1) self-calibration is inherently difficult for users, as it is challenging to anticipate how cues will be perceived during dreams while still awake; and (2) even with the WBTB technique, participants reported being in various levels of consciousness that did not always support lucid dreaming.

To navigate this delicate balance and reach the "sweet spot," we suggest two directions for design strategies to shift the user experiences toward the center: perception control and consciousness-level management. For **perception control**, it is possible to **(1) change the intensities of cues by employing iterative calibration with user feedback, (2) explore multiple modalities (e.g., tactile, thermal), and (3) vary the cue duration**. Future systems could incorporate a more systematic calibration process, for example, each night it could ask the user about their experiences during that day and automatically adjust intensity based on their feedback. Furthermore, triggering cues in different modalities might be another strategy for perception control. we currently used visual and auditory cues for the participants, which could be useful for light or sound-sensitive users. While olfactory cues appear ineffective for lucid dream induction [27], tactile [76], and haptic cues [75] are promising areas of exploration. Longer cue durations or repetitive cues could increase the likelihood of being perceived, but overly long cues might risk being ignored once the user becomes accustomed to them.

For **consciousness-level management**, designers could **(1) fine-tune the timing of cue delivery based on real-time data, (2) use sleep aids or alcohol, and (3) use electrical stimulation**. Adjusting the trigger timing is a logical starting point for managing the level of consciousness at which cues are presented. As participants still reported perceiving cues while awake or sleeping through them, incorporating iterative calibration — where the system asks for feedback on whether the timing is appropriate — could be beneficial. This might, again, involve iterative calibration, where the system uses user feedback to adjust cue timings. Alternatively, some people may use sleep aids or alcohol to enter a state of altered cognition. LaBerge et al. showed that galantamine (an Alzheimer's medication) can help to induce lucid dreaming by changing participants' neurochemistry [51], though 14% reported side effects such as gastrointestinal upset, insomnia, and next-day fatigue. Electrical stimulation of the brain is another emerging approach: Voss et al. applied 40 Hz tACS to increase self-reflective awareness in dreams [94], while Semertzidis et al. explored electrical brain stimulation to induce sleep onset [81]. This area remains under-explored but shows promise. Overall, designing for the sweet spot requires balancing perception and consciousness with user-centered adaptability, leveraging both physiological signals and behavioral feedback.

6.7 Consider minimizing the mental effort for altered states of consciousness

Designing for altered states of consciousness requires special attention to users' limited cognitive resources, especially during transitions between sleep and wakefulness. We included indicator lights on the cue modules to make troubleshooting easier. However, three participants reported that the indicator lights disrupted their sleep, which aligns with Spiekermann et al.'s argument that human attention is a scarce resource that should be carefully managed [84]. In altered states of consciousness, attention is even more limited. Therefore, future systems might display information only when needed to avoid disrupting these states. For example, adding a geophone sensor to the module could enable information displays only when the user actively interacts with it.

On the other hand, we designed LuciEntry with a modular approach to enable easy customization. However, participants reported that LuciEntry was too complicated when they were sleepy—a likely consequence of limited attention in an altered state of consciousness. Thus, the complexity of a modular design can be overwhelming in such contexts. An all-in-one system might be more suitable for sleepers, as suggested by prior works [34, 81]. For example, a single smartphone application to trigger visual and auditory cues might be more suitable for the user than separate cue modules. In summary, systems designed for altered states should minimize unnecessary mental effort, reduce complexity, and deliver information only when relevant to support seamless, low-effort interaction.

7 Limitations and future work

7.1 Placebo effect

One limitation of our study was the lack of a placebo testing protocol. However, lucid dreaming rarely occurs naturally [47, 65, 66], and prior works have proven the effectiveness of the lucid dream techniques we adopted [16, 28, 46, 73]. Hence, most of the lucid dreams our novice participants experienced are unlikely to have a placebo effect. We noted that we focused on the user experience. By understanding the lucid dream induction user experience, we proposed design considerations to guide future lucid dream induction designs. Testing the placebo effect would make our already lengthy experimental process even longer, further increasing the effort required from participants. Therefore, we did not incorporate the testing for the placebo effect in our study.

7.2 Individual component effectiveness

As noted, our study focused on the overall user experience, which is not well understood. To that end, we employed multiple techniques simultaneously, a common practice in lucid dream research. For example, Carr et al. used visual and auditory stimulation to induce lucid dreaming [16], while Esfahani et al. used visual, auditory, and tactile stimulation [39]. However, this multi-stimulation process makes it difficult to isolate the effectiveness of individual techniques. We still suggest that future work assign participants to separate groups (e.g., some only receiving auditory cues) to explore the specific effects of a single modality. Further divisions could be made to help understand different classes of auditory cues (e.g., ambient versus vocal stimuli).

7.3 Different modalities for system design

In our current system design, we explored the user experience of visual and auditory cues for lucid dream induction, mainly because of their effectiveness [16, 73]. As discussed in subsection 6.6, we still see the opportunity to use other modalities, such as tactile [76], haptic [75], and brain stimulation [94]. Using different modalities might create different user experiences, as the cues would be incorporated into dreams differently [79].

7.4 Real-time lucid dreaming confirmation

Although our interview data suggest that LuciEntry enhanced participants' lucidity, the failure of participants to remember performing the LR signals prevented objective verification of their lucidity. Performing LR signals in lucid dreaming is challenging as dreaming contains involuntary autobiographical memory [83], making it easy for people to forget their intentions. Consequently, there is often a large discrepancy between the proportion of people who report lucidity and those who perform LR signals [73, 74]. We, therefore, recommend that future studies incorporate more consistent and distinct training for LR signaling to establish a more reliable confirmation mechanism on which to base qualitative data collection.

7.5 Ethics

Finally, we encourage future research on the ethics of using interactive technology to influence users in altered states of consciousness. We can also imagine scenarios in which such technology might be misused. For example, a highly portable design that induces altered states of consciousness could be misused and lead to harm at an inappropriate time, such as driving. Furthermore, as the cognitive load is usually low in altered states of consciousness, does the user really understand what the prototype does to them? Prior works on "dark patterns" in HCI [21, 58] suggest that examining such scenarios early on in the emergence of technologies could help inform the design of more responsible technologies in the future. We, also emphasize the importance of examining ethical considerations early on when designing altered states of consciousness systems.

7.6 Everyday life usage

Furthermore, we acknowledge that, although we focus on the user experience, our prototype and study procedure occasionally caused unexpected emotions, such as tiredness and annoyance, due to disrupted sleep. By implementing the design considerations proposed in this paper, we envision a follow-up future work could induce lucid dreaming with less disruption, making it suitable for integration into everyday life.

8 Conclusion

In this paper, we presented LuciEntry, a portable prototype that aims to facilitate lucid dream induction by triggering visual and auditory cues. We conducted a study with 13 participants to investigate LuciEntry's user experiences. The interviews revealed three themes: facilitating lucidity, challenges around system usability, and trade-offs of the analog lucid dream induction techniques. We also offered design considerations for design researchers who wish to further explore lucid dream system designs. Ultimately, we hope this work inspires additional research into interactive technologies for altered states of consciousness.

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References

[1] Denholm Jay Adventure-Heart. 2020. Findings From the International Lucid Dream Induction Study. *Frontiers in Psychology* 11 (2020). doi:10.3389/fpsyg.2020.01746

[2] Denholm Jay Adventure-Heart, Paul Delfabbro, Michael Proeve, and Philip Mohr. 2017. Reality testing and the mnemonic induction of lucid dreams: Findings from the national Australian lucid dream induction study. *Dreaming* 27, 3 (2017), 206–231. doi:10.1037/drm0000059

[3] Denholm Jay Adventure-Heart, Paul Delfabbro, Michael Proeve, and Philip Mohr. 2017. Reality testing and the mnemonic induction of lucid dreams: Findings from the national Australian lucid dream induction study. *Dreaming* 27, 3 (2017), 206.

[4] Marco Altini and Hannu Kinnunen. 2021. The Promise of Sleep: A Multi-Sensor Approach for Accurate Sleep Stage Detection Using the Oura Ring. *Sensors* 21, 1313 (Jan. 2021), 4302. doi:10.3390/s21134302

[5] Katsuhisa Ando and Daniel F. Kripke. 1996. Light attenuation by the human eyelid. *Biological Psychiatry* 39, 1 (1996), 22–25. doi:10.1016/0006-3223(95)00109-3

[6] Eugene Aserinsky and Nathaniel Kleitman. 1953. Regularly Occurring Periods of Eye Motility, and Concomitant Phenomena, During Sleep. *Science* 118, 3062 (Sept. 1953), 273–274. doi:10.1126/science.118.3062.273

[7] Benjamin Baird, Sergio A. Mota-Rolim, and Martin Dresler. 2019. The cognitive neuroscience of lucid dreaming. *Neuroscience & Biobehavioral Reviews* 100 (2019), 305–323. doi:10.1016/j.neubiorev.2019.03.008

[8] Davide Benedetti, Emma Frati, Orsolya Kiss, Dilara Yuksel, Ugo Faraguna, Brant P. Hasler, Peter L. Franzen, Duncan B. Clark, Fiona C. Baker, and Massimiliano de Zambotti. 2023. Performance evaluation of the open-source Yet Another Spindle Algorithm sleep staging algorithm against gold standard manual evaluation of polysomnographic records in adolescence. *Sleep Health* 9, 6 (2023), 910–924. doi:10.1016/j.sleh.2023.07.019

[9] Andrew Bierman, Mariana G. Figueiro, and Mark S. Rea. 2011. Measuring and predicting eyelid spectral transmittance. *Journal of Biomedical Optics* 16, 6 (June 2011), 067011. doi:10.1117/1.3593151

[10] Andrew Bierman, Mariana G. Figueiro, and Mark S. Rea. 2011. Measuring and predicting eyelid spectral transmittance. *Journal of Biomedical Optics* 16, 6 (June 2011), 067011. doi:10.1117/1.3593151

[11] Ann Blandford, Dominic Furniss, and Stephann Makri. 2016. *Qualitative HCI research: Going behind the scenes.* Morgan & Claypool Publishers.

[12] Virginia Braun and Victoria Clarke. 2006. Using thematic analysis in psychology. *Qualitative Research in Psychology* 3, 2 (2006), 77–101. doi:10.1191/1478088706qp063oa arXiv:https://www.tandfonline.com/doi/pdf/10.1191/1478088706qp063oa

[13] SELECT BUTTON. 2024. Pokémon Sleep Official Webpage. https://www.pokemonsleep.net/en

[14] Richard Byrne, Joe Marshall, and Florian 'Floyd' Mueller. 2020. Designing Digital Vertigo Experiences. *ACM Trans. Comput.-Hum. Interact.* 27, 3, Article 19 (may 2020), 30 pages. doi:10.1145/3387167

[15] Michelle Carr, Adam Haar, Judith Amores, Pedro Lopes, Guillermo Bernal, Tomás Vega, Oscar Rosello, Abhinandan Jain, and Pattie Maes. 2020. Dream engineering: Simulating worlds through sensory stimulation. *Consciousness and cognition* 83 (2020), 102955.

[16] Michelle Carr, Karen Konkoly, Remington Mallett, Christopher Edwards, Kristoffer Appel, and Mark Blagrove. 2020. 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).

[17] Bernard Allan Cohen, Enrique J Bravo-Fernandez, and Anthony Sances Jr. 1976. Quantification of computer analyzed serial EEGs from stroke patients. *Electroencephalography and clinical neurophysiology* 41, 4 (1976), 379–386.

[18] Bernard Allan Cohen and Anthony Sances. 1977. Stationarity of the human electroencephalogram. *Medical and Biological Engineering and Computing* 15 (1977), 513–518.

[19] Francis B. Colavita. 1974. Human sensory dominance. *Perception & Psychophysics* 16, 2 (March 1974), 409–412. doi:10.3758/BF03203962

[20] Core-electronics. 2025. Dupont Wire 20cm Female / Female 100pcs Pack. https://core-electronics.com.au/dupont-wire-20cm-female-female-100pcs-pack.html

[21] Rod Dickinson, Nathan Semertzidis, and Florian Floyd Mueller. 2022. Machine In The Middle: Exploring Dark Patterns of Emotional Human-Computer Integration Through Media Art. In *Extended Abstracts of the 2022 CHI Conference on Human Factors in Computing Systems* (New Orleans, LA, USA) *(CHI EA '22)*. Association for Computing Machinery, New York, NY, USA, Article 43, 7 pages. doi:10.1145/3491101.3503555

[22] Ajar Diushekeeva, Santiago Hidalgo, and Antonio Zadra. 2024. Impact of Pre-Sleep Visual Media Exposure on Dreams: A Scoping Review. *Brain Sciences* 14, 77 (July 2024), 662. doi:10.3390/brainsci14070662

[23] Alan B. Douglass, Robert Bomstein, German Nino-Murcia, Sharon Keenan, Laughton Miles, Jr. Zarcone, Vincent P., Christian Guilleminault, and William C. Dement. 1994. The Sleep Disorders Questionnaire I: Creation and Multivariate Structure of SDQ. *Sleep* 17, 2 (03 1994), 160–167. doi:10.1093/sleep/17.2.160 arXiv:https://academic.oup.com/sleep/article-pdf/17/2/160/13701833/sleep-17-2-160.pdf

[24] Sophie Dyck, Michael Schredl, and Anja Kühnel. 2017. Lucid dream induction using three different cognitive methods. *International Journal of Dream Research* 10, 2 (2017), 151–156.

[25] Jean-Baptiste Eichenlaub, Sydney S Cash, and Mark Blagrove. 2017. Daily life experiences in dreams and sleep-dependent memory consolidation. *Cognitive neuroscience of memory consolidation* (2017), 161–172.

[26] Emadeldeen Eldele, Zhenghua Chen, Chengyu Liu, Min Wu, Chee-Keong Kwoh, Xiaoli Li, and Cuntai Guan. 2021. An Attention-Based Deep Learning Approach for Sleep Stage Classification With Single-Channel EEG. *IEEE Transactions on Neural Systems and Rehabilitation Engineering* 29 (2021), 809–818. doi:10.1109/TNSRE.2021.3076234

[27] Daniel Erlacher, Daniel Schmid, Silvan Schuler, and Björn Rasch. 2020. Inducing lucid dreams by olfactory-cued reactivation of reality testing during early-morning sleep: A proof of concept. *Consciousness and Cognition* 83 (2020), 102975. doi:10.1016/j.concog.2020.102975

[28] Daniel Erlacher and Tadas Stumbrys. 2020. Wake up, work on dreams, back to bed and lucid dream: A sleep laboratory study. *Frontiers in psychology* 11 (2020), 1383.

[29] Mahdad Jafarzadeh Esfahani, Amir Hossein Daraie, Paul Zerr, Frederik D Weber, and Martin Dresler. 2023. Dreamento: an open-source dream engineering toolbox for sleep EEG wearables. *SoftwareX* 24 (2023), 101595.

[30] Expo. 2025. Expo Go. https://expo.dev/go

[31] Yanwei Fu, Jianxiong Gao, Baofeng Yang, and Jianfeng Feng. 2025. Making Your Dreams A Reality: Decoding the Dreams into a Coherent Video Story from fMRI Signals. arXiv:2501.09350 (Jan. 2025). doi:10.48550/arXiv.2501.09350 arXiv:2501.09350 [cs].

[32] Jarrod Gott, Michael Rak, Leonore Bovy, Emma Peters, Carmen F.M. van Hooijdonk, Anastasia Mangiaruga, Rathiga Varatheeswaran, Mahmoud Chaabou, Luke Gorman, Steven Wilson, Frederik Weber, Lucia Talamini, Axel Steiger, and Martin Dresler. 2020. Sleep fragmentation and lucid dreaming. *Consciousness and Cognition* 84 (2020), 102988. doi:10.1016/j.concog.2020.102988

[33] David E. Gray. 2018. *Doing Research in the Real World* (4th ed.). SAGE Publications, London.

[34] Adam Haar Horowitz, Ishaan Grover, Pedro Reynolds-Cuéllar, Cynthia Breazeal, and Pattie Maes. 2018. Dormio: Interfacing with dreams. In *Extended Abstracts of the 2018 CHI Conference on Human Factors in Computing Systems*. 1–10.

[35] Michael Jeffrey Daniel Hoefer, Bryce E Schumacher, and Stephen Voida. 2022. Personal Dream Informatics: A Self-Information Systems Model of Dream Engagement. In *Proceedings of the 2022 CHI Conference on Human Factors in Computing Systems*. 1–16.

[36] Tomoyasu Horikawa and Yukiyasu Kamitani. 2017. Hierarchical Neural Representation of Dreamed Objects Revealed by Brain Decoding with Deep Neural Network Features. *Frontiers in Computational Neuroscience* 11 (Jan. 2017). doi:10.3389/fncom.2017.00004

[37] Jonathan Hunter. 2024. Umwelt—A New Strategy for Mentalizing Patient Experience. *American Journal of Psychotherapy* 77, 4 (Dec. 2024), 212–214. doi:10.1176/appi.psychotherapy.20240003

[38] Mari Hysing, Ståle Pallesen, Kjell Morten Stormark, Reidar Jakobsen, Astri J Lundervold, and Børge Sivertsen. 2015. Sleep and use of electronic devices in adolescence: results from a large population-based study. *BMJ open* 5, 1 (2015), e006748.

[39] Mahdad Jafarzadeh Esfahani, Leila Anna Christina Salvesen, Claudia Picard-Deland, Tobi Matzek, Ema Demsar, Tinke Van Buijtene, Victoria Libucha, Bianca Pedreschi, Giulio Bernardi, Paul Zerr, Nico Adelhofer, Sarah Schoch, Michelle Carr, and Martin Dresler. 2024. Highly effective verified lucid dream induction using combined cognitive-sensory training and wearable EEG: a multi-centre study. (June 2024). doi:10.1101/2024.06.21.600133

[40] Sangwon Jung, Oğuz 'Oz Buruk, and Juho Hamari. 2022. Altered States of Consciousness in Human-Computer Interaction: A Review. In *Nordic Human-Computer Interaction Conference (NordiCHI '22)*. Association for Computing Machinery, New York, NY, USA, 1–13. doi:10.1145/3546155.3546667

[41] Tuomas Kari, Jenni Piippo, Lauri Frank, Markus Makkonen, and Panu Moilanen. 2016. To gamify or not to gamify? Gamification in exercise applications and its role in impacting exercise motivation. (2016).

[42] Alexandra Kitson, Steve DiPaola, and Bernhard E. Riecke. 2019. 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* (Glasgow, Scotland Uk) *(CHI EA '19)*. Association for Computing Machinery, New York, NY, USA, 1–6. doi:10.1145/3290607.3312952

[43] Alexandra Kitson, Thecla Schiphorst, and Bernhard E. Riecke. 2018. Are You Dreaming? A Phenomenological Study on Understanding Lucid Dreams as a Tool for Introspection in Virtual Reality. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems* (Montreal QC, Canada) *(CHI '18)*. Association for Computing Machinery, New York, NY, USA, 1–12. doi:10.1145/3173574.3173917

[44] Karen R. Konkoly, Kristoffer Appel, Emma Chabani, Anastasia Mangiaruga, Jarrod Gott, Remington Mallett, Bruce Caughran, Sarah Witkowski, Nathan W. Whitmore, Christopher Y. Mazurek, Jonathan B. Berent, Frederik D. Weber, Başak Türker, Smaranda Leu-Semenescu, Jean-Baptiste Maranci, Gordon Pipa, Isabelle Arnulf, Delphine Oudiette, Martin Dresler, and Ken A. Paller. 2021. Real-time dialogue between experimenters and dreamers during REM sleep. *Current Biology* 31, 7 (2021), 1417–1427.e6. doi:10.1016/j.cub.2021.01.026

[45] Karen R. Konkoly, Nathan W. Whitmore, Remington Mallett, Christopher Y. Mazurek, and Ken A. Paller. 2024. Provoking lucid dreams at home with sensory cues paired with pre-sleep cognitive training. *Consciousness and Cognition* 125 (Oct. 2024), 103759. doi:10.1016/j.concog.2024.103759

[46] Stephen LaBerge. 1988. Induction of lucid dreams including the use of the Dreamlight. *Lucidity Letter* 7, 2 (1988).

[47] Stephen LaBerge. 1990. *Exploring the World of Lucid Dreaming.* http://www.newforestcentre.info/uploads/7/5/7/2/7572906/stephan_laberge_-_exploring_the_world_of_lucid_dreaming.pdf

[48] Stephen LaBerge. 1990. *Exploring the World of Lucid Dreaming.* BALLANTINE BOOKS. http://www.newforestcentre.info/uploads/7/5/7/2/7572906/stephan_

laberge_-_exploring_the_world_of_lucid_dreaming.pdf
[49] Stephen LaBerge. 1990. *Exploring the World of Lucid Dreaming*. BALLANTINE BOOKS. http://www.newforestcentre.info/uploads/7/5/7/2/7572906/stephan_laberge_-_exploring_the_world_of_lucid_dreaming.pdf
[50] Stephen LaBerge. 1990. *Lucid dreaming: Psychophysiological studies of consciousness during REM sleep.* American Psychological Association, Washington, DC, US, 109–126. doi:10.1037/10499-008
[51] Stephen LaBerge, Kristen LaMarca, and Benjamin Baird. 2018. Pre-sleep treatment with galantamine stimulates lucid dreaming: A double-blind, placebo-controlled, crossover study. *PLoS One* 13, 8 (2018), e0201246.
[52] Grégoire S. Larue, Christopher N. Watling, Alexander A. Black, Joanne M. Wood, and Mahrokh Khakzar. 2020. Pedestrians distracted by their smartphone: Are in-ground flashing lights catching their attention? A laboratory study. *Accident Analysis and Prevention* 134 (2020), 105346. doi:10.1016/j.aap.2019.105346
[53] Jong-Min Lee, Dae-Jin Kim, In-Young Kim, Kwang-Suk Park, and Sun I. Kim. 2002. Detrended fluctuation analysis of EEG in sleep apnea using MIT/BIH polysomnography data. *Computers in Biology and Medicine* 32, 1 (2002), 37–47. doi:10.1016/S0010-4825(01)00031-2
[54] Alexandre Lemyre, Lidia Légaré-Bergeron, Roxanne B. Landry, Donald Garon, and Annie Vallières. 2020. High-Level Control in Lucid Dreams. *Imagination, Cognition and Personality* 40, 1 (Sept. 2020), 20–42. doi:10.1177/0276236620909544
[55] David J Lewkowicz. 2001. The concept of ecological validity: What are its limitations and is it bad to be invalid? *Infancy* 2, 4 (2001), 437–450.
[56] Pinyao Liu, Alexandra Kitson, Claudia Picard-Deland, Michelle Carr, Sijia Liu, Ray Lc, and Chen Zhu-Tian. 2024. Virtual Dream Reliving: Exploring Generative AI in Immersive Environment for Dream Re-experiencing. In *Extended Abstracts of the CHI Conference on Human Factors in Computing Systems*. 1–11.
[57] Pinyao Liu, Ekaterina R Stepanova, Alexandra Kitson, Thecla Schiphorst, and Bernhard E Riecke. 2022. Virtual transcendent dream: empowering people through embodied flying in virtual reality. In *Proceedings of the 2022 CHI Conference on Human Factors in Computing Systems*. 1–18.
[58] Siyi Liu, Nathan Semertzidis, Gun A. Lee, Florian 'Floyd' Mueller, and Barrett Ens. 2024. Exploring Superpower Design Through Wi-Fi Twinge. In *Proceedings of the Eighteenth International Conference on Tangible, Embedded, and Embodied Interaction* (Cork, Ireland) *(TEI '24)*. Association for Computing Machinery, New York, NY, USA, Article 4, 16 pages. doi:10.1145/3623509.3633352
[59] Raspberry Pi Ltd. 2024. Raspberry Pi 4 Model B specifications. https://www.raspberrypi.com/products/raspberry-pi-4-model-b/specifications/
[60] Remington Mallett, Michelle Carr, Martin Freegard, Karen Konkoly, Ceri Bradshaw, and Michael Schredl. 2021. Exploring the range of reported dream lucidity. *Philosophy and the Mind Sciences* 2 (2021), 1–23.
[61] Meta. 2025. React Native · Learn once, write anywhere. https://reactnative.dev/
[62] James Miller. 2007. *The Human in the Loop: Human Fatigue and its Effects*. doi:10.13140/RG.2.2.12101.78565
[63] Miro. 2025. Miro | The Innovation Workspace. https://miro.com/
[64] Maria F. Montoya, YuYang Ji, Ryan Wee, Nathalie Overdevest, Rakesh Patibanda, Aryan Saini, Sarah Jane Pell, and Florian 'Floyd' Mueller. 2023. Fluito: Towards Understanding the Design of Playful Water Experiences through an Extended Reality Floatation Tank System. *Proc. ACM Hum.-Comput. Interact.* 7, CHI PLAY (Oct. 2023), 410:948–410:975. doi:10.1145/3611056
[65] Sérgio Mota-Rolim, Zé Targino, Bryan Souza, Wilfredo Blanco, John Araujo, and Sidarta Ribeiro. 2013. Dream characteristics in a Brazilian sample: an online survey focusing on lucid dreaming. *Frontiers in Human Neuroscience* 7 (2013). https://www.frontiersin.org/articles/10.3389/fnhum.2013.00836
[66] Sérgio A. Mota-Rolim, Achilleas Pavlou, George C. Nascimento, John Fontenele-Araujo, and Sidarta Ribeiro. 2019. Portable Devices to Induce Lucid Dreams—Are They Reliable? *Frontiers in Neuroscience* 13 (2019), 459918. https://www.frontiersin.org/articles/10.3389/fnins.2019.00428
[67] Sérgio A Mota-Rolim, Achilleas Pavlou, George C Nascimento, John Fontenele-Araujo, and Sidarta Ribeiro. 2019. Portable devices to induce lucid dreams—are they reliable? *Frontiers in neuroscience* 13 (2019), 459918.
[68] L.F. Márton, S.T. Brassai, L. Bakó, and L. Losonczi. 2014. Detrended Fluctuation Analysis of EEG Signals. *Procedia Technology* 12 (2014), 125–132. doi:10.1016/j.protcy.2013.12.465 The 7th International Conference Interdisciplinarity in Engineering, INTER-ENG 2013, 10-11 October 2013, Petru Maior University of Tirgu Mures, Romania.
[69] Michael R Nash and Amanda J Barnier. 2012. *The Oxford handbook of hypnosis: Theory, research, and practice.* Oxford University Press.
[70] OpenBCI. 2021. Cyton Board | OpenBCI Documentation. https://openbci.github.io/Cyton/CytonLanding/
[71] Oura. 2024. Oura Ring. Smart Ring for Fitness, Stress, Sleep and Health. https://ouraring.com
[72] Andrey Parfenov. 2024. BrainFlow. https://brainflow.org/
[73] Emma Peters, Daniel Erlacher, Friedrich Müller, and Michael Schredl. 2023. Using hypnotic enhancement with auditory suggestion for lucid dream induction. *Somnologie* 27, 3 (Sept. 2023), 198–205. doi:10.1007/s11818-023-00414-7
[74] Emma Peters, Daniel Erlacher, Martin Rühl, and Melanie Schädlich. 2024. Sounds of lucidity: Auditory stimulation for triggering reality checks in lucid dream induction. *Dreaming* (2024).
[75] Emma Peters, Jakob Pöhlmann, Xinlin Wang, Martin Dresler, and Daniel Erlacher. 2024. A Comparative Study of Muscular, Vestibular, and Haptic Stimulation on Dream Incorporation. *bioRxiv* (Dec. 2024), 2024.12.05.626974. doi:10.1101/2024.12.05.626974
[76] Emma Peters, Xinlin Wang, Martin Dresler, and Daniel Erlacher. 2024. Dream incorporation of three different bodily stimuli. *Current Issues in Sport Science (CISS)* 9, 2 (2024), 006–006.
[77] Claudia Picard-Deland, Maude Pastor, Elizaveta Solomonova, Tyna Paquette, and Tore Nielsen. 2020. Flying dreams stimulated by an immersive virtual reality task. *Consciousness and Cognition* 83 (2020), 102958.
[78] Armin Ronacher. 2010. Welcome to Flask — Flask Documentation (3.1.x). https://flask.palletsprojects.com/en/stable/
[79] Leila Salvesen, Elena Capriglia, Martin Dresler, and Giulio Bernardi. 2024. Influencing dreams through sensory stimulation: A systematic review. *Sleep Medicine Reviews* 74 (April 2024), 101908. doi:10.1016/j.smrv.2024.101908
[80] Melanie Schädlich and Daniel Erlacher. 2012. Applications of lucid dreams: An online study. *International Journal of Dream Research* 5, 2 (Nov. 2012), 134–138. doi:10.11588/ijodr.2012.2.9505
[81] Nathan Arthur Semertzidis, Annaelle Li Pin Hiung, Michaela Jayne Vranic-Peters, and Florian 'Floyd' Mueller. 2023. Dozer: Towards Understanding the Design of Closed-Loop Wearables for Sleep. In *Proceedings of the 2023 CHI Conference on Human Factors in Computing Systems* (Hamburg, Germany) *(CHI '23)*. Association for Computing Machinery, New York, NY, USA, Article 195, 14 pages. doi:10.1145/3544548.3581044
[82] Ramkumar Sivasakthivel, K. Kumar, Dhiliphan Rajkumar, Ilayaraja .M, and Kripa Shankar. 2018. A review-classification of electrooculogram based human computer interfaces. *Biomedical Research (India)* 29 (04 2018). doi:10.4066/biomedicalresearch.29-17-2979
[83] Elizaveta Solomonova and Michelle Carr. 2022. *Chapter 7 The Role of Attention and Intention in Dreams*. De Gruyter Saur, Berlin, Boston, 163–188. doi:10.1515/9783110647242-008
[84] Sarah Spiekermann. 2008. Attention & Interruption Management for Systems Design-A Research Overview. *Available at SSRN 1244622* (2008).
[85] Bert O. States. 2000. Dream Bizarreness and Inner Thought. *Dreaming* 10, 4 (Dec. 2000), 179–192. doi:10.1023/A:1009438406510
[86] Tadas Stumbrys and Daniel Erlacher. 2016. Applications of lucid dreams and their effects on the mood upon awakening. *International Journal of Dream Research* 9, 2 (Oct. 2016), 146–150. doi:10.11588/ijodr.2016.2.33114
[87] Tadas Stumbrys, Daniel Erlacher, and Michael Schredl. 2013. Testing the involvement of the prefrontal cortex in lucid dreaming: a tDCS study. *Consciousness and cognition* 22, 4 (2013), 1214–1222.
[88] Shuyue Tan and Jialin Fan. 2023. A systematic review of new empirical data on lucid dream induction techniques. *Journal of Sleep Research* 32, 3 (2023), e13786. doi:10.1111/jsr.13786 arXiv:https://onlinelibrary.wiley.com/doi/pdf/10.1111/jsr.13786
[89] Paul Tholey. 1983. Techniques for Inducing and Manipulating Lucid Dreams. *Perceptual and Motor Skills* 57, 1 (Aug. 1983), 79–90. doi:10.2466/pms.1983.57.1.79
[90] Jarno Tuominen, Sakari Kallio, Valtteri Kaasinen, and Henry Railo. 2021. Segregated brain state during hypnosis. *Neuroscience of Consciousness* 2021, 1 (03 2021), niab002. doi:10.1093/nc/niab002 arXiv:https://academic.oup.com/nc/article-pdf/2021/1/niab002/52809878/niab002.pdf
[91] Raphael Vallat and Matthew P Walker. 2021. An open-source, high-performance tool for automated sleep staging. *eLife* 10 (oct 2021), e70092. doi:10.7554/eLife.70092
[92] Curzio Vasapollo. 2025. Hypnodyne ZMax. https://hypnodynecorp.com/
[93] Visaton. 2025. FR 10 HM - 4 Ohm | Visaton. https://www.visaton.de/en/products/drivers/fullrange-systems/fr-10-hm-4-ohm
[94] Ursula Voss, Romain Holzmann, Allan Hobson, Walter Paulus, Judith Koppehele-Gossel, Ansgar Klimke, and Michael A Nitsche. 2014. Induction of self awareness in dreams through frontal low current stimulation of gamma activity. *Nature neuroscience* 17, 6 (2014), 810–812.
[95] Po-Yao (Cosmos) Wang, Nathaniel Yung Xiang Lee, Rohit Rajesh, Antony Smith Loose, Nathan Semertzidis, and Florian 'Floyd' Mueller. 2024. LuciEntry: A Modular Lab-Based Lucid Dream Induction Prototype. In *Extended Abstracts of the 2024 CHI Conference on Human Factors in Computing Systems (CHI EA '24)*. Association for Computing Machinery, New York, NY, USA, Article 644, 2 pages. doi:10.1145/3613905.3649123
[96] Po-Yao (Cosmos) Wang, Nathaniel Yung Xiang Lee, Rohit Rajesh, Antony Smith Loose, Nathan Semertzidis, and Florian 'Floyd' Mueller. 2024. LuciEntry: A Modular Lucid Dream Induction Prototype. In *Extended Abstracts of the 2024 CHI Conference on Human Factors in Computing Systems (CHI EA '24)*. Association for Computing Machinery, New York, NY, USA, Article 230, 6 pages. doi:10.1145/3613905.3651061
[97] Po-Yao (Cosmos) Wang, Nathaniel Yung Xiang Lee, Rohit Rajesh, Antony Smith Loose, Nathan Semertzidis, and Florian 'Floyd' Mueller. 2024. LuciEntry HOME:

An Anywhere Lucid Dream Induction Prototype. In *Extended Abstracts of the 2024 CHI Conference on Human Factors in Computing Systems (CHI EA '24)*. Association for Computing Machinery, New York, NY, USA, Article 643, 2 pages. doi:10.1145/3613905.3649122

[98] Po-Yao (Cosmos) Wang, Rohit Rajesh, Nathaniel Yung Xiang Lee, Antony Smith Smith Loose, Nathalie Overdevest, Nathan Semertzidis, and Florian 'Floyd' Mueller. 2024. DreamCeption: Towards Understanding the Design of Targeted Lucid Dream Mediation. In *Extended Abstracts of the 2024 CHI Conference on Human Factors in Computing Systems (CHI EA '24)*. Association for Computing Machinery, New York, NY, USA, 1–2. doi:10.1145/3613905.3649121

[99] David P. White. 2006. Sleep Apnea. *Proceedings of the American Thoracic Society* 3, 1 (March 2006), 124–128. doi:10.1513/pats.200510-116JH

[100] Fiona Wiltshier et al. 2011. Researching with NVivo. In *Forum Qualitative Sozialforschung/Forum: Qualitative Social Research*, Vol. 12.

[101] Jennifer Windt. 2013. Reporting dream experience: Why (not) to be skeptical about dream reports. *Frontiers in Human Neuroscience* 7 (2013). doi:10.3389/fnhum.2013.00708