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Exploring “lucid sleep” and altered states of consciousness using meditation and visual stimulation: A case series study

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Abstract

The scientific study of lucid sleep, defined as the ability to retain critical self-awareness during ongoing sleep, has traditionally focused on lucid dreaming and induction techniques that specifically target REM sleep. Recently, interest has grown to include other forms of lucid sleep, such as out-of-body experiences, sleep paralysis, and “witnessing-sleep” episodes described in Indian philosophical traditions. Empirical data on these states remain limited, primarily due to the lack of specific induction techniques designed for their study. In this case series study, we examine four individuals who reported lucid sleep episodes in a controlled laboratory setting, using a novel induction method combining pre-sleep meditation and visual stimulation. While this method requires future validation, we captured five lucid sleep episodes, including one instance of lucid dreamless sleep, one out-of-body-like experience, and three different types of lucid dreams. Sleep was monitored using wearable EEGs and submental EMGs. A detailed phenomenological analysis provided further context for these experiences, which were reported during both REM and non-REM sleep. Together, the induction protocol and findings described here may inform future research on lucid sleep and altered states of consciousness during sleep.

Keywords

Altered states of consciousness · Dream yoga · Lucid dream induction · Lucid dreamless sleep · Lucid sleep · Mindfulness · Out-of-body experiences · Sleep paralysis

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1 Introduction

Cognitive processing and mnemonic functioning are considerably restricted during sleep (Hobson, 1996; Hobson & Voss, 2011). Even when immersed in a vivid hallucinatory dreaming world, we often remain entirely absorbed by the content of these hallucinations and unable to pay attention to other dimensions that potentially coexist within the experience (Hobson et al., 2000; Noreika et al., 2010; Voss et al., 2013). In exceptional cases, the experiential subject can transcend this "auto-pilot" mode and attain a state of "critical self-awareness" during ongoing sleep. Critical self-awareness enables sleepers to focus their attention on different aspects of themselves—such as their own thoughts, bodily sensations, and behaviour—and to observe their subjective experiences from a critical perspective (see Carr et al., 2020). This process may eventually lead individuals to recognize discrepancies within their sleep experience. For instance, they might notice differences between the body posture assumed in their dreams and their actual physical position in bed (Carr et al., 2020). Additionally, they may reflect on their current state of consciousness, questioning whether they are asleep or dreaming (Carr et al., 2020; Noreika et al., 2010). In the present paper, we will use the term "lucid sleep" to describe states in which individuals exhibit critical self-awareness during sleep.

A commonly studied instance of "lucid sleep" is that of lucid dreaming: to be aware of the fact that one is currently dreaming (Noreika et al., 2010; Van Eeden, 1913; Windt & Metzinger, 2007). In the past few years, the practice of lucid dreaming has become increasingly popular because it offers an extensive range of possibilities to the practitioners. Once individuals realize that they are dreaming, they can also regain control of their own actions in the dream, enabling them to fly, pass through walls or engage in sexual activities (Stumbrys et al., 2014). Moreover, from a purely scientific perspective, the topic of lucid dreaming has also gained great popularity within the last few decades, especially since it was suggested as a key state for the study of consciousness (Hobson, 2009). Current lucid dreaming studies focus on finding reliable and less time-consuming methods to induce these experiences within the laboratory environment , on exploring the therapeutic potential of lucid dreaming (Ellis et al., 2021; Macêdo et al., 2019; Sackwild & Stumbrys, 2021), or investigating the possibility to communicate with lucid dreamers in real time (Konkoly et al., 2021).

Nevertheless, the phenomenon of lucid sleep can also be found in sleep states other than dreaming, such as during wake-sleep transitions (Cheyne & Girard, 2009), or episodes of dreamless sleep (Thompson, 2015; Windt et al., 2016). For the latter, the possibility of a form of awareness during sleep that lacks both hallucinatory experiences and imagery opens up several opportunities for the exploration of the nature of consciousness (see Alcaraz-Sánchez, 2021; Alcaraz-Sánchez et al., 2022). In contrast to lucid dreaming, these other forms of lucid sleep have seldom been explored in any depth, partly because they seem to be uncommon and tend to

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appear spontaneously, making it difficult to reliably capture them in a controlled laboratory setting. Thus, the development of new techniques that can facilitate the emergence of these diffuse but possibly associated phenomena (Campillo-Ferrer et al., 2024; Mahowald & Schenck, 2005), may help us to better understand the phenomenon of lucid sleep, including (but not only restricted to) episodes of lucid dreaming.

In this context, various methods have been implemented to facilitate other forms of lucid sleep beyond lucid dreaming—as it has been classically understood. For instance, sleep paralysis is a phenomenon whereby postural muscle atonia (which characterizes REM sleep) is present while the sleeper perceives themselves to be paralyzed and awake in bed (Denis et al., 2018). These paralysis sensations may occur in the presence of hypnagogic hallucinations (while falling asleep) or hypnopompic hallucinations (while waking up) (Cheyne et al., 1999; Denis et al., 2018). Although sleep paralysis has been associated with the phenomenon of lucid sleep (Denis & Poerio, 2017; Kliková et al., 2021; Mainieri et al., 2021; Raduga et al., 2020), not all episodes of this kind are reported together with critical self-awareness. For instance, sleep paralysis was induced for the first time in healthy participants using specific sleep interruption methods (Takeuchi et al., 1992, 1994, 2002). However, these studies did not control the level of lucidity experienced by participants. Similarly, a different technique has been described to induce lucid sleep during distressing sleep paralysis episodes, yet its efficacy has only been assessed through anecdotal reports (Conesa, 2002).

Another wake-sleep transitional phenomenon that has traditionally been linked to lucid sleep is that of out-of-body experiences (for discussion see Blackmore, 1988; Irwin, 1988; Levitan et al., 1999). During out-of-body experiences, individuals experience their own self as if it were located outside of their physical body, either during wakefulness or while falling or being asleep (Blanke et al., 2004, 2005; Irwin, 1988; Levitan et al., 1999; Rabeyron & Caussie, 2016; Smith & Messier, 2014). Interestingly, out-of-body experiences reported during sleep (sleep-related out-of-body experiences) have been linked to sleep paralysis, wake-sleep transitions and REM sleep (Cheyne et al., 1999; Cheyne & Girard, 2009; Kliková et al., 2021; Levitan et al., 1999; Nelson et al., 2007; Rabeyron & Caussie, 2016). To induce and explore out-of-body-like experiences, several research groups have employed relaxation and mild sensory limitation methods (McCreery & Claridge, 1996a, 1996b; Palmer & Lieberman, 1975), hypnosis (Facco et al., 2019; Zeev-Wolf et al., 2016), and visuo-tactile conflict in combination with virtual reality (Lenggenhager et al., 2011). However, a method to induce these experiences within the sleep environment is still lacking.

Finally, both sleep paralysis and out-of-body experiences have been linked to a specific lucid dreaming technique called the "wake-initiated method", or Wake Initiated Lucid Dreaming (WILD) technique (Levitan et al., 1999). This method provides individuals with the ability to enter a lucid dream directly from wakefulness (LaBerge et al., 1986). Thus, instead of becoming spontaneously aware of

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the fact that they are dreaming (dream-initiated lucid dreaming), individuals in wake-initiated lucid dreams may remain self-aware and focused on their own mental state during the entire wake-sleep transition (LaBerge et al., 1986; Levitan et al., 1999). As such, the wake-initiated method may become a powerful tool for the study of consciousness, allowing for the exploration of the whole process of "falling" and "being" asleep, and the nature and upper-bound potential of critical self-awareness within the different sleep stages (LaBerge, 1980; LaBerge et al., 1986; Levitan et al., 1999).

Although no specific research protocol has yet been described to induce wake-initiated lucid dreams in a sleep laboratory setting, some general guidelines can be found on the scientific literature. For instance, Aspy (2020) presented a version of the Senses-initiated Lucid Dreaming technique—a variation of the Wake-Initiated Lucid Dreaming technique which consists of carrying out a series of cycles focusing on different sensorial modalities prior to sleep (Tan & Fan, 2022). Within each cycle, participants focus firstly on their visual perception, secondly on their auditive perception, and finally on their bodily sensations (Aspy, 2020). Other authors have described different self-induction techniques that may facilitate wake-initiated lucid dreams, such as focusing on counting, visual imagery, or the body image while falling asleep (LaBerge, 1980; LaBerge & Rheingold, 1991; Raduga, 2021; Tholey, 1983).

The maintenance of critical self-awareness during the falling asleep period has also been explored by several non-Western traditions. For instance, the Yoga Nidrâ technique seeks to achieve complete relaxation and awareness of the self in an intermediate state between waking and sleep (for review see Pandi-Perumal et al., 2022). By following this technique, practitioners claim it is possible to experience the "*Divine Nature*", the "*Supreme Goddess*", or the "*Essential Nature of Self*" (Singh, 1979), a state that appears when no thoughts and other mind constructs are present during sleep (Pandi-Perumal et al., 2022; Singh, 1979). Similarly, according to certain lineages in Tibetan Buddhism, the skilful meditator practitioner can achieve a state of "*clear light*" in the moment prior to dreaming or during sleep (Norbu, 1983; Wangyal, 1998). This state is said to lack the subject/object distinction characteristic of ordinary wakefulness (Holecek, 2016; Raveh, 2008), and to contain no dreaming and no thinking (Norbu, 1983; Padmasambhava & Gyatrul, 2008). More recently, some contemporary researchers have proposed that certain instances of this state of clear light sleep could involve a state of awareness similar to that experienced during lucid dreaming, thus, coining the term "lucid dreamless sleep" (see Thompson, 2015; Windt, 2015; Windt et al., 2016).

In summary, the development of a detailed protocol centered on retaining critical self-awareness from wakefulness into sleep, may enable us to get physiological recordings from different lucid sleep phenomena, including wake-initiated lucid dreams, sleep-related out-of-body experiences, lucid dreamless sleep experiences, and episodes of "lucid sleep paralysis". In the present case series study, we describe the phenomenology and electrophysiology of N=4 participants who re-

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ported different forms of lucid sleep in a laboratory setting. All of them underwent a custom-made induction protocol focused on preserving critical self-awareness during the falling asleep process, combining pre-sleep meditation and visual stimulation. While this procedure has not yet been validated by a complete sample of participants or via the inclusion of specific control groups, we have designed an initial protocol that may be valuable for future empirical research.

As a proof of concept, we implemented this protocol during single-morning nap sessions and used wearable EEG devices (Hypnodyne Zmax) and external EMGs to monitor the different sleep stages. In contrast to standard polysomnography, wearable EEG devices may offer comfort to the sleepers—potentially aiding with the completion of the meditation task and falling asleep process—but they may also introduce errors during the sleep scoring stage (see discussion). We additionally conducted in-depth phenomenological interviews to assess the subjective experience of participants during the entire sleep period (see Demšar & Windt, 2024). In contrast to the classical practice of collecting "dream reports", the interview approach employed here may help us identify different forms of lucid sleep occurring at any moment during the sleep period. For instance, hallucinations emerging while falling asleep, which may otherwise remain unreported. Our goal is to assist future researchers to induce, detect, and explore different forms of lucid sleep; and broaden the conceptual understanding of sleep-related altered conscious states—such as out-of-body-like experiences—through a methodological decomposition of their phenomenal and electrophysiological substrates.

2 Methods

2.1 Subjects and ethics

This study was approved by the local medical ethical committee in Nijmegen, the Netherlands, under the blanket approval of the Donders Centre for Cognitive Neuroimaging (Imaging Human Cognition, CMO2014/288). Four subjects were recruited using the Radboud University research participation online system and flyers that were spread across the university campus. We defined the following inclusion and exclusion criteria:

- Healthy young people (18-40 years old, not taking any medication)
- At least experienced one lucid dream in their lifetime
- Able to recall dreams frequently (at least once per week)

2.2 Study design

The experiments were conducted at the EEG Lab of the Donders Centre for Cognitive Neuroimaging (Radboud University, Nijmegen, the Netherlands) from Febru-

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ary 2022 to March 2022. The researchers had an intake meeting with each participant a few days before the experimental session to introduce them to the study and procedures. During the intake meeting (1 hour approximately), the first author discussed with each participant the differences between dream-initiated and wake-initiated lucid dreams, described the general procedures of the experiment, shared some tips on how to remain critically self-aware while falling asleep, and instructed them on what to do if any sort of lucid sleep experience was noticed during the nap: they would perform a left-right-left-right eye signal, then explore the environment (if present) for approximately 1 minute, and finally perform the same eye signal again. The researcher remarked several times during this meeting and also during the day of the experiments, that if participants felt unwell or uncomfortable at any point (because of sleep paralysis, negative hallucinations or other reasons), they should stop the procedure and go to sleep as they would usually do at home. Participants were given the opportunity to ask any questions during this meeting. At the end of the meeting, participants filled in a battery of questionnaires ('baseline questionnaires' in **Figure 1**) to assess their overall dream recall frequency and lucid dreaming frequency (MADRE, Schredl et al., 2014). In addition, they were asked about their previous experience with different lucid sleep phenomena and meditation techniques (see **Table 1** for more details).
Previous to the experimental session, participants were instructed to:

- Sleep 2–3 hours less than usual on the night prior to the experiments, aiming to increase sleepiness, but ensuring a minimum of 5 hours of sleep. We selected this sleep schedule because the likelihood of experiencing wake-initiated lucid dreams, sleep paralysis and sleep-related out-of-body experiences may increase if the individual enters REM sleep directly from wakefulness—also called sleep-onset REM periods (Hishikawa & Kaneko, 1965; LaBerge et al., 1986; Levitan et al., 1999; Mainieri et al., 2021; Takeuchi et al., 1992). Moreover, sleeping for more than 5 hours enhances the probability of interrupting any REM sleep period during the morning awakening (Chokroverty, 2017). This, in turn, increases the likelihood of experiencing sleep-onset REM periods when falling asleep in the laboratory (Moses et al., 1978; Takeuchi et al., 1992).

- Refrain from consuming caffeine on the morning of the experimental session, increasing sleepiness and relaxation.

On the day of the experiments, participants came to the laboratory at 7:00 a.m. and signed an informed consent form. Then, the researchers reminded them the general procedures of the experiment and answered any remaining questions. In order to help participants stay sleepy, all this procedure was done while keeping the general lights off. Only a small lamp lighted up the room and participants were instructed not to look at it directly. Wearable EEG devices and external EMGs were used to monitor sleep (for details see Electrophysiology and sleep staging).

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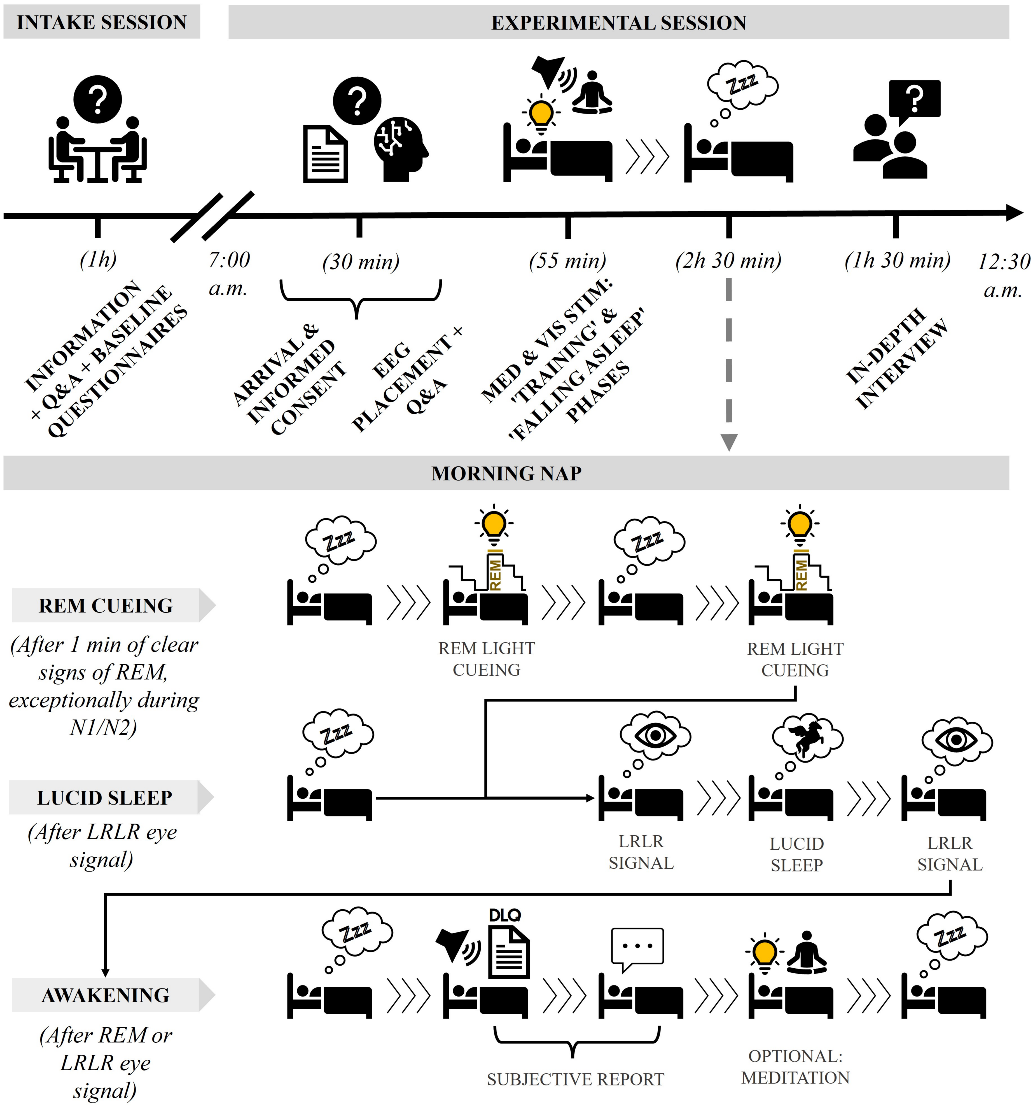

Figure 1: Research design. This figure shows the main steps and strategy followed in this study. Q&A: questions and answers session; Med & Vis Stim: meditation and visual stimulation protocol; LRLR eye signal: left-right-left-right eye signal; DLQ: Dream Lucidity Questionnaire (Stumbrys et al., 2013).

After placing the electrodes and guiding participants to bed, we played an audio file recorded by the first author which contained detailed instructions on how to become critically aware of their breathing and bodily sensations (55-minute semi-guided meditation, see Meditation and visual stimulation protocol). This recording was intentionally designed to feel conversational and natural, simulating the experience of speaking to participants through an intercom (see **Supplementary Material** for a template). Please note that the template provided is an adaptation to written form and not an exact transcription of the recording. In parallel to this recording, the researchers presented several light cues following a specific proce-

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dure adapted from Carr et al. (2020). Participants then had the opportunity to sleep for 2'5 h. During this time, additional light cues were primarily presented during REM sleep and occasionally during non-REM sleep. Moreover, we awakened subjects each time they exited REM sleep or after they had performed the pre-arranged left-right-left-right eye signal (see **Figure 1** for more details). During this whole procedure, including the 55-minute semi-guided meditation, the researchers also played an audio file with white noise. The white noise intensity was adjusted to each participant at the beginning of the session for their own comfort.

After each awakening, the researchers asked participants to provide a general report of the last conscious experience prior to awakening (see Siclari et al., 2013), asking them the following questions: (1) "*Are you awake?*", (2) "*Were you asleep just before I called you?*" and finally, (3) "*Were you dreaming just before I called you?*". If participants indicated that they had experienced a dream, we prompted them to elaborate on the content of the dream. If they reported not having any dreams, we asked for an open description about "*what was happening exactly*" right before we called them through the intercom. Lastly, participants were asked to rate their lucidity levels during this experience. The latter was done by reading out loud the Dream Lucidity Questionnaire (DLQ) through an intercom (Stumbrys et al., 2013). In this process, participants assigned a number to each item of the questionnaire (from 0 to 4) and the researcher encouraged them to justify their answers. This report was later utilized to guide an in-depth phenomenological interview (for details see In-depth phenomenological interviews). If there was any time remaining after the awakening, participants were given the option to continue sleeping. Once the sleep experiment was finished and participants had taken off the electrodes, the first author carried out an in-depth phenomenological interview (1h 30 min maximum). Except for Subject 1, all participants were interviewed in the same room where they had meditated and slept, in order to aid with the recollection of the experience.

2.3 Meditation and visual stimulation protocol

This protocol was developed informally from a series of pilot studies with N=33 voluntary participants and building on previous literature (Blackmore, 1984, 1988; Cheyne et al., 1999; Cheyne & Girard, 2009; Fox, 1962; Irwin, 1988; Jalal & Hinton, 2013; Kliková et al., 2021; LaBerge, 1980, 1986; Levitan et al., 1999; McCreery & Claridge, 1996a, 1996b; Monroe, 1971; Muldoon & Carrington, 1974; Norbu, 1983; Palmer & Lieberman, 1975; Price & Cohen, 1988; Rabeyron & Caussie, 2016; Singh, 1979; Takeuchi et al., 1992, 1994, 2002; Twemlow et al., 1982; Wangyal, 1998) and theoretical work conducted by the first author, second author, and colleagues (Campillo-Ferrer et al., 2024). The initial version of the protocol, completed in April 2021, combined a semi-guided meditation incorporating elements of Body Scan meditation (Kabat-Zinn, 2018) and Square Breathing (Norelli et al., 2022). Additional elements were drawn from the Yoga Nidrâ technique (Pandi-Perumal

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et al., 2022) and the Tibetan Yogas of Sleep and Dreams practice (Norbu, 1983; Wangyal, 1998). In August 2021, an adapted version of the light cueing procedure presented by Carr et al. (2020) was integrated into the protocol.

The final version of this protocol (see **Supplementary Material** for a template) consists of two main parts. First, a 'training' phase (38 minutes, see below). In this phase, individuals learn how to perform the meditation practice step by step. In parallel, the researchers apply several light cues accompanied by a verbal prompt. Second, a 'falling asleep' phase (16'5 minutes, see below) in which individuals are instructed to fall asleep while practicing this meditation. We also apply a specific number of light cues during this period, which are not accompanied by the verbal prompt.

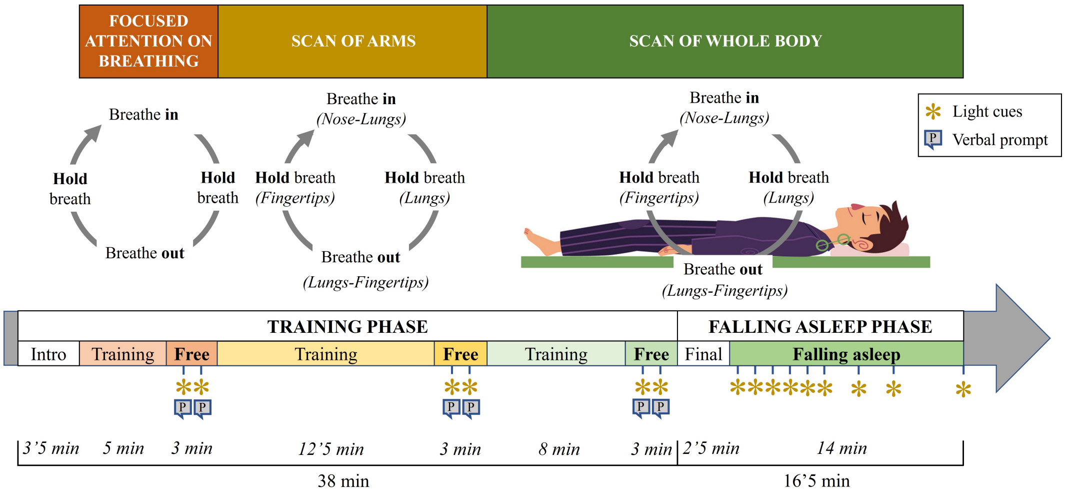

Figure 2: Schematic representation of the 'training' and 'falling asleep' phases of the meditation and visual stimulation protocol. During the 'training' phase (38 min), participants undergo an 'introduction' block ('Intro', 3'5 min) and then engage in a semi-guided meditation that is structured in three main blocks: (1) 'Focused attention on breathing' (5 min), where participants are asked to let go of "intrusive thoughts" and start familiarizing themselves with the Square Breathing practice; (2) 'Scan of arms' (12'5 min) and (3) 'Scan of whole body' (8 min), where participants perform a body scan of the arms ('Scan of arms') or whole body ('Scan of whole body') following the breathing pace. At the end of each meditation block, participants are instructed to meditate independently and without receiving any further instructions from the researchers ('Free', periods of 3 min each). During these three periods, researchers play two light cues in a one-minute interval, while also playing a verbal prompt adapted from Carr et al. (2020). Finally, during the 'falling asleep' phase (16'5 min), participants continue meditating ('Scan of whole body') while trying to fall asleep in a "lucid" way. The researcher first gives them the final instructions ('Final', 2'5 min) and then plays a series of light cues ('Free', 14 min, 9 light cues) that are not accompanied by the verbal prompt, first at one-minute interval (6 cues), then at two-minute intervals (2 cues) and finally at a 4-minute interval (1 cue). This protocol is interrupted if the participant becomes anxious in any way. © Can Stock Photo Inc. / [sabelskaya].

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2.3.1 'Training' phase

This phase consists of four different blocks. In the 'introduction' block, we inform participants about the general procedures and provide them with some tips on how to let go of "*intrusive thoughts*". We then move to the meditation blocks: (1) 'Focused attention on breathing', (2) 'Scan of arms' and (3) 'Scan of whole body' (see **Figure 2**). Within these three blocks, participants engage in a semi-guided meditation practice that finishes with three minutes of independent meditation. During the 'Focused attention on breathing' block, participants learn how to focus only on their breathing sensations and how to let go of any "*intrusive thoughts*". To this aim, we use a modification of the Square Breathing or Box Breathing practice (see Norelli et al., 2022). During the meditation training, participants are instructed to breathe in, hold the air for a few seconds, breathe out, and hold again, but they are not instructed to keep these steps of the same length (as it is common practice during Square Breathing). They can instead adapt it to their own preferences to make the practice more comfortable. This change was made during the developmental phase of the protocol, after receiving feedback from several subjects who found it stressful or difficult to keep track of the breathing steps during the meditation. In the following meditation blocks ('Scan of arms' and 'Scan of whole body'), participants continue to apply the same breathing technique while scanning their bodily sensations. While breathing in, they focus on the sensations experienced from their nose to their lungs, and then hold the air for a few seconds, while only focusing on their lungs. When breathing out, they first do a series of trials with different body parts, and finally focus on the sensations experienced from their lungs to the fingertips of their hands (during the 'Scan of arms' block) or to the fingertips of both their hands and feet at the same time (during the 'Scan of whole body' block).

The way in which the body scan is narrated was inspired by Kabat-Zinn (2018). Contrary to this author, we encourage practitioners to focus firstly on the arms and lastly on the legs. We inverted the order because most participants during our pilot sessions remarked feeling sensations more strongly in their arms and particularly in their hands. For example, they described a "*tingling*" sensation in the fingertips of their hands while performing the meditation, something that was not commonly experienced in their feet or legs. Thus, previous to the 'Scan of arms', participants are asked to carry out a specific task to connect with these sensations (see below). This task was developed with the intention of temporarily suspending any preexisting beliefs or judgements that participants might hold regarding their own bodily sensations. It encourages participants to observe their body from a new and fresh perspective, thereby helping them to unveil or examine unexplored aspects of themselves. In other words, it prompts participants to practice a state of "critical self-awareness" (see Carr et al., 2020) regarding how they perceive their own bodily sensations:

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> “*I want you to focus your attention on your hands... try to feel the tip of your fingers... and progressively the whole hand... [10-sec pause] and from this place, try to reflect about which sensations make you feel that these are your hands and not the hands of another person... and which sensations make you feel that these are indeed your hands... and not another part of your body. You don’t have to answer; just give yourself a moment to reflect about this and feel the sensations... while you focus on your hands... and especially on your fingertips. I will give you a brief moment for that. [25-sec pause]*”

This activity is repeated several times throughout the ‘training’ phase with different parts of their body, especially focusing on their arms. In addition, participants are also instructed to remain in a supine position, with their stomach facing up, and to try not to move during both body scan blocks. With the lack of movement, we seek to minimize the sensation of touch during the meditation training and facilitate the falling asleep process. We ask them to find a position where their legs are not touching each other, with their arms not touching other parts of their body, and with their hands looking upwards or downwards. In the literature, the adoption of a supine position has been linked to the occurrence of out-of-body experiences and sleep paralysis episodes (see Bünning & Blanke, 2005; Cheyne & Girard, 2009 for review). Moreover, this position—in combination with the lack of contact between the limbs and the lack of movement of the practitioner—is also key in the practice of Yoga Nidrâ, being part of the “*Shavasana*” or “*corpse pose*” (see Pandi-Perumal et al., 2022 for review).

At the end of each meditation block, participants engage in a 3-minute period of ‘independent meditation’ (referred to as ‘Free’ periods in **Figure 2**). During these 3 minutes, participants are instructed to practice the meditation techniques from each corresponding block while receiving no further instructions from the researchers. Meanwhile, the researchers apply two light cues (each separated by a one-minute interval) at the highest intensity threshold (see **Figure 2**). This threshold is set at the beginning of each session by asking participants which is the minimum light intensity they can see with their eyes closed (lowest threshold) and which light intensity they think would wake them up in the middle of the night (highest threshold). The light cueing procedure was inspired by Carr et al. (2020) and it is accompanied by a modification of the verbal prompt used by the same researchers:

> “*As you notice the cue, you become lucid. Bring your attention to your thoughts, notice how your mind has wandered... Now observe your body, sensations, and feelings... observe your breathing... and remain critically aware, lucid... And now... continue with the meditation.*” (for original verbal prompt see Carr & Solomonova, 2019)

This light cueing procedure was introduced with two primary aims:

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(1) To assist participants in maintaining focus on their meditation practice. In the event of mind-wandering, the light cues may act as a reminder to regain attention on the task.

(2) To encourage participants to associate the light cues with a state of critical self-awareness (Carr et al., 2020), what we refer here to as the "lucid" state. In this context, our aim was for participants to "become lucid" by attentively observing their thoughts, sensations and feelings when the light cues were presented (as outlined in Carr et al., 2020)—first during wakefulness and meditation, and eventually while falling asleep or during sleep itself. In line with Carr et al. (2020), we hypothesize that when the light cues are played during the meditation training and then reintroduced during sleep (see Study design), the mental state of "critical self-awareness" may intrude into the sleep experience. This could potentially enable participants to pay attention to unnoticed elements of the experience and, in some cases, to become aware of being currently dreaming (see Carr et al., 2020).

Participants were informed about these aims during both the intake and experimental sessions.

2.3.2 'Falling asleep' phase

Right after finishing the 'training' phase, the researcher informs participants that they might experience some images, sounds, or bodily sensations in the process of falling asleep—if they feel uncomfortable in any way, they are instructed to stop the procedure and go to sleep; if they feel comfortable with them, they are instructed to stop meditating and try to amplify these images, sounds or bodily sensations, until they start lucid dreaming (wake-initiated lucid dream). After receiving this information, participants are finally instructed to fall asleep while practicing the 'Scan of whole body' meditation in a supine position and without moving. While they engage in this activity, we play more light cues (this time without playing the verbal prompt) following this protocol: 6 light cues in a 1-minute interval, 2 light cues in a 2-minute interval, and 1 light cue in a 4-minute interval (see **Figure 2**). The intensity of the light cues is progressively decreased from the highest to the lowest threshold (see 'Training' phase) during this process. The light cueing protocol is interrupted if the participant shows clear signs of feeling restless or anxious. Moreover, the researcher also informs participants that they could see some light cues while being already asleep. In that case, these light cues could aid participants in recognizing their current state of mind as one of being asleep or dreaming, potentially leading them to experience episodes of lucid sleep. Finally, if participants wake up in the middle of the nap (or if they are awakened by the researchers), they are instructed to fall asleep again while playing more light cues—from 1 to 7, at a 1 or 2 minute interval, depending on whether individuals seem sleepy or anxious during this time. In this case, participants can choose either to meditate or not while falling asleep.

2.4 Electrophysiology and sleep staging

The electrode montage included a portable headband with two frontal EEGs (Hypnodyne Zmax, Hypnodyne Corp., Sofia, Bulgaria); and two EMGs positioned on the left and right submental muscle area. The EMGs were referenced to the chin (BrainAmp ExG, BrainProducts GmbH, Munich, Germany) following recommendations by the American Academy of Sleep Medicine (Berry et al., 2020). In addition to the EMG activity recorded from the chin, Zmax detects a mixture of electrooculographic (EOG) and frontal EEG activity (Mota-Rolim et al., 2019), utilizing disposable solid hydrogel electrodes positioned at F7 (left frontal EEG) and F8 (right frontal EEG), both referenced to FpZ.

Seep scoring of lucid sleep episodes was performed by the first and third authors, who evaluated epoch by epoch (30 seconds each) and reached an agreement by visual inspection of:

- The raw EEG and EMG signals using Spisop Software (RRID:SCR_015673, https://www.spisop.org) and the Fieldtrip toolbox (Oostenveld et al., 2011) in Matlab Version 9.10 (R2021a).
- The multitaper spectrogram of the raw EEG and EMG signals using the Multitaper (Prerau et al., 2017) and Sleeptrip (RRID:SCR_017318, https://github.com/Frederik-D-Weber/sleeptrip) toolboxes in Matlab Version 9.10 (R2021a).

2.5 In-depth phenomenological interviews

Interviews were conducted in English with participants who were non-native speakers, comprising both Dutch nationals and international residents living in the Netherlands. All interviews were conducted, recorded and manually transcribed by the first author, following a procedure inspired by the micro-phenomenological technique. This interview technique pursues to set aside any preconceptions and judgements from both participants and researchers, while also helping participants establish sensory-motor contact with their past experiences (Petitmengin, 2006; Valenzuela-Moguillansky & Vásquez-Rosati, 2019; Varela, 1996). In addition, this interview technique advocates for an identification (bottom-up process) rather than a classification (top-down process) of the experiences under study, as well as for the use of “*how*” instead of “*what*” questions (see Petitmengin, 2006; Valenzuela-Moguillansky & Vásquez-Rosati, 2019). Prior to the study onset, the micro-phenomenological interview technique was adapted to the sleep environment and specific goals of the study following recommendations provided by Demšar & Windt (2024). Since we were aiming to investigate the whole experience of “falling” and “being” asleep, the interview was fragmented into four blocks: ‘meditation and visual stimulation training’, ‘falling asleep’, ‘transition to sleep’ and ‘sleep’. These four blocks could appear several times within the same interview (e.g. if the participant woke up and fell asleep again). The researcher explored each of these blocks consecutively (see **Figure 3** for schematic representation):

Campillo-Ferrer, T., Alcaraz-Sánchez, A., & Torres-Platas, S. G. (2024). Exploring “lucid sleep” and altered states of consciousness during sleep using meditation and visual stimulation: A case series study. *Philosophy and the Mind Sciences*, *5*. https://doi.org/10.33735/phimisci.2024.10227

(1) During the 'meditation and visual stimulation training' period, participants were asked to describe their subjective experience after listening to the following sentence during the 'training' phase of the protocol: "*I want you to contact with your legs and the trunk of your body, but without losing contact with your arms*". If the participant did not remember that sentence, both researcher and participant looked for another moment in time to explore.

(2) During the 'falling asleep' phase of the interview, a general scan of the whole experience of "falling asleep" was conducted. This could include the 'falling asleep' phase of the meditation and visual stimulation protocol (e.g. when a participant fell asleep during the 'training' phase) or not. If the researcher identified any content within this phase (e.g. imagery, sounds, bodily sensations, etc), the temporal and spatial dimensions of these phenomena were explored. Moreover, awareness and attention towards the experience were also examined at this point.

(3) During the 'transition to sleep' period, the researcher focused first on exploring the awareness and attention levels during the experience. If the wake-sleep transition was experienced in a "lucid" way, the researcher also conducted a general scan of this experience (see **Figure 11**).

(4) During the 'sleep' phase, we first assessed the overall sleep experience (detailed report). If the sleep period was experienced as "lucid", different moments/features were further explored—for example, focusing on bodily sensations when investigating out-of-body-like experiences (see **Figure 7** for an example of the latter).

Previous to the onset of the interview, the first author presented a schematic figure to the participants, which contained a summary of the different phases followed during the interview (like **Figure** 3**B**). These figures were sometimes modified by participants themselves—for instance, when the participant could remember the approximate moment when they had performed the eye signal (e.g. within the 'transition to sleep' phase)—and helped the researcher with the interview conduction process. Moreover, during the experimental session, the researcher also drew a temporal line of the whole experience in the laboratory, writing down any shifts in the sleep stage, any remarks from researchers, and some key words from each participant's general dream report. This information was then used to guide the interview.

For the analysis of the interviews, the first author discarded any sections including irrelevant responses to the phenomenon of interest, and performed diachronic and synchronic analyses of the remaining sections. This whole process was done following guidelines provided by Valenzuela-Moguillansky & Vásquez-Rosati (2019). The second author revised the interview transcripts and reviewed the final diachronic and synchronic structures identified by the first author. Two

Campillo-Ferrer, T., Alcaraz-Sánchez, A., & Torres-Platas, S. G. (2024). Exploring "lucid sleep" and altered states of consciousness during sleep using meditation and visual stimulation: A case series study. *Philosophy and the Mind Sciences*, *5*. https://doi.org/10.33735/phimisci.2024.10227

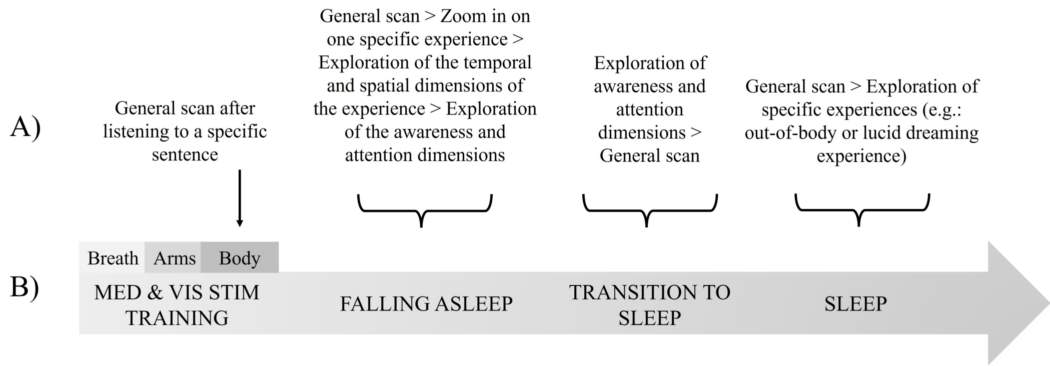

Figure 3: Conduction of interviews. This figure shows **A)** the key steps followed to explore an entire sleep period through in-depth phenomenological interviews; **B)** the different blocks in which the sleep laboratory experience was fragmented. Med & Vis Stim Training: 'training' phase of the 'meditation and visual stimulation protocol'; Breath: 'Focused attention on breathing' meditation block; Arms: 'Scan of arms' meditation block; Body: 'Scan of whole body' meditation block.

rounds of feedback were given by the second author which helped on the construction of new or modified diachronic and synchronic units and thematic categories. The final diachronic and synchronic structures identified by the first and second authors are presented in **Figures** 5, 7 and 11. Based on these final structures, the first author classified the different experiences into three main categories: 1) lucid dreaming, 2) lucid dreamless sleep, and 3) out-of-body-like experiences, and identified other contents within the experience, such as the presence of hypnagogic hallucinations (see **Table** 3). For the latter, the Immersive Spatiotemporal Hallucination Model of Dreaming was used by the first author as a guide (Windt, 2010).

3 Results

3.1 Subjects

We were contacted by four subjects who met the inclusion/exclusion criteria of the study, with ages ranging from 19 to 38 years old. One of them (Subject 4) participated two times in one of our previous pilot studies, therefore having experience with another version of the protocol. Another participant (Subject 3) did not have previous experience with this specific method, but remarked that the meditation technique and posture reminded them of some self-hypnotism classes they took years ago. All subjects reported having at least some experience with meditation and mindfulness practices, and all of them reported having experienced out-of-body experiences before. Except for Subject 1, all of them had experienced sleep paralysis. Except for Subject 3, all subjects had also experienced hypnagogic or hypnopompic hallucinations previously (see **Table** 1 for a full comparison).

Campillo-Ferrer, T., Alcaraz-Sánchez, A., & Torres-Platas, S. G. (2024). Exploring "lucid sleep" and altered states of consciousness during sleep using meditation and visual stimulation: A case series study. *Philosophy and the Mind Sciences*, *5*. https://doi.org/10.33735/phimisci.2024.10227

Table 1: Research subject's comparative table.

Category	Subject 1	Subject 2	Subject 3	Subject 4
General Information				
Age	19	31	38	24
Dream Frequency				
Dream recall frequency	About once a week	Almost every morning	Several times a week	Several times a week
Lucid dreaming frequency	2–4 times a year	Several times a week	2–4 times a year	2–3 times a month
Previous Experience				
Hypnagogic or hypnopompic hallucinations	Yes	Yes	No	Yes
Sleep paralysis	No	Yes	Yes	Yes
Out-of-body experiences	Yes	Yes	Yes	Yes
Meditation	Yes	Yes	Yes	Yes
Meditation and visual stimulation protocol presented in this paper	No	No	No, but they attended self-hypnotic classes with a similar approach	Yes, two times (previous version)
Other mindfulness techniques	Focusing on breathing and thought	Jacobson's relaxation technique, mantras, others	Asana yoga, self-hypnosis, reiki, others	Focusing on breathing, bodily parts, counting, or external sounds

3.2 Meditation and visual stimulation training

We used in-depth phenomenological interviews to assess the subjective experiences of participants during the 'training' phase of the protocol. The 'Scan of arms' block was explored in subjects 1 and 2 (who did not remember the subsequent phases), and the 'Scan of whole body' block was explored in subjects 3 and 4.

Campillo-Ferrer, T., Alcaraz-Sánchez, A., & Torres-Platas, S. G. (2024). Exploring "lucid sleep" and altered states of consciousness during sleep using meditation and visual stimulation: A case series study. *Philosophy and the Mind Sciences*, *5*. https://doi.org/10.33735/phimisci.2024.10227

3.2.1 Subject 1 (‘Scan of arms’ meditation block):

This subject experienced how the smallest parts of their body were “*numb*” and “*harder to feel without moving them*”, getting “*increasingly like paralyzed*”. In contrast, they described the biggest parts of their body as “*heavier*”, “*most present*” and “*more dominant*”. Subject 1 also mentioned being more aware of “*gravity*” during this state, while trying to focus on bodily sensations from their fingers and on reducing the frequency of their thoughts.

3.2.2 Subject 2 (‘Scan of arms’ meditation block):

During this period, Subject 2 reported feeling “*like an expansion*” of themselves and as if being “*a bit above*” their body. This sensation was experienced as a “*good*” and “*growing*” feeling which started in the arms and was felt mostly in the extremities. However, Subject 2 lost this sense of expansion after feeling cold during the meditation practice, something they experienced as if “*everything contract(ed) inwards*”. After this, Subject 2 asked the researchers to increase the heating in the room.

3.2.3 Subject 3 (‘Scan of whole body’ meditation block):

This subject remarked several times how the meditation practice “*relaxed*” them and made their body feel “*really light*”, a sensation that was experienced as a “*good feeling*”. Subject 3 described the bodily perception during this state as “*lower than the normal situation, something between sensing and not sensing*”. Moreover, Subject 3 mentioned they could hear the meditation instructions and were trying to concentrate on them, but at the same time they were having some other thoughts—for example, thinking about the out-of-body induction technique they were planning to test later, or thinking about how the meditation technique reminded them of some self-hypnotism classes they used to take years ago. Subject 3 also mentioned being confused and focused on correctly following the breathing technique, since they had prior experience with other breathing techniques involving three instead of four steps.

3.2.4 Subject 4 (‘Scan of whole body’ meditation block):

This subject reported feeling very “*calm*” and “*relaxed*”, while being in a “*barely conscious*” state. Subject 4 remarked several times that they were not asleep, but rather in a “*dizzy*”, “*more like drowsy*” stage, similar to when you can “*fall asleep in a moment*”. This subject used different metaphors to explain how they felt while they were meditating (as if having “*milk everywhere on your body*”, as if being “*in a bucket of milk*” or as if “*floating*”). Moreover, they remarked that these metaphors do not describe the bodily sensations they were having at the moment, but only their state of mind and consciousness. At the same time, Subject 4 could feel their own breathing, described as if their breathing pace were producing a “*vibration*” or “*slow wave*” on the surface of the “*bucket of milk*” that is “*somehow everywhere*”.

Campillo-Ferrer, T., Alcaraz-Sánchez, A., & Torres-Platas, S. G. (2024). Exploring “lucid sleep” and altered states of consciousness during sleep using meditation and visual stimulation: A case series study. *Philosophy and the Mind Sciences*, *5*. https://doi.org/10.33735/phimisci.2024.10227

During this experience, Subject 4 could also hear the meditation instructions from a distance, without focusing on the specific words the researcher was saying. Although Subject 4 was consciously thinking about following the meditation instructions before this, at some point they stopped and "*could maintain the pace without putting too much effort*", and "*managed to not have any*" thoughts, being "*surprised*" that they "*made it work*".

Table 2: Illustrative examples of the subjective experiences reported by all participants during the 'training' phase of the protocol.

Subject number	Meditation block and subjective report
SUBJECT 1	**'Scan of arms'** *"It's like those parts are s::eeking you into the bed and... um... more dominant... than the others. [...] like, those main parts, that my body is only those parts and not the other ones. That the other ones don't exist."*
SUBJECT 2	**'Scan of arms'** "*I would just say like it-it's not really a vibration but it's kind of like... a sensation that... your... like-like my skin is here and then like it's like something is moving out to here... [The participant points to their left arm with their right hand, first bringing it closer to the arm and then moving it further away] like, that's how I felt.*"
SUBJECT 3	**'Scan of whole body'** *"Um... when you are relaxed um... your muscle is loosened ah... you're somewhat that... you can feel all parts of your body um... as the normal situation, but when it's lighter ah... the sense is um... lighter as I say, um... you feel the body but... not as... tense as the normal situation. [Researcher: And what is the normal situation?] Yeah, yeah... This was lower than the normal situation, something between sensing and not sensing."*
SUBJECT 4	**'Scan of whole body'** *"Indeed, if I have to... if I can probably somehow... give you another metaphor. So, imagine, again, that you're in a bucket of milk, but you manage to stay completely still, like you relax your body so much it doesn't move. But still, no, it's going to move a little bit because you're going to breathe very slowly... and this would produce a vibration that you can... see... on... the surface. But still, you're kind of floating... and... in your mind is super still because it has to be super still not to... to make other movements... ((Laughs)) so t-that is why ah-this was very confusing..."*

Campillo-Ferrer, T., Alcaraz-Sánchez, A., & Torres-Platas, S. G. (2024). Exploring "lucid sleep" and altered states of consciousness during sleep using meditation and visual stimulation: A case series study. *Philosophy and the Mind Sciences*, *5*. https://doi.org/10.33735/phimisci.2024.10227

3.3 Lucid sleep episodes

After finalizing the 'training' phase of the protocol, subjects 2, 3, and 4 were instructed to fall asleep while meditating ('Scan of whole body') and while maintaining critical self-awareness in this process. Subject 1, however, fell asleep during the 'training' phase. A variety of lucid sleep experiences were reported by different participants during this period (see **Table 3** for a classification). We present here the EEG and EMG features characterizing each phenomenon in the form of a spectrogram, and the final diachronic (temporal) and synchronic (thematic) phenomenological structures isolated during the interview analysis. We additionally include several EEG/EMG segments of interest for each experience.

3.3.1 Subject 1:

This subject reported an episode of lucid sleep that lasted for only one second. This episode was described as one of being "*about to start lucid dreaming*" and like "*one second of being surely away and then more conscious again*". Subject 1 remarked that this experience was not "*complete*" and was like "*just being dizzy*". This episode was not eye-signal verified. Due to its fleeting nature, this episode was not further explored nor included in **Table 3**.

3.3.2 Subject 2:

This subject reported multiple hypnagogic lucid hallucinations that finally led them to experience a lucid dream. This subject described how they "*couldn't grasp anything*" and were "*pulled back*" in their body each time they were about to enter a dream scenery. This process is depicted in the form of a cycle in **Figure 5B** ('Drifting off' phase). From Subject 2's perspective, the hypnagogic hallucinations (which they refer to as "*little things*") were "*coming up*" within "*like a circle*" around them that constantly changed its shape and had no ending, while they experienced their body as if being in "*a gas form*" (see **Figure 5C**). During the initial phase of the nap, visual inspection of the multitaper spectrogram and raw EEG/EMG signals (see **Figures 4** and **5A**) shows periods of muscle atonia accompanied by sleep spindles and k-complexes (indicative of non-REM sleep, most likely N2) alternating with periods of increased muscular tone and slow or rapid eye movements (indicative of wakefulness or drowsiness). For comparison, **Figures 4A** and **4B** illustrate these alternating states.

Afterwards, Subject 2 reported entering into a longer lucid dream environment where the scenery started "*shaping*" until they were awakened by the light cueing procedure ('Non-REM cueing' in **Figure 5A**). At the onset of this dream, they could only see green, until more complex visual elements started to appear gradually (first nature elements, and then a dream character). During the hypnagogic period described before, Subject 2 felt "*distant to the room*" and "*not completely detached from the body*". In contrast, they felt during the lucid dream as if they

Campillo-Ferrer, T., Alcaraz-Sánchez, A., & Torres-Platas, S. G. (2024). Exploring "lucid sleep" and altered states of consciousness during sleep using meditation and visual stimulation: A case series study. *Philosophy and the Mind Sciences*, *5*. https://doi.org/10.33735/phimisci.2024.10227

were "*in a movie*" and not in their body but "*somewhere else*" (see **Figure 5C** for a full comparative of the hypnagogic and dream periods). This lucid dream was not eye-signal verified because the participant woke up suddenly from this experience. Interestingly, approximately 4 minutes prior to this awakening, the EEG spectrogram shows increased relative power of faster frequencies (from 20 to 30 Hz), especially coming from the left EEG electrode (see **Figure 5A**). The last two epochs prior to awakening (1 minute in total) were scored as non-REM sleep, possibly N2, due to the presence of multiple sleep spindles and one k-complex. We additionally observed no slow waves during this period (see **Figure 6**). This whole episode was classified as a 'hypnagogic lucid dreaming' experience (see **Table 3**) as understood by Price & Cohen (1988).

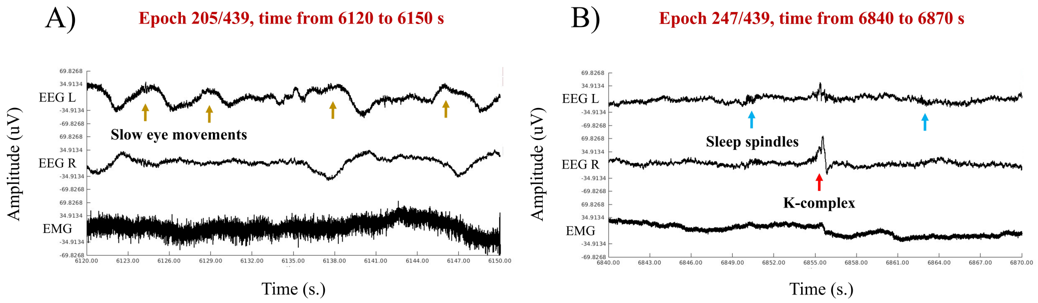

Figure 4: Nap onset in Subject 2 – selected epochs. Notice the presence of slow eye movements (indicated by yellow arrows) and elevated EMG activity in the first epoch (**A**, wake-like activity), contrasting with sleep spindles (blue arrows), k-complexes (red arrows) and reduced EMG activity in the second epoch (**B**, N2-like activity). EEG L: left frontal EEG; EEG R: right frontal EEG.

Campillo-Ferrer, T., Alcaraz-Sánchez, A., & Torres-Platas, S. G. (2024). Exploring "lucid sleep" and altered states of consciousness during sleep using meditation and visual stimulation: A case series study. *Philosophy and the Mind Sciences*, *5*. https://doi.org/10.33735/phimisci.2024.10227

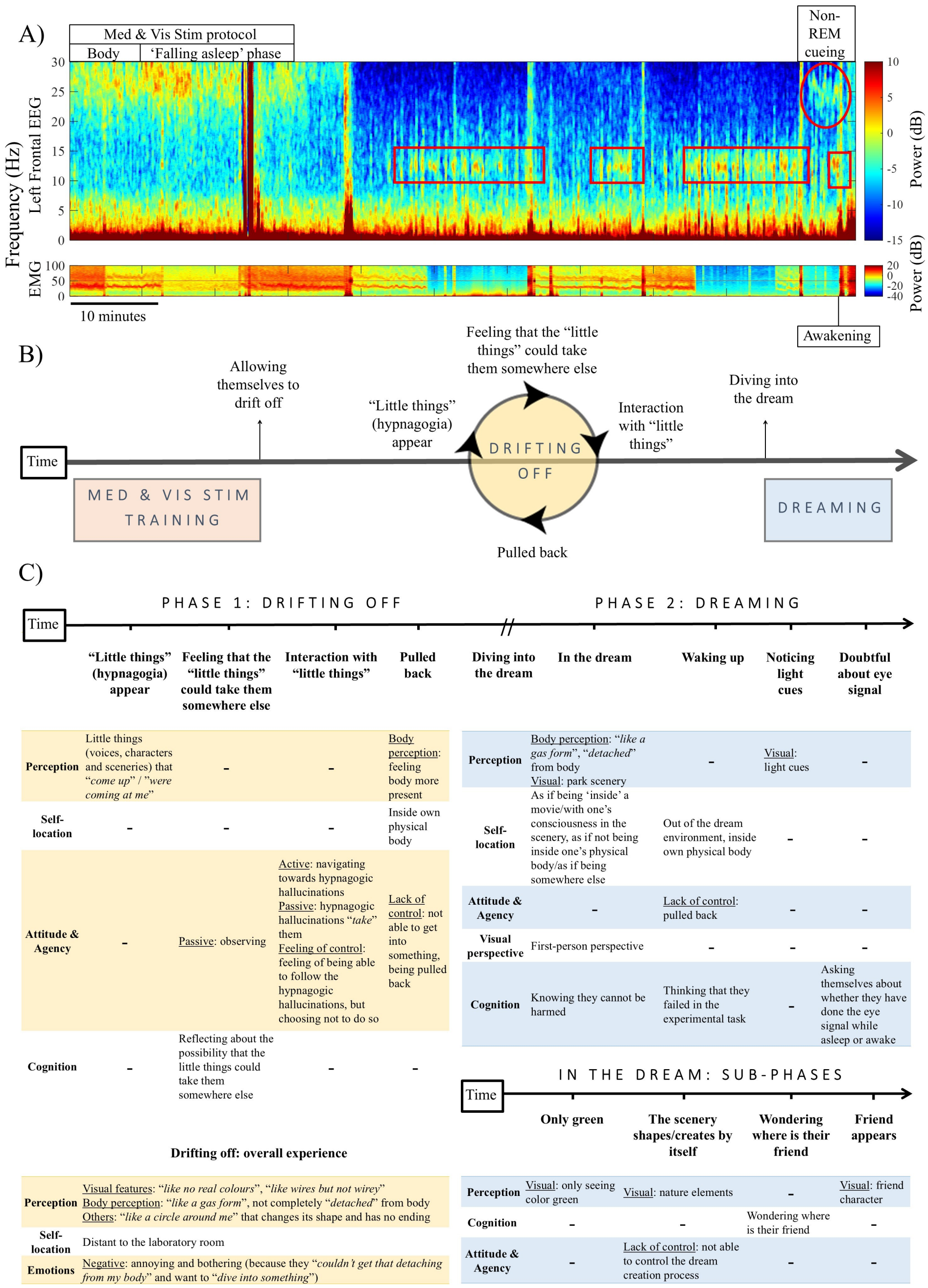

Figure 5: 'Hypnagogic lucid dreaming' experience reported by Subject 2 – detailed phenomenology and main EEG features. **A)** Multitaper spectrogram of the EEG and EMG signals. Red rectangles mark periods containing sleep spindles (scored as non-REM sleep, most likely N2). The red circle marks a period with increased relative power of 30-40 Hz frequencies, approximately 4 minutes prior to awakening. **B)** General diachronic structure of the overall experience. **C)** Detailed diachronic and synchronic structures identified during the 'Drifting off' and 'Dreaming' phases of the experience and their respective subphases. Med & Vis Stim protocol: meditation and visual stimulation protocol; Body: 'Scan of whole body' meditation block. Non-REM cueing: light cueing procedure performed by the researchers during non-REM sleep.

Campillo-Ferrer, T., Alcaraz-Sánchez, A., & Torres-Platas, S. G. (2024). Exploring "lucid sleep" and altered states of consciousness during sleep using meditation and visual stimulation: A case series study. *Philosophy and the Mind Sciences*, *5*. https://doi.org/10.33735/phimisci.2024.10227

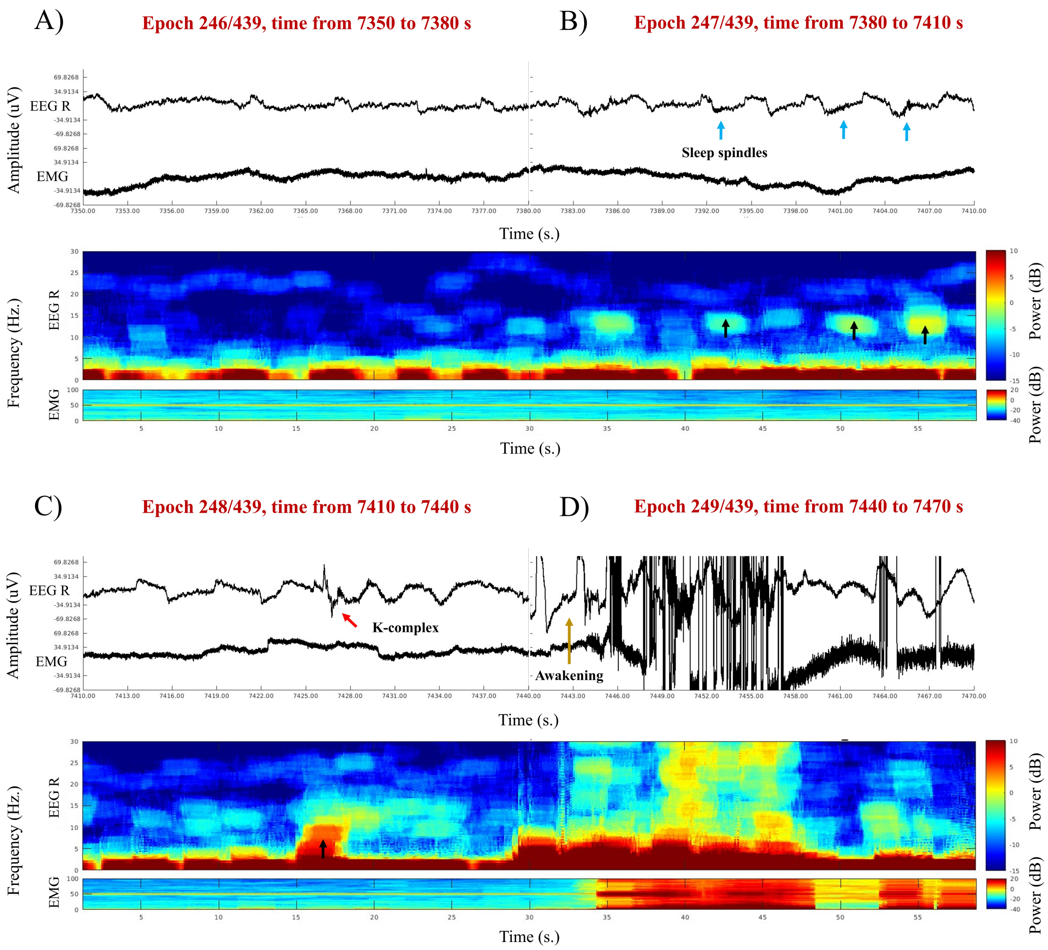

Figure 6: 'Hypnagogic lucid dreaming' experience reported by Subject 2 – selected epochs. **A)** Epoch number 3 prior to awakening (non-REM sleep, most likely N1). **B)** Epoch number 2 prior to awakening (non-REM sleep, most likely N2). **C)** Epoch number 1 prior to awakening (non-REM sleep, most likely N2). **D)** Epoch showing the participant's awakening (wakefulness). For each epoch (30 seconds), we included an extract of the raw EEG and EMG signals (top of the figure) and the multitaper spectrogram of the raw EEG and EMG signals (bottom of the figure), both used for sleep staging. Main events within each epoch are marked with arrows. Blue arrows indicate sleep spindles. Red arrows indicate k-complexes. Yellow arrows indicate the participant's awakening. Black arrows show events that have been marked in the raw EEG/EMG signals, but which are also visible in the multitaper spectrogram (e.g. sleep spindles). EEG R: right frontal EEG.

Campillo-Ferrer, T., Alcaraz-Sánchez, A., & Torres-Platas, S. G. (2024). Exploring "lucid sleep" and altered states of consciousness during sleep using meditation and visual stimulation: A case series study. *Philosophy and the Mind Sciences*, *5*. https://doi.org/10.33735/phimisci.2024.10227

3.3.3 Subject 3:

After the ‘training’ phase of the protocol, this subject followed the meditation instructions until achieving a high level of relaxation, which they referred to as the “*alpha mode*”. Once this state was reached, Subject 3 used a vestibular imagining strategy to induce out-of-body experiences. They mentioned they had learned this technique at self-hypnotism classes years ago (‘blowing the body’ technique in **Figure 7A**) and this was the first time they had been successful in years. Next, this subject experienced an ‘awareness’ episode, described as a period whereby you can have “*awareness of the surrounding*” and you are “*so free to just be expanded*” or “*free to go out of body*”. However, Subject 3 decided to “*kept (themselves) in (their) brain*” and refrained from leaving the body with the intention of inducing a lucid dream from this state. For this reason, we decided to classify this experience as an out-of-body-like experience, rather than as a full-blown out-of-body experience (**Table 3**). Since they could not induce a lucid dream from this state, Subject 3 decided to return back “*to the brain*” and take “*control of the body again*”. This whole experience was eye-signal verified twice. Afterwards, Subject 3 reported falling asleep and having a dream-initiated lucid dream in a period scored as REM sleep (eye-signal verified). The latter was not further explored in the current paper.

In **Figure 7A**, we present the different phases that Subject 3 went through during the ‘awareness’ episode, starting with a feeling of being “*sucked in*” by a tunnel, and finishing with a sequence of actions they made to “*limit*” that awareness to only their body. A more detailed description of the first two phases can be found in **Figure 7C** (‘sucked in’ and ‘awareness state’). While being “*sucked in*” by the tunnel, Subject 3 reported feeling the heart beat very “*high*” and experiencing a “*very active brain*”. Moreover, they were also having involuntary eye movements (eye fluttering) during this period. After going through this “*tunnel*”, Subject 3 experienced a complete absence of perception “*from the five senses*”, described as an episode of “*almost darkness, total darkness*” and as if “*not having a body*” or not being their “*body anymore*”. However, this subject remarked that they could have awareness of their surroundings (including their physical body) and could access their imaginations and memories in this state. Immediately before the eye fluttering started, the participant seemed to be awake: on the one hand, visual inspection of the raw EEG signal and multitaper spectrogram shows alpha activity and slow eye movements (**Figure 7B**); on the other hand, the muscular tone observed during this period was similar to that recorded during wakefulness in the same subject. At the onset of the ‘awareness’ episode, the eye fluttering intruded into the EEG and EMG signals and particularly into the right EEG electrode (see **Figures 7B, 7D, 7E** and **7F**). Therefore, we could not determine the sleep stage in which the ‘awareness’ episode occurred.

Campillo-Ferrer, T., Alcaraz-Sánchez, A., & Torres-Platas, S. G. (2024). Exploring “lucid sleep” and altered states of consciousness during sleep using meditation and visual stimulation: A case series study. *Philosophy and the Mind Sciences*, *5*. https://doi.org/10.33735/phimisci.2024.10227

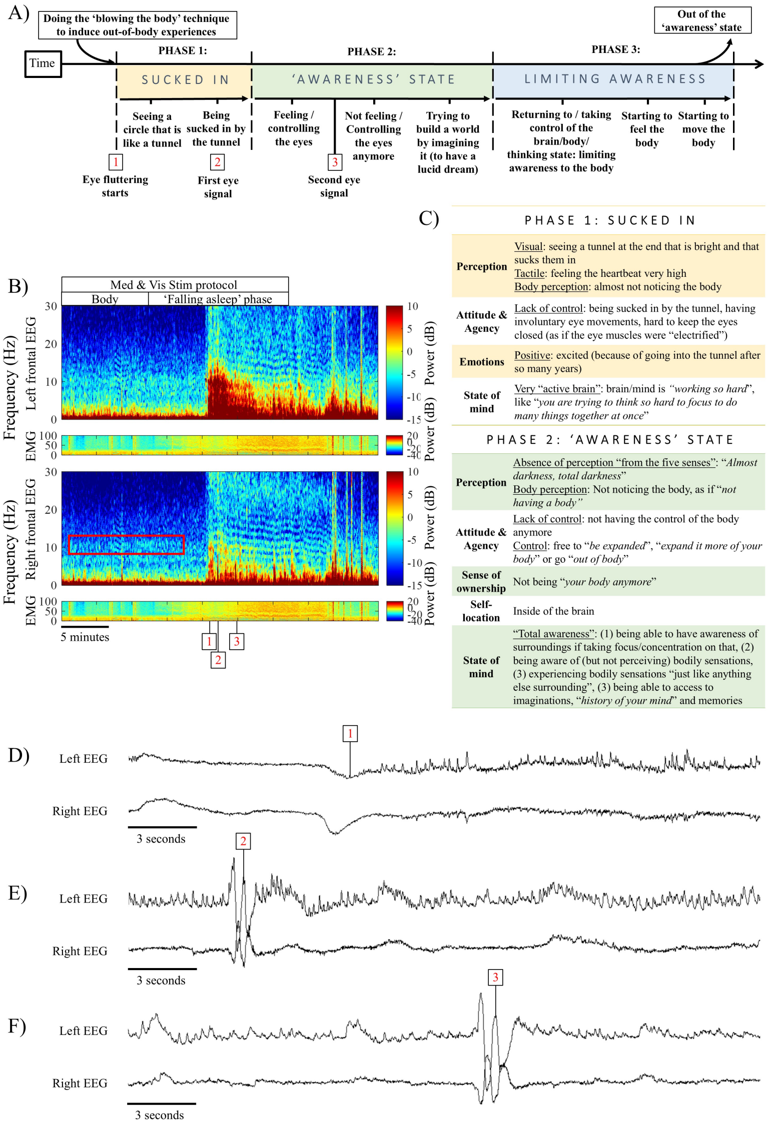

Figure 7: 'Awareness' episode experienced by Subject 3 – detailed phenomenology and main EEG features. **A)** General diachronic structure identified during the 'awareness' episode. Three EEG events have been time-marked within this structure: (1) The moment when Subject 3 started having involuntary eye movements ('Eye fluttering starts'); (2) The first left-right-left-right eye signal performed by Subject 3, when they were still going through the "tunnel" ('First eye signal'); and (3) The second left-right-left-right eye signal performed by Subject 3, when they were already out of the "tunnel" ('Second eye signal'). **B)** Multitaper spectrogram of the left EEG (top), right EEG (bottom) and EMG signals during the 'awareness' episode. Red rectangles mark periods containing high alpha activity (scored as wakefulness). Numbers (1), (2) and (3) mark the moment when each EEG event occurs: (see A)). **C)** Detailed synchronic structures identified during the 'Sucked in' and 'Awareness state' phases of the experience. **D), E)** & **F)** EEG signal extracts containing the main EEG events described in A): 'Eye fluttering starts' (D), 'First eye signal' (E), 'Second eye signal (F). Med & Vis Stim protocol: meditation and visual stimulation protocol; Body: 'Scan of whole body' meditation block.

Campillo-Ferrer, T., Alcaraz-Sánchez, A., & Torres-Platas, S. G. (2024). Exploring "lucid sleep" and altered states of consciousness during sleep using meditation and visual stimulation: A case series study. *Philosophy and the Mind Sciences*, *5*. https://doi.org/10.33735/phimisci.2024.10227

3.3.4 Subject 4:

After Subject 4 completed the entire meditation and visual stimulation protocol, the researcher gave them the final instructions: "*you can now fall asleep, and thanks for your time doing the meditation*". Immediately prior to this moment, the participant mentioned that they were experiencing the 'bucket of milk' state of mind described above (see the experience of Subject 4 in the previous section) and subsequently heard the researcher's voice. Subject 4 remarked that they did not feel as if they had "*just woke(n) up*" upon hearing the instructions. Additionally, they did not feel asleep during the 'bucket of milk' experience, but rather "*dizzy*" or "*drowsy*". Nevertheless, visual inspection of the EEG and EMG raw signals and multitaper spectrograms revealed that a period with sleep spindles (typical of N2 sleep) was interrupted when the researcher gave them these final instructions. The muscular tone also increased at this point and eye movements re-appeared, indicating the subject's awakening (see **Figures 8** and **9**). This suggests that the 'bucket of milk' experience described by Subject 4 took place during non-REM sleep, with a high probability of occurring within N2 sleep. This experience was classified as an episode of lucid dreamless sleep (see **Table 3**) due to two main reasons: (1) the participant noted an absence of thoughts during this period; and (2) the participant only described the state of mind and consciousness experienced, without mentioning the presence of any kind of hallucinatory perceptual content.

After this episode of lucid dreamless sleep, Subject 4 reported that they tried to "*focus on the breathing*" but they fell asleep "*quite fast afterwards*". The next thing Subject 4 could remember was hearing a sound "*like a vent*" and feeling the body "*like vibrating, a lot*", while being aware that they were transitioning into a lucid dream (see **Figure 11C**). This subject remarked that they had previously experienced bodily vibrations during their participation in earlier pilot experiments—however, this time they were aware that the vibrations originated from the "*inside*" of them, whereas on other occasions, they mistakenly believed they had "*actually moved in the real world*". Subject 4 then reported looking from a "*very long tube*" to see if they were awake, and finally having a lucid dream (eye-signal verified twice) that started as if they were "*looking a bit from above*".

In **Figure 11**, we represent in detail the whole transition into the dream that Subject 4 experienced, from the first awakening that took them into this state ('Hearing the researcher's final instructions') to the final phase of dreaming ('Trying to do something else / switch the environment'). Although Subject 4 could not remember the transition from the meditative state ('Stops thinking about meditation') into the hypnagogic period ('Hearing a sound like a vent and feeling bodily vibrations'), we decided to classify this experience as a 'wake-initiated lucid dream' (see **Table 3**) due to two main reasons: (1) the participant experienced a sleep-onset REM period during this experience (direct transition from wakefulness into REM sleep, see **Figures 10** and **11A**), which is typical of wake-initiated lucid dreams (see Levitan et al., 1999); (2) the participant was able to describe the entire hypnagogic experience and subsequent entry into the dream.

Several phenomenological events identified during the interview analysis of Subject 4 (**Figure 11B**) were coupled with the EEG and EMG events observed in the multitaper spectrogram (**Figure 11A**). Some of the most remarkable features of this experience include several instances mentioned by Subject 4 of feeling or thinking they were paralyzed. This occurred both before entering the dream environment ('Thinking maybe they are not asleep, but awake and paralyzed in bed', **Figure 11D**) and while already in the dream ('Body paralyzed while lying down in bed', **Figure 11E**, 'Perception' category). Moreover, Subject 4 also experienced out-of-body and false-awakening phenomenology, such as feeling bodily vibrations before entering into the dream environment (**Figure 11C**), having an above visual perspective during the dream (**Figure 11E**, 'Visual perspective' category), or being confused about being asleep because of the realistic environment and characters (**Figure 11B**, 'Researcher comes into the room and S4 gets confused about being asleep'; **Figure 11D**, 'Looking through a very long tube: seeing a very realistic room with light in it'; **Figure 11E**, 'Realism/bizarreness' category).

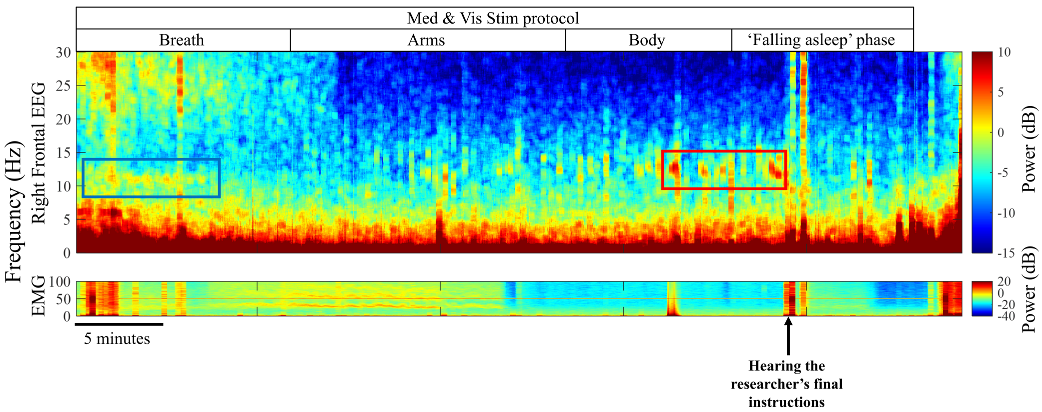

Figure 8: 'Bucket of milk' experience reported by Subject 4 – main EEG features. This figure shows the multitaper spectrogram of the EEG and EMG signals during the 'training' and 'falling asleep' phases of the meditation and visual stimulation protocol as experienced by Subject 4. The blue rectangle marks a period with high alpha activity (scored as wakefulness). The red rectangle marks a period containing sleep spindles (scored as non-REM sleep, most likely N2). The arrow marks the moment when the researcher awakened Subject 4 by giving them the final instructions. Med & Vis Stim protocol: meditation and visual stimulation protocol; Breath: 'Focused attention on breathing' meditation block; Arms: 'Scan of arms' meditation block; Body: 'Scan of whole body' meditation block.

Campillo-Ferrer, T., Alcaraz-Sánchez, A., & Torres-Platas, S. G. (2024). Exploring "lucid sleep" and altered states of consciousness during sleep using meditation and visual stimulation: A case series study. *Philosophy and the Mind Sciences*, *5*. https://doi.org/10.33735/phimisci.2024.10227

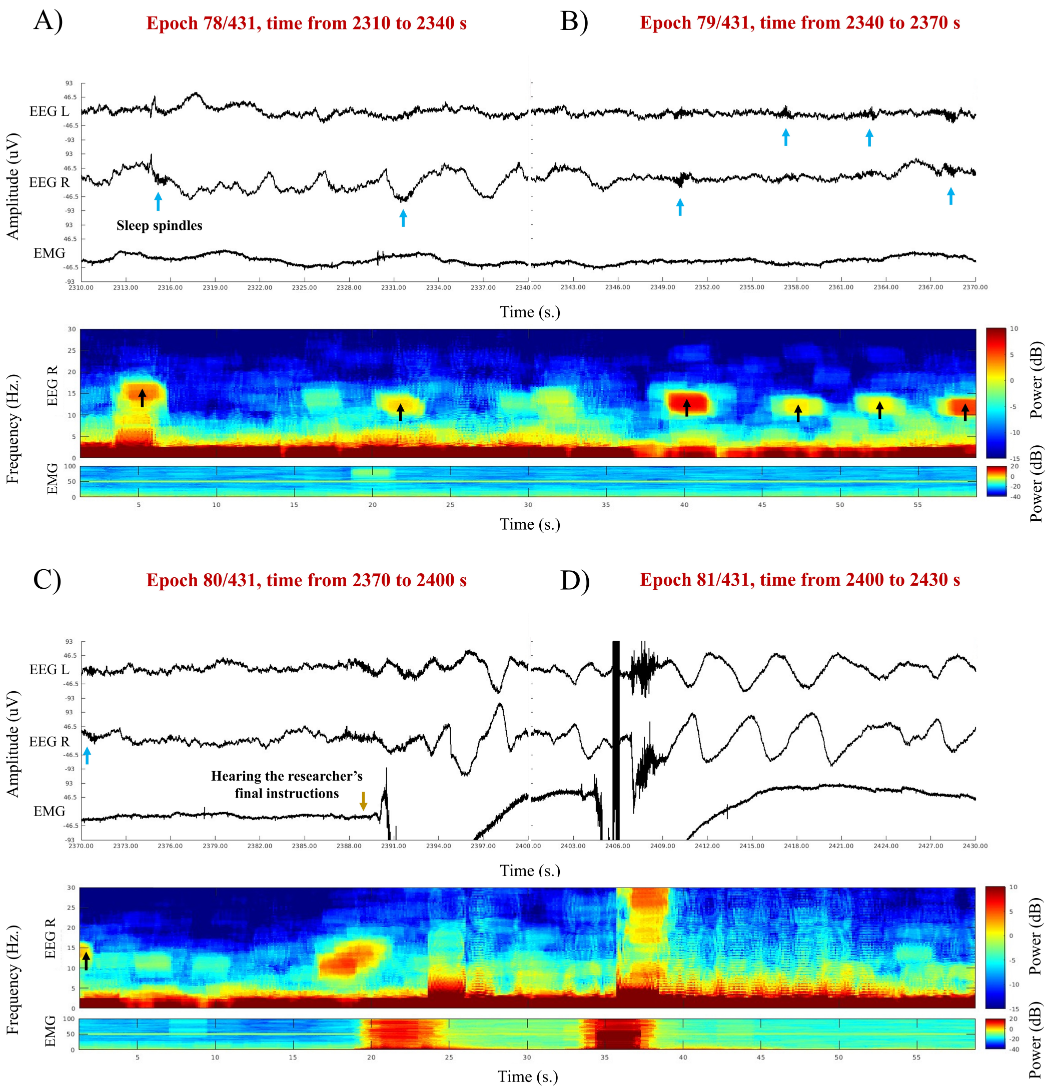

Figure 9: ‘Bucket of milk’ experience reported by Subject 4 – selected epochs. **A)** Epoch number 2 prior to awakening (non-REM sleep, most likely N2). **B)** Epoch number 1 prior to awakening (non-REM sleep, most likely N2). **C)** Epoch showing the participant’s awakening due to hearing the researcher’s final instructions (wakefulness). **D)** First epoch after the participant’s awakening (wakefulness). For each epoch (30 seconds), we included an extract of the raw EEG and EMG signals (top of the figure) and the multitaper spectrogram of the raw EEG and EMG signals (bottom of the figure), both used for sleep staging. Main events within each epoch are marked with arrows. Blue arrows indicate sleep spindles. Yellow arrows indicate the participant’s awakening. Black arrows show events that have been marked in the raw EEG/EMG signals, but which are also visible in the multitaper spectrogram (e.g. sleep spindles). EEG L: left frontal EEG; EEG R: right frontal EEG.

Campillo-Ferrer, T., Alcaraz-Sánchez, A., & Torres-Platas, S. G. (2024). Exploring “lucid sleep” and altered states of consciousness during sleep using meditation and visual stimulation: A case series study. *Philosophy and the Mind Sciences*, *5*. https://doi.org/10.33735/phimisci.2024.10227

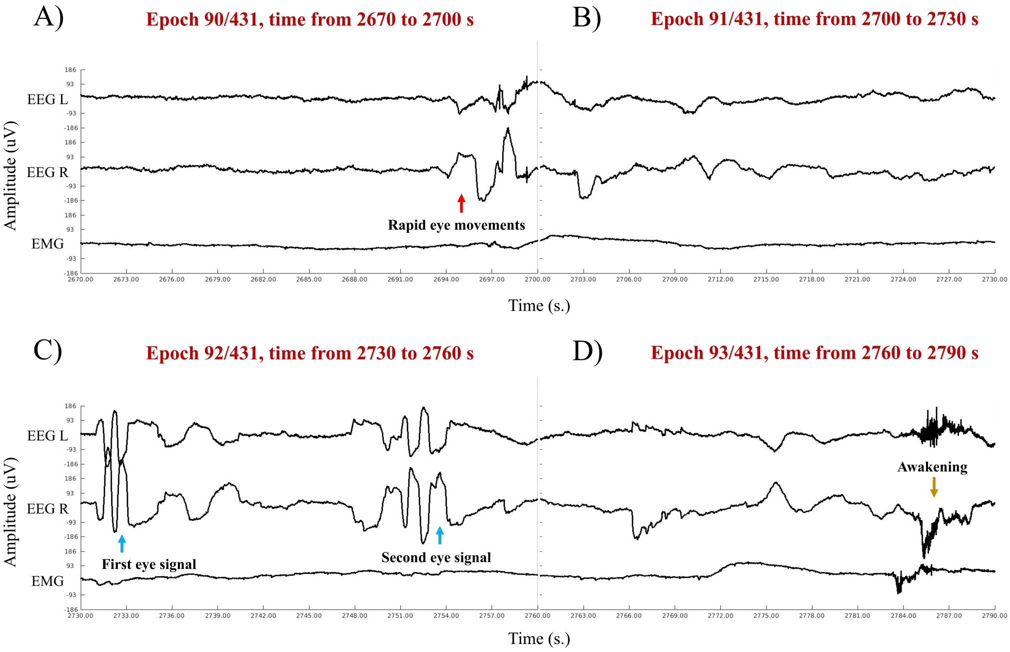

Figure 10: 'Wake-initiated lucid dream' experience reported by Subject 4 – selected epochs. **A)** Epoch showing the onset of rapid eye movements (REM sleep). **B)** Epoch prior to left-right-left-right eye signals (REM sleep). **C)** Epoch showing left-right-left-right eye signals (REM sleep). **D)** Epoch showing the participant's awakening (wakefulness). For each epoch (30 seconds), we included an extract of the raw EEG and EMG signals. Main events within each epoch are marked with arrows. Red arrows indicate rapid eye movements. Blue arrows indicate the first and second left-right-left-right eye signals. Yellow arrows indicate the participant's awakening. EEG L: left frontal EEG. EEG R: right frontal EEG.

Campillo-Ferrer, T., Alcaraz-Sánchez, A., & Torres-Platas, S. G. (2024). Exploring "lucid sleep" and altered states of consciousness during sleep using meditation and visual stimulation: A case series study. *Philosophy and the Mind Sciences*, *5*. https://doi.org/10.33735/phimisci.2024.10227

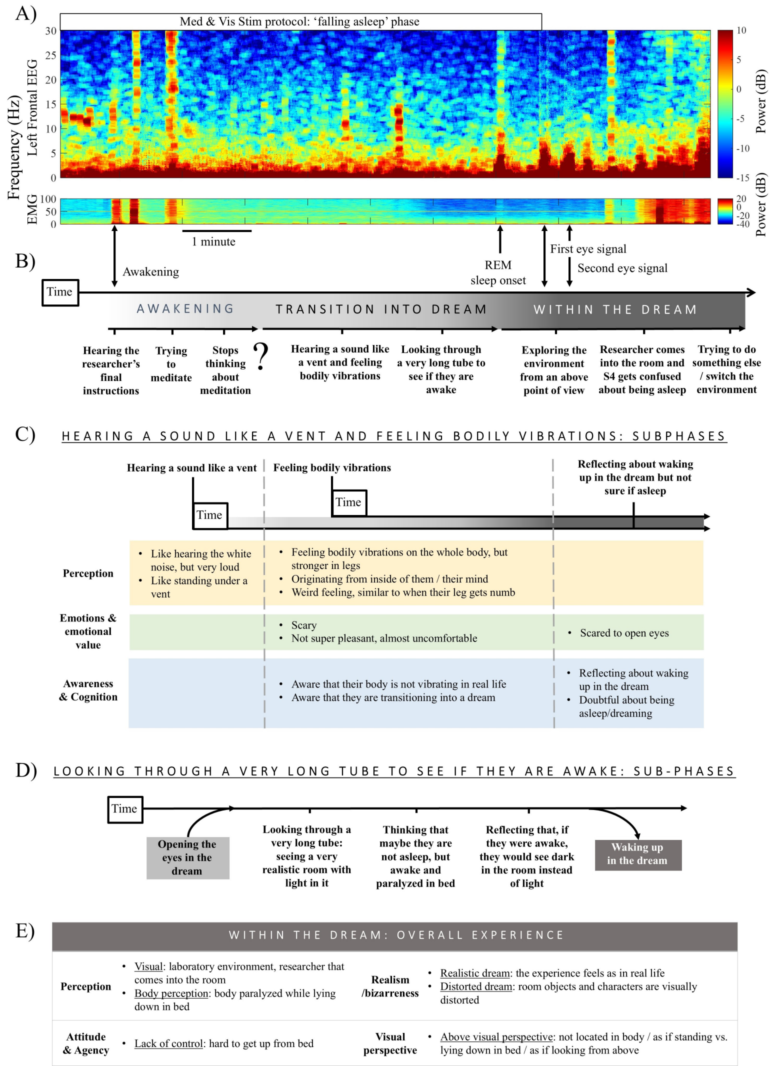

Figure 11: 'Wake-initiated lucid dream' experience reported by Subject 4 – detailed phenomenology and main EEG features. **A)** Multitaper spectrogram of the EEG and EMG signals during the sleep-onset REM period experienced by Subject 4. Two-directional arrows mark EEG events that were time-matched with specific moments from the phenomenological report. Unidirectional arrows mark EEG events that could not be located within any specific phase of the phenomenological report. **B)** General diachronic structure identified during the 'Awakening', 'Transition into the dream' and 'Within the dream' phases of the experience. The question mark indicates how Subject 4 was not certain about what happened between the sub-phases 'Stops thinking about meditation' and 'Hearing a sound like a vent and feeling bodily vibrations'. **C)** Detailed diachronic and synchronic structures identified within the 'Hearing a sound like a vent and feeling bodily vibrations' subphase. The grey gradient in the timeline represents how the 'sound like a vent' and the 'bodily vibrations' were continuous but accelerated in intensity as time passed. **D)** Detailed diachronic structure identified within the 'Looking through a very long tube to see if they are awake' subphase. **E)** Detailed synchronic structure identified during the 'Within the dream' phase. Med & Vis Stim protocol: meditation and visual stimulation protocol.

Campillo-Ferrer, T., Alcaraz-Sánchez, A., & Torres-Platas, S. G. (2024). Exploring "lucid sleep" and altered states of consciousness during sleep using meditation and visual stimulation: A case series study. *Philosophy and the Mind Sciences*, *5*. https://doi.org/10.33735/phimisci.2024.10227

Table 3: Summary of the lucid sleep experiences reported by all participants

	Overall experiences			Other elements reported		
Subject 1	-	-	-	-	-	-
Subject 2	Hypnagogic	-	-	Present	Not present	Not present
Subject 3	Dream-initiated	-	'Awareness' experience	Present	Present	Not present
Subject 4	Wake-initiated	'Bucket of milk' experience	-	Present	Present	Present

4 Discussion

Numerous authors have provided detailed instructions to facilitate the retention of critical self-awareness during the falling asleep period (Aspy, 2020; LaBerge & Rheingold, 1991; Norbu, 1983; Pandi-Perumal et al., 2022; Raduga, 2021; Tholey, 1983; Wangyal, 1998). However, these primarily encompass self-induction techniques that lack external input by researchers—such as real-time guidance or sensory stimulation—and their feasibility has not yet been tested in a controlled sleep environment. At the same time, strategies that incorporate external input and guidance by researchers mainly focus on inducing lucid dreams that appear specifically in REM sleep (Appel et al., 2020; Carr et al., 2020; Konkoly et al., 2021; Kumar et al., 2018). This leaves the prospect of examining other forms of lucid sleep that may occur outside of REM sleep relatively closed. For example, consider Levitan et al. (1999), in which only very experienced lucid dreamers (1 or more lucid dreams per week) were trained to explore wake-initiated lucid dreams—a specific type of lucid dream that emerges from wake-REM transitions.

In the current paper, we present a case series study involving four participants who followed a meditation and visual stimulation protocol designed to maintain critical self-awareness throughout the falling asleep process. This study was conducted in a controlled laboratory environment, enabling us to capture different manifestations of lucid sleep. We provided a broad overview of the electrophysiology and phenomenology characterizing these lucid sleep episodes. Moreover, we presented a detailed analysis of their main phenomenological characteristics and a proposed classification of these experiences.

Overall, we observed three different types of lucid dreams. One of them was classified as a dream-initiated lucid dream (Subject 3); and the other two types are concrete examples of different lucid dreams that can be achieved when retaining critical self-awareness during the falling asleep period (subjects 2 and 4, see **Figures 5** and **11**). On the one hand, we captured an instance of the "*hypnagogic lucid* *dream*” presented by Price & Cohen (1988). This kind of lucid dream appears after a period of hypnagogic activity and has been observed to occur during non-REM sleep (LaBerge, 1980). In this case, Subject 2 experienced multiple hypnagogic hallucinations and finally entered into a lucid dream environment that most likely occurred in non-REM sleep (possibly during N2 and/or N1). On the other hand, we also captured a wake-initiated lucid dream (LaBerge et al., 1986; Levitan et al., 1999) appearing after a direct transition from wakefulness into REM sleep. We observed this kind of transition happening in the case of Subject 4, who reported being aware of “*transitioning into a dream*”, while having several hypnagogic hallucinations in the process (‘Hearing a sound like a vent’ and ‘Feeling bodily vibrations’ in **Figure 11**).

We furthermore captured several mentions of feelings of paralysis that happened during sleep or while participants were still meditating. Firstly, Subject 1 reported feeling “*increasingly like paralyzed*” during the ‘training’ phase of the protocol. Moreover, Subject 4 thought for a moment that they were paralyzed and awake in bed (rather than asleep) while transitioning into the dream, and not able to move once they entered into the dream environment. Important to note, neither of these experiences were reported together with negative emotions or fearful hypnagogic hallucinations, as it is frequent in sleep paralysis episodes (Kliková et al., 2021; Mainieri et al., 2021; Takeuchi et al., 1992). While Subject 4 mentioned that they were having some negative emotions while transitioning into the dream (qualifying this experience as “*scary*”), these refer to the phase in which the subject was experiencing bodily vibrations rather than to any episode of sleep paralysis. Pleasant sleep paralysis episodes have previously been reported in the literature, although these are less common and have mostly been associated with unusual bodily hallucinations and out-of-body experiences (Cheyne, 2003; Kliková et al., 2021). Interestingly, when Subject 4 entered the lucid dream environment, they felt paralyzed in bed while also experiencing a highly realistic dream environment and above visual perspective—both considered key features of out-of-body experiences (Blackmore, 1988; Bünning & Blanke, 2005; Irwin, 1988; Levitan et al., 1999; Twemlow et al., 1982).

In addition to the sleep paralysis and out-of-body phenomenology reported by Subject 4, Subject 3 combined the ‘meditation and visual stimulation protocol’ with a vestibular imagining method in order to induce an out-of-body experience. Next, they experienced a very relaxed state with decreased sense of boundaries (feeling free to “*expand it more of your body*” or go “*out of body*”) and decreased body ownership (as if not being “*your body anymore*”). However, the episode reported by Subject 3 cannot completely be classified as an ‘out-of-body experience’ since this subject remarked that they decided to remain “*inside*” of the body during this episode (‘awareness’ episode, see **Figure 7**). During this experience, Subject 3 mentioned not having standard sensorial perceptions (“*almost darkness, total darkness*”) while experiencing “*total awareness*” and the potentiality to be aware of—rather than to perceive—their surroundings and physical body. The combination of di-

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minished sense of boundaries and reduced body ownership has been observed in 'selfless' and 'ego-dissolution' states reported during meditation (Ataria et al., 2015; Dor-Ziderman et al., 2013, 2016) and under the effects of several psychedelic drugs (Lebedev et al., 2015; Nour et al., 2016; Tagliazucchi et al., 2016). Moreover, episodes of minimal sensorial perception and increased self-awareness during sleep have previously been explored in another research study using in-depth phenomenological interviews (Alcaraz-Sánchez et al., 2022). Unfortunately, this study did not control the sleep stage of these experiences. Due to the eye fluttering presented by Subject 3, we also couldn't determine whether the 'awareness' episode reported here happened during sleep or while the participant was awake. Nevertheless, deep relaxation combined with eye fluttering has been observed in hypnotized patients (Gravitz, 1995; Kohen, 1986; Tebécis & Provins, 1975; Tilton, 1984). Therefore, we should consider the possibility that the state reached by Subject 3 was one of self-hypnosis, especially considering that the vestibular strategy used here was a technique learned by the participant at self-hypnotism classes.

Out of all participants, only Subject 4 remarked being successful at letting go of all "*intrusive thoughts*" during the meditation practice. Interestingly, the cessation of thinking activity was reported simultaneously with a state of mind described as if being "*in a bucket of milk*" or as if "*floating*", which contained no hallucinatory sensorial perception. Subject 4 mentioned several times during the interview that they were not asleep while the 'bucket of milk' experience was still occurring, but rather in a "*more like drowsy*" state happening immediately before falling asleep. In contrast, electrophysiological recordings suggest that this experience occurred in non-REM sleep (see sleep spindles in **Figures 8** and **9**). The phenomenon described by Subject 4 bears some resemblance with states of "*transcendental consciousness during sleep*" reported in the literature—within these states, subjects claim to remain aware of their own self during deep sleep, while experiencing no object of thinking and perception (Mason et al., 1990, 1997). A similar state discussed in the literature is that of "*yoga-nidra*", in which the experiential subject also remains aware of their own surroundings during deep sleep, thus maintaining some object of perception within the experience (Pandi-Perumal et al., 2022; Parker et al., 2013; Parker, 2019). This was also the case for Subject 4, who could feel their own breathing pace and hear the meditation instructions at the same time they were experiencing the 'bucket of milk' state of mind. Nevertheless, the absence of slow waves in the EEG recordings suggests that the episode reported by Subject 4 emerged from N2 sleep rather than N3 (deep sleep), implying that the phenomenon described here could potentially serve as a precursor to the 'yoga-nidra' state mentioned by other authors (Parker et al., 2013; Parker, 2019).

Overall, the temporal decomposition of the subjective experiences enabled us to obtain very precise descriptions of the different lucid sleep phenomena. Moreover, the identification of different thematic categories allowed for a detailed comparison of the experiences captured in the laboratory (e.g. hypnagogic vs. dream-

Campillo-Ferrer, T., Alcaraz-Sánchez, A., & Torres-Platas, S. G. (2024). Exploring "lucid sleep" and altered states of consciousness during sleep using meditation and visual stimulation: A case series study. *Philosophy and the Mind Sciences*, *5*. https://doi.org/10.33735/phimisci.2024.10227

ing experience in **Figure 5**). These phenomenological structures were successfully matched with the EEG and EMG signals when possible.

However, our findings were constrained by the limited number and location of sensors utilized for the experiments. In comparison to the montage outlined here (see Electrophysiology and sleep staging), the American Academy of Sleep Medicine (AASM) recommends incorporating additional parameters to ensure precise sleep scoring. These parameters include leg EMG, electrocardiogram (ECG) and oxygen saturation levels, among others (Berry et al., 2020). Furthermore, the AASM advocates for the inclusion of central and occipital EEGs, along with positioning EOGs in the outer canthus of the eyes rather than in the frontal area. As a consequence, the use of Zmax may pose challenges in the sleep staging process, especially since EEG activity acquired in this scenario may be intertwined with EOG activity (Mota-Rolim et al., 2019). To address this potential limitation, we computed multitaper spectrograms for all raw EEG and EMG signals. This technique enabled us to isolate activity from the different frequency bands, facilitating a clearer observation of specific features crucial for sleep staging, such as occipital alpha activity and sleep spindles (for alpha activity, see **Figures 7B** and **8**; for sleep spindles, see back arrows in **Figures 6B**, **9A** and **9B**).

Although occipital derivations are conventionally used to observe occipital alpha waves during sleep scoring (Berry et al., 2020), our approach focused on frontal derivations. As a result, some occipital alpha activity (observed during periods of eyes-closed wakefulness) may not have been captured by our wearable EEG devices. This could lead to a misclassification of several wakefulness epochs as periods of N1 sleep—according to the AASM guidelines, an epoch should exhibit more than 50% of occipital alpha and/or reading, rapid or blinking eye movements to be scored as wakefulness (Berry et al., 2020). In the case of subjects who do not generate occipital alpha with eyes closed (constituting 10% of the population), sleep onset is determined by the earliest indication of a slowing of background frequencies or the emergence of slow eye movements or vertex sharp waves (Berry et al., 2020). In this case, vertex sharp waves are most prominent in central derivations, implying that the Hypnodyne Zmax device, which uses only frontal derivations, may not adequately capture these features.

Likewise, Zmax might not effectively characterize sleep spindles (observed during N2 and N3 sleep), as these are maximal in central derivations (Berry et al., 2020). Moreover, standard polysomnography employs frontal electrodes referenced to the contralateral ear or mastoid (F4-M1, F3-M2) to identify slow waves (typically observed in N3 sleep), in contrast to the derivations obtained from Zmax (F7-Fpz, F8-Fpz). Consequently, we cannot completely rule out the possibility that some sleep spindles or slow waves were not captured by our wearable EEG devices. This limitation could lead to the potential misidentification of N2 epochs as episodes of N3 or N1 sleep, or vice versa. Finally, Zmax records data at higher impedance levels when compared to standard EEG electrodes used in polysomnography, which could potentially compromise the quality of the sleep data.

Campillo-Ferrer, T., Alcaraz-Sánchez, A., & Torres-Platas, S. G. (2024). Exploring "lucid sleep" and altered states of consciousness during sleep using meditation and visual stimulation: A case series study. *Philosophy and the Mind Sciences*, *5*. https://doi.org/10.33735/phimisci.2024.10227

In light of these limitations, future studies should include larger sample sizes and a more extensive scalp coverage in order to further investigate the sleep stages and EEG features characterizing hypnagogic and wake-initiated lucid dreams, and compare them with those sleep stages and EEG traits observed during dream-initiated lucid dreams. Such a paradigm shift may even open up the prospect of more assiduous investigation into less studied phenomena, such as lucidity during dreamless sleep (Mason et al., 1990, 1997) and out-of-body experiences during sleep (Levitan et al., 1999; Tart, 1967, 1968).

In this paper, we also provided a detailed description of the meditation and visual stimulation protocol followed by our research participants, which could serve as an initial protocol for inducing and measuring states of 'lucid sleep' in a laboratory setting. It is crucial to emphasize that this protocol has not yet undergone statistical validation. We acknowledge that the sample size of the current study is insufficient to reach adequate statistical power and that we lack the implementation of control measures to account for potential confounding factors. Thus, the results presented here should be interpreted carefully.

For instance, some participants in our study had prior experience with earlier versions of this protocol (Subject 4) or with similar relaxation techniques (Subject 3). This factor may have played a role in inducing lucid sleep experiences among this subset of participants in specific. Moreover, although our recruitment criteria targeted individuals who had at least experienced one lucid dream in their lifetime, several participants also reported having experienced out-of-body experiences (all subjects), sleep paralysis (subjects 2, 3 and 4), and hypnagogic or hypnopompic hallucinations (subjects 1, 2 and 4) in the past. Consequently, we are unable to assess whether the different lucid sleep phenomena investigated in this study were triggered by the induction protocol itself, or rather occurred spontaneously. Moreover, there is currently insufficient evidence to support the successful application of this technique for participants who are unfamiliar with lucid sleep experiences, with other mindfulness techniques, or with these procedures in specific.

A further point to consider is that other lucid dreaming induction techniques described in the literature may also trigger some states of lucid sleep. Presently, many of these states may go unreported, as individuals may not recognize them as conventional dreams or may have concerns about being judged by the researcher (e.g. in the case of out-of-body experiences). Additionally, the chosen interview approach can significantly impact the research outcomes of a given study (see Demšar & Windt, 2024). For instance, it is common practice in lucid dream research to gather a "dream report" focused solely on the experience that immediately precedes awakening (Tan & Fan, 2022). This leaves it open whether or not additional (lucid) sleep experiences occurred during the experimental session, and especially at earlier sleep stages, such as during wake-N1 transitions. In order to mitigate these potential issues, we assessed the whole sleep period through in-depth phenomenological interviews and informed our research participants about the possibility of experiencing paralysis, bodily vibrations and other unusual bod-

Campillo-Ferrer, T., Alcaraz-Sánchez, A., & Torres-Platas, S. G. (2024). Exploring "lucid sleep" and altered states of consciousness during sleep using meditation and visual stimulation: A case series study. *Philosophy and the Mind Sciences*, *5*. https://doi.org/10.33735/phimisci.2024.10227

ily sensations while falling asleep. Thus, we cannot disregard the possibility that the selected interview method and the information provided to our research participants might have influenced the success rates of the study by assisting participants in recognizing the occurrence of 'lucid sleep' experiences.

As a final cautionary note, it is important to remark that people during dream reports may confabulate or fabricate false memories (Rosen, 2013). In this context, we might have increased the likelihood of confabulation by forewarning participants about the diverse sensations they may expect during the nap (e.g. paralysis, bodily vibrations). Although most experiences were corroborated through a left-right-left-right eye signal executed by participants ('awareness' episode and 'dream-initiated lucid dream' of Subject 3, and 'wake-initiated lucid dream' of subject 4) or via the sudden awakening and immediate dream report provided by participants ('hypnagogic lucid dream' of Subject 2), we cannot entirely rule out the possibility of confabulation during the final interviews. To further minimize the probability of false memories intruding into the phenomenological reports, we awakened participants at the end of REM sleep or upon identifying the occurrence of a left-right-left-right eye signal. We additionally collected dream reports of the most recent conscious experience prior to these awakenings, asked participants to rate their lucidity levels during the experience, and used these reports to guide the final phenomenological interview (for details see Study design). For Subjects 2, 3 and 4, the final interview took place next to the bed where participants were sleeping to help with the recall process. Thus, while we cannot definitely rule out the possibility of confabulation, we took reasonable precautions to minimize its occurrence.

Considering these factors, it is imperative that forthcoming investigations determine whether the described meditation and visual stimulation protocol (or any variations of this method) holds potential to induce states of lucid sleep within one or more sessions, in either naïve or experienced participants. To attain this objective, researchers should prioritize the inclusion of larger sample sizes and the meticulous design of distinct control conditions. A comprehensive array of control conditions would facilitate the evaluation of possible interactions among the different elements that comprise this protocol; for example, by comparing the impact of the visual stimulation procedure, versus the meditation procedure, versus the combined utilization of both techniques. Finally, we encourage researchers to adapt this protocol to their own interests and necessities. For instance, the combination of the meditation and visual stimulation protocol with a specific vestibular imagining strategy by Subject 3 (see **Figure 7**) may serve as an example of how this method could be customized in the future to induce out-of-body-like experiences.

Campillo-Ferrer, T., Alcaraz-Sánchez, A., & Torres-Platas, S. G. (2024). Exploring "lucid sleep" and altered states of consciousness during sleep using meditation and visual stimulation: A case series study. *Philosophy and the Mind Sciences*, *5*. https://doi.org/10.33735/phimisci.2024.10227

5 Conclusions

The present study advances our understanding of lucid sleep phenomena through an in-depth exploration of a range of states that exhibit critical self-awareness during sleep. To facilitate such states in a controlled sleep environment, we developed a novel approach combining pre-sleep meditation and visual stimulation, which we applied to N=4 subjects. While this protocol requires future statistical validation, its aim is to enable participants to preserve critical self-awareness throughout the falling asleep process. Upon the systematic analysis of the interview reports and electrophysiological data (Zmax Hypnodyne) from these four subjects, we identified the main diachronic and synchronic phenomenological structures of N=4 lucid sleep experiences. These episodes were either eye-signal verified or time-marked in the EEG recordings (e.g., through the sudden awakening and immediate dream report of one participant). These episodes were observed to occur during both non-REM sleep (N=1 hypnagogic lucid dream, N=1 lucid dreamless sleep episode) and following direct transitions from wakefulness to REM sleep (N=1 wake-initiated lucid dream including out-of-body-like and sleep paralysis phenomenology). We additionally captured N=1 dream-initiated lucid dream emerging from REM sleep. We could not determine the sleep stage of N=1 out-of-body-like experience due to the involuntary eye fluttering experienced by this subject. While our findings are inherently limited, they offer valuable preliminary insights into the complex realm of lucid sleep phenomena, setting the stage for further comprehensive exploration on the field. In the long-term, a better understanding of lucid dreaming, out-of-body experiences, and lucid dreamless sleep is crucial to determine the brain processes underlying human consciousness, self-awareness and body ownership.

Author contributions
The first author designed the experiments and induction protocol, collected the data, prepared the interview and electrophysiological data for analysis, wrote the paper with contributions from all authors and created the figures and tables. The first and second authors analyzed the interview data and worked on the theoretical background of the study. The first and third authors performed sleep stage scoring of the electrophysiological data. The second and third authors provided substantial feedback on different versions of the manuscript.

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