Two-way communication in lucid dreaming using Electrical Muscle Stimulation (EMS)

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Summary. Dream reports are usually recorded upon waking, and their reliability is influenced by memory processing during sleep, often leading to partial or selective recollections. Recently, there has been increasing interest in exploring the possibility of direct communication from within a dream. This study explores the feasibility of bidirectional communication during lucid dream-ing, using a counting task facilitated by electrical muscle stimulation (EMS). Four participants with varying levels of lucid dreaming experience engaged in overnight recordings, monitored by polysomnography to ensure the presence of lucid dreams. Over four nights, two participants successfully perceived, counted and communicated the number of stimuli during lucid dreams in real-time. Out of eleven trials, five (45.5%) successfully elicited a response, while six (54.5%) did not. These findings highlight the potential of EMS as a reliable method for bidirectional communication in lucid dreaming, reinforcing previous research and offering valuable insights for future studies. Furthermore, this study advances the field of dream engi-neering and sheds light on the relationship between the physical and dreamed body. Dream communication and engineering will advance by experimenting with creative methods and ideas, leading to more detailed, nuanced, and reliable dream data.

Keywords: Lucid dreaming, communication, electrical muscle stimulation, dream engineering

1. Introduction

Dreams, a regular phenomenon during sleep, often fade from memory upon awakening, leaving little trace. Traditional methods of collecting dream experiences, like interviewing participants after waking, hinder data quality. These dream reports are often incomplete and distorted due to poor memory formation during dreams and limited capacity to retain recent information upon waking (Wamsley & Stickgold, 2010). Lucid dreaming, however, offers a solution to the limitations posed by post-dream reports. Lucid dreaming is a phenomenon defined as a dream in which a dreamer becomes aware that they are dreaming (LaBerge, 1985). A lucid dream is a unique state of mind that enables the ability to have control of the dream body and content. The validation of lucid dreaming through voluntary eye movements has been the gold standard for decades, and these volitional eye movements have another promising novel application (Hearne, 1978; LaBerge, 1985). One way to expand scientific research on dream experiences is through real-time communication with lucid dreamers. This approach enables dreamers to articulate their dream experiences as they are happening without the need for interruption or awakening, providing immediate insights into their dreams (Konkoly et al., 2021). While lucid dreaming has a high potential for dream and consciousness exploration, experiencing frequent spontaneous lucid dreams is a relatively rare phenomenon. Various techniques have been developed for the induction of lucid dreams (Tan & Fan, 2022). Researchers have shown that tactile, acoustic, and visual stimuli, such as flashing lights, can be perceived in the dream and in some cases, allow the dreamer to recognize that they are dreaming and thus achieve lucidity (Baird, LaBerge & Tononi, 2021). Studies have shown that on the one hand, the sleeping brain reacts to external stimuli without the sleeper waking up, and on the other, that the sleeper processes environmental and bodily information during sleep, changing dream content due to the somatosensory, auditory, olfactory and visual stimuli (Solomonova & Carr, 2019). In conclusion, there are several ways to access the physical, sleeping body which may also be used for communication in lucid dreaming.

A potential novel method of engaging with the dreamer involves the use of electrical muscle stimulation (EMS). By directly stimulating the muscles, EMS replicates the signals typically generated by the motor cortex. EMS thus has the capacity to induce muscle movements in the physical body during sleep, potentially influencing the corresponding dream body and serving as a cue for lucidity. Even in the absence of overt physical movement, EMS generates an electrical sensation on the skin that can be integrated into the dream experience (Peters et al., 2024). Given the correlation between dream content and muscle activity, EMS presents a promising avenue for facilitating communication from the experimenter to the dreamer and back (Erlacher & Schredl, 2008).

The concept of real-time dream communication is currently in its infancy, yet previous instances have demonstrated its feasibility and potential. Strelen (2006) investigated auditory stimulus discernment in lucid dreaming, which was validated later (Appel et al., 2018). Six participants spent one to seven nights in the sleep lab, experiencing tones randomly. They signaled lucidity and successfully discerned higher tones using eye movement signaling, completing the

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trial in eight lucid dreams (Appel & Pipa, 2017, p. 100). Later, Konkoly et al. (2021) outlined successful two-way communication in lucid dreaming, with experiments across the U.S., France, Germany, and the Netherlands. These experiments employed various communication methods, such as presenting trials or asking questions. Success rates varied, with 18% achieving two-way communication. Polysomnography, including EEG, EOG, and EMG, verified participants' reports. For instance, the U.S. team induced lucid dreams through sensory stimulation, with participants responding to math problems, presented as auditory stimulation, using eye movements. In the Netherlands, participants responded to math problems as well, resulting in a relatively low success rate. In Germany, Morse code was utilized using the presentation of lights, resulting in a correct response to a visual math problem. The French team worked with a single participant diagnosed with narcolepsy, achieving two-way communication through facial muscle contractions for answering spoken 'yes' and 'no' questions. and the presentation of tactile stimulation. The participant was also presented with hand taps and responded by contracting the corrugator muscles, counting the number of taps they perceived.

The possibility of two-way communication during lucid REM sleep using a form of kinesthetic stimulation has been documented previously using the stimulation of an electrical shock to the forearm. Fenwick et al. (1984) explored the capacity of a single proficient lucid dreamer to perceive and respond to external stimuli during lucid dreams. Conducted with a single 43-year-old participant, the study involved morning naps following four hours of sleep. In one experiment, a combination of eye movements and muscle bursts were used to communicate. Electric shocks would be delivered to the subject's forearm if the amplitude of a horizontal eye movement exceeded a pre-set level. Forearm muscle bursts were used for solely communicating from the dreamer to the researcher. As soon as the subject experienced a lucid dream, he signaled this with horizontal eye movements. After that, the experiment started as he indicated the number of electroshocks he intended to give himself using forearm muscle bursts. Then, by providing the corresponding number of horizontal eye movements, he administered the electroshocks himself. After receiving the shocks, he subsequently indicated the number of electroshocks received with forearm muscle bursts.

The participant successfully executed this trial while asleep, demonstrating the ability to recall and execute planned actions from wakefulness, comprehend the relationship between eye movements and shocks, count the administered and received shocks, and retain the corresponding numbers for signaling through muscle contractions. Fenwick et al. (1984) concluded that lucid dreaming allows for complex cognitive processes such as memory, cognition, and counting during REM sleep.

Our study builds upon this research by using with multiple participants and employing electrical muscle stimulation (EMS) in a lucid dream counting trial. We aim to establish two-way communication between experimenters and dreamers while also paying close attention to how the actual stimulus affects the dream body. By integrating physiological data with dream reports, we seek to understand how external stimuli influence dream content and sensory perception.

2. Method

2.1. Participants

Recruitment targeted highly skilled lucid dreamers through posters and word-of-mouth advertising around the University of Bern Campus, with selection criteria including extensive prior experience with lucid dreaming, the ability to self-induce a lucid dream, and the ability to sleep in unfamiliar environments. Prospective participants completed the Lucid Dreaming Skills Questionnaire (LUSK) to assess qualifications (Schredl et al., 5 C.E.). Four individuals (N female = 2) with a mean age of 26.3 years (SD = 3.34) were included in the study.

2.2. Experimental Setting and Equipment

The experiment was conducted at the sleep laboratory at the University of Bern's Institute for Sports Science (ISPW). A camera and microphone enabled communication between the participant and the experimenter. To monitor sleep stages, 12-channel polysomnography (PSG) was administered, consisting of electroencephalography (EEG), electrooculography (EOG) and electromyography (EMG). PSG set-up was applied according to the 10-20 system (Klem et al., 1999). F3, F4, C3, C4, O1, O2, horizontal EOG1 and EOG2, chin EMGl, chin EMGr, a reference (earlobe) and ground (Cz) electrodes were used. Electrical muscle stimulation (EMS) was administered using the RehaMove 3 by placing two electrodes on the inner forearm in such a manner that low intensity stimulation would cause a ring finger flexion. The intensity of the stimuli was adjustable to ensure effectiveness without causing discomfort or interrupting sleep.

2.3. Procedure and Protocol

Each participant spent a single night in the sleep lab. Participants arrived at the sleep laboratory in Bern at 9:00 pm, where they were given a tour of the sleep laboratory and informed of the night's procedures. All participants were briefed on the experiment's objectives prior to the experiment and signed informed consent. As lucid dreaming is a highly individual experience, and so is the induction, a semi-standardized protocol was followed. The specific protocol for each participant is detailed in individual case reports. Participants were prepared for sleep, and polysomnography (PSG) and the RehaMove 3 device for electrical muscle stimulation (EMS) were applied. The stimulation intensity was selected based on the lowest intensity that would case a hand movement (ring finger flexion) during wakefulness. Before lights out, the participants had the opportunity to practice the counting trial and the eye-signaling. Participants typically fell asleep between 23:00 and 00:00 (N2 onset). Each participant performed the wake-back-to-bed (WBTB) method after four hours of sleep. Participants were awakened and remained awake for thirty minutes, engaging in reading activities, followed by a final rehearsal of the counting trial. After sleep onset, in the event of a lucid dream, participants signaled with the LRLR eye movement pattern, followed by the attempted execution of the counting trial and subsequent collection of a dream report. After the collection of the dream report, the participant could fall asleep again and repeat the protocol. During each REM phase, the experimenter awaited the participant's initial lucidity signal. If no signal was observed within approximately ten minutes of REM sleep, a single EMS stimulation of 2 seconds was administered with the function of cueing the participant. This cue aimed to prompt the participant to recognize their dreaming state and potentially induce lucidity. Upon detection of a lucidity signal followed by a ten-second wait period, EMS stimulation was administered with the goal of communication. A 2-second stimulation was administered randomly between one and four times, with a five-second interval between each stimulus. The participant's trial was to count the number of stimulations received accurately. If no further stimulation occurred ten seconds after the last one, the participant indicated the number of stimulations using left-right eye movements, with LR representing one, LRLR representing two, LRLRLR representing three, and LRLRLRLR representing four stimulations. Both after a response and no response, a new trial was randomly selected and executed. The cycle continued until the participant either fully awakened or showed signs of NREM sleep for at least three epochs. In the case of NREM, the participant was awakened to collect a dream report. If a brief arousal occurred, the researcher waited for the participant to either return to REM sleep, enter NREM sleep, or fully awaken before responding accordingly.

Upon awakening, the participant provided a verbal dream report by answering four questions:

- What went through your head just before you woke up?
- Were you aware that you were dreaming while you were dreaming?
- Did you notice the stimulation on your arm? How did your hand feel and move in your dream?
- Is there something more you want to tell me?

Further questions were posed to clarify dream content details. Dream reports were audio recorded.

2.4. Sleep Scoring and Data Pre-Processing

Polysomnography data were analyzed and assigned to sleep stages using U-Sleep, an online service for automatic clinical sleep staging (Perslev et al., 2021). The dream reports were transcribed, converted using the Dream Conversion Manual (Schredl, 2010) and translated if they were originally in German. Participant 1, 2 and 4 reported their dream in German and participant 3 in English.

3. Results

3.1. Results Overview

Four individuals (N female = 2) took part in this study. The mean age was 26.3 years (SD = 3.34). Their lucid dream frequency was 'Several times a week' (N=1, participant 1), 'Two or three times a month' (N=2, participant 2 and participant 4), and 'About two to four times a year' (N=1, participant 3). For each participant, a spontaneous signal-verified lucid dream (SVLD) during REM sleep was observed. Throughout these four lucid dreams, a series of eleven trials were performed to establish two-way communication using EMS. Two of these four SVLDs (50.0%) resulted in at least one successfully completed counting trial. In five trials (45.5%), the participants were able to successfully complete the counting trial, providing an answer. In one of those, there was communication, but the answer was a miscount. The experimenters received no response in six trials (54.5%). In the following sections, parts from dream reports recorded after the two-way communication trials are presented. In each trial, two raters independently evaluated the responses, then discussed and reached a consensus on the outcomes. Their assessment included agreement on the sleep stage during the trials, the content of the dream reports, and the corresponding observed signals.

3.2. Successful Two-Way Communication in Lucid Dreaming

3.2.1 Participant 1

Participant 1 is a 22-year-old male participant who regularly experiences several lucid dreams per week. A spontaneous SVLD was observed at 5:24 during REM sleep. In the first communication trial, the participant was stimulated twice using EMS. The participant succeeded in performing the correct eye signal: two left-right eye movements

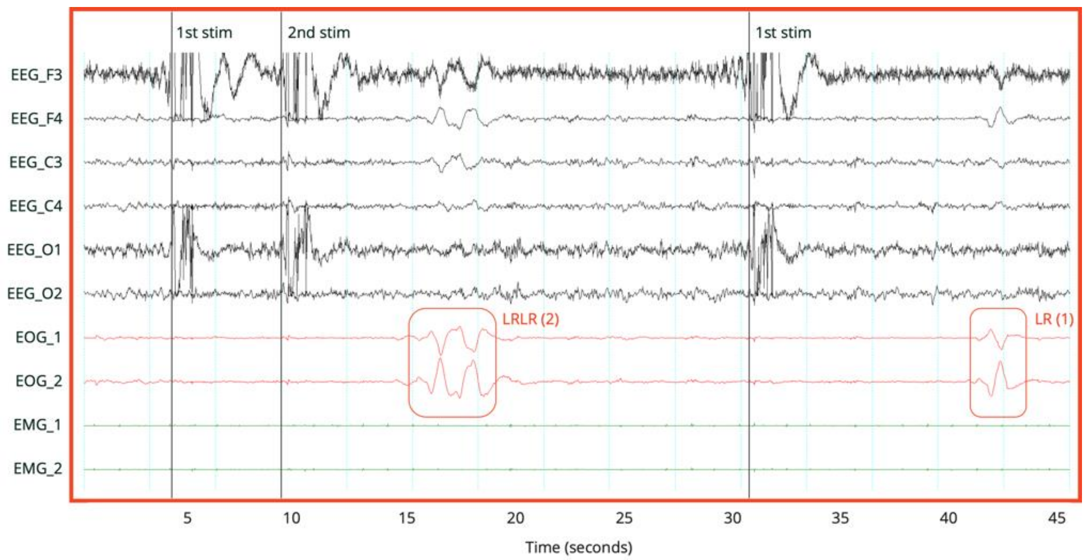

Figure 1. Successful two-way communication trials with participant 1.

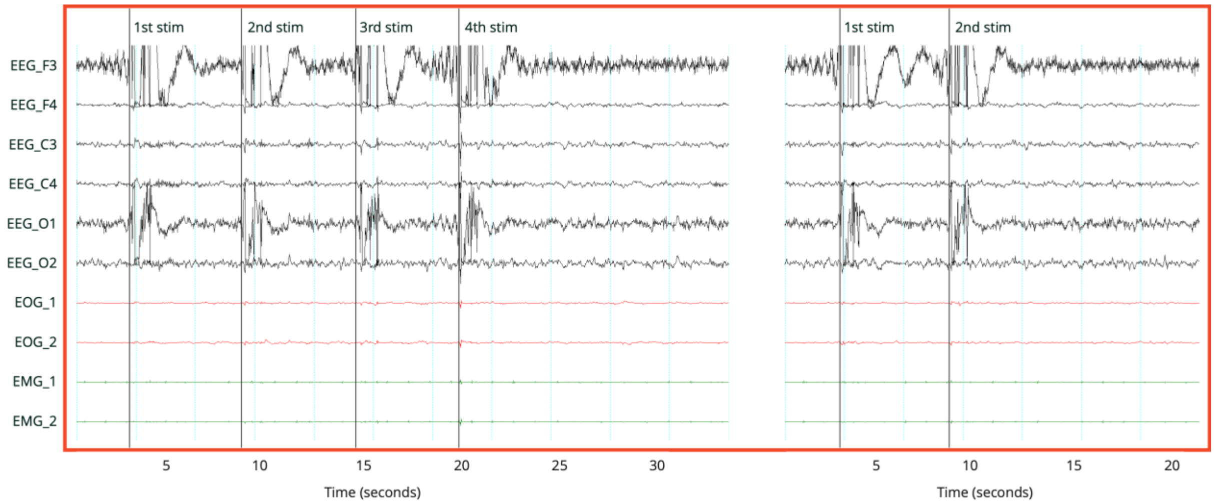

Figure 2. EMS communication trials resulting in no response with participant 1.

(LRLR). The participant was also able to correctly complete the second trial, during which he was stimulated a single time, with a single left-right eye movement (LR) (see Figure 1). After the third trial, during which the participant received four stimulations, and after the fourth and final trial, during which he was stimulated twice, no eye movements were detected, and the participant was subsequently awakened. Figure 2 shows the PSG data of the two unsuccessful trials to establish two-way communication. Upon awakening, the participant was able to confirm both the initial lucidity signal (LRLR) and the completion of the first two successful two-way communication trials. The dream report is consistent with the PSG data collected and presented in Figure 1 and 2. Participant 1 reported a false awakening after completing the first two trials. During the false awakening, the stimulations on his forearm were perceived, but the participant was unable to respond to them.

> *[…] And then my brother also came with a Real [Madrid] T-shirt and then I thought, now something is wrong. That was the moment when I knew, ah, I'm dreaming! Then I tried to give the sign – left, right, left, right – and then I waited a little bit. […] And then suddenly the sign came, the vibration, I think the first time it was two times and then one time. […] Until I was woken up just now, I thought I was already awake. […] I was also woken up after-wards, so I woke up because something was not right anymore. Then they told me that the twitching went on and on and that I had to get rid of it, […] But then I looked at my arm and it still kept twitching. […] The [stimulation] actually twitched just like it twitches in real life. […]*

Participant 1 succeeded twice in recognizing electrical stimulations, counting them, and responding appropriately with left-right eye movements. Furthermore, he reported that stimulation in a dream felt like stimulation while awake.

3.2.2 Participant 2

Participant 2 is a 32-year-old female participant who experiences several lucid dreams per week. A spontaneous SVLD was observed at 06.40 during REM sleep, followed by the initiation of the first trial, which was a single EMS stimulation.

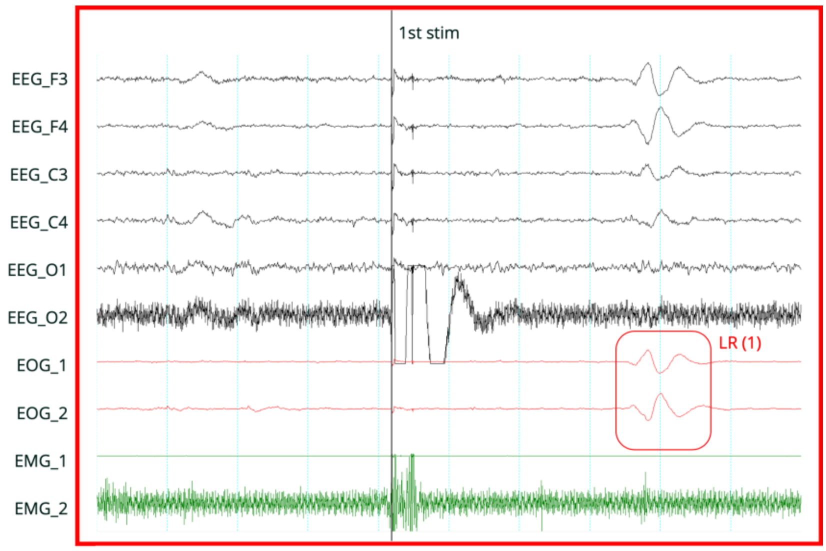

Figure 3. First, successful two-way communication attempt with participant 2.

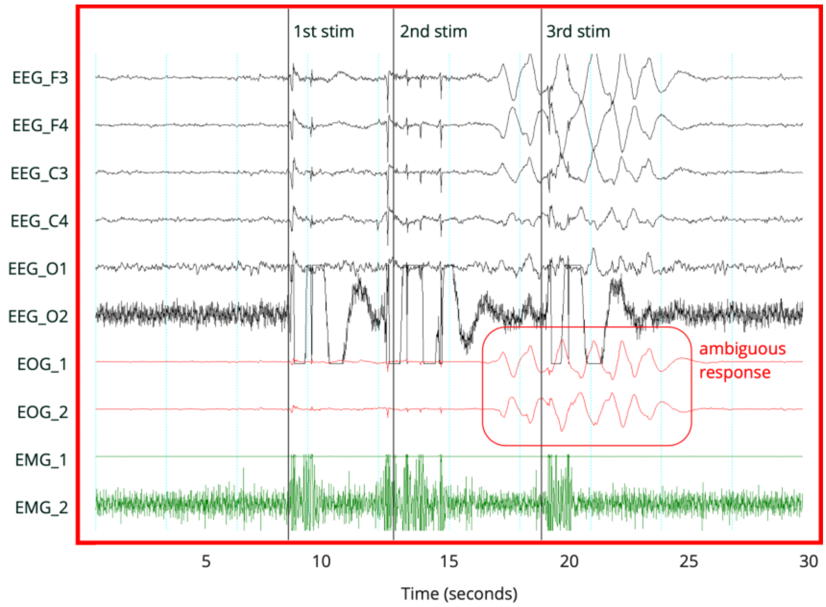

Figure 4. Second, ambiguous two-way communication response with participant 2.

The participant was able to respond with a single left-right eye signal. Figure 3 shows the results of the two-way communication trials with participant 2. In the second trial, the participant received three stimulations but began responding after the second one (Figure 4). During this response, the third stimulation was administered, causing an overlap with the eye movements and making their interpretation uncertain. This response is considered a successful communication attempt, but the chaotic nature of the interaction prevents labeling it as correct or incorrect. The ambiguity is not in whether this was a response or an attempt at communication, which it clearly is. The ambiguity comes from the timing and miscommunication. In the third trial, the participant received two EMS stimulations, which she was again able to identify and indicate with eye movements, as seen in Figure 20, just before waking up from her lucid dream as can be seen from the increase in EMG_1 activity after the eye movements. In the dream report, the execution of the initial lucidity signal and the two LR eye movements was confirmed, just before waking up. The participant reported perceiving two stimulation trials, to which she responded, although a total of three trials were presented.

> *[…] And then I was like, I'm dreaming! Now I have to move my eyes and then I did this [movement] twice and then I almost felt a bit like I was floating out of the body. And that scared me a little bit, but then I was still like, I have to go on now. […] And then I had the same strange feeling on my neck and then I was a bit afraid. […] So, the first series I was still in the dream, and I just felt it here [on my arm], but then in the dream I just counted. And the second series I was just in this state between the dream*

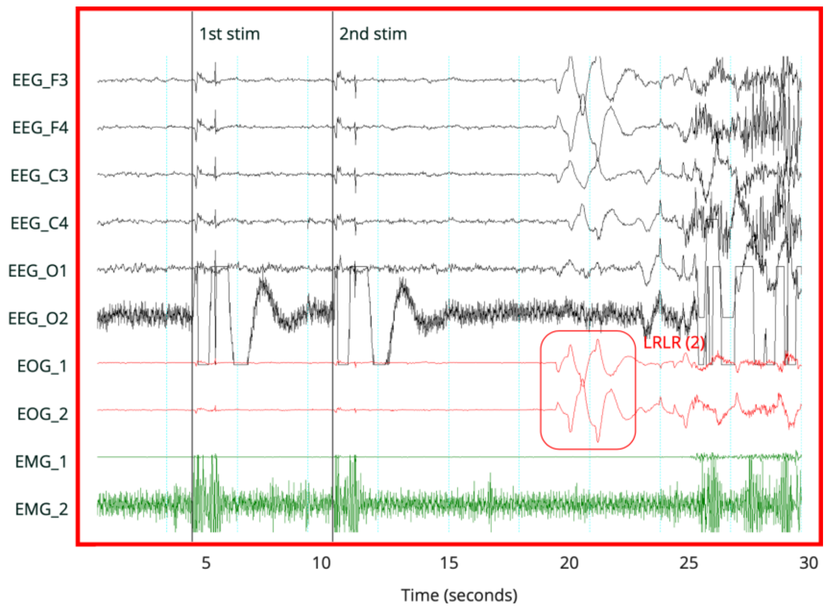

Figure 5. Third, successful two-way communication attempt with participant 2.

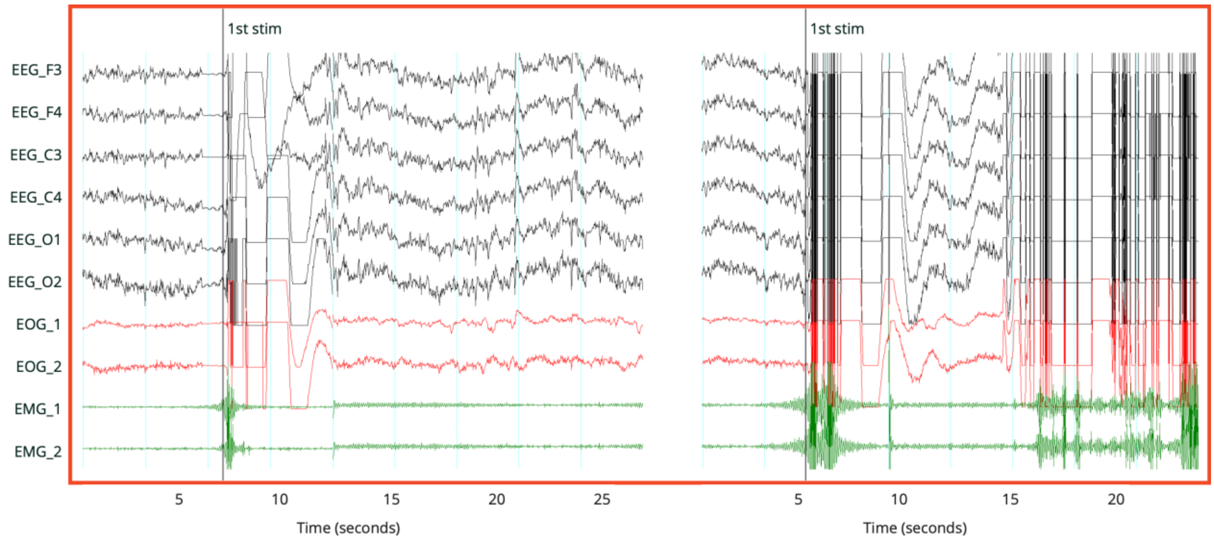

Figure 6. Failed two-way communication trials with participant 3.

and waking up. I was just counting. I didn't see anything, my dream wasn't so clear, maybe I didn't sleep so deeply, […].

In her experimental night, participant 2 succeeded twice to recognize electrical impulses by EMS on the forearm, count stimulations and respond appropriately. It should be noted that the participant reports feeling nearly awake when she provided the answer to the third and final counting trial, however this was not corroborated by the PSG data. She reported feeling the stimulation on both her arm and in her neck but could not specify if and how the hand moved due to the stimulation and was unable to provide any information about how the stimulation affected dream content.

3.3. Unsuccessful Two-Way Communication in Lucid Dreaming

3.3.1 Participant 3

Participant 3 is a 24-year-old female participant who has experienced only a few lucid dreams in their lifetime. The spontaneous SVLD was observed at 06:16 during REM sleep, followed by the initiation of the first trial. Figure 6 shows the two trials for two-way communication with participant 3. The participant was stimulated once, followed by no-response. A second trial was started, but the participant woke up just after the first EMS stimulation. The dream report showed the experience of a lucid dream and the perception of the EMS stimulation on the arm in the dream. The participant reports trying to communicate as clearly as possible, but this was not verified by the PSG data.

[…] And then I was like, okay, no this is not normal. And then I felt like the stimulus or something. […] But then I was like, okay I'm dreaming, I'm giving the signal. And then I tried to do the signal as obvious as possible. And then I was like, okay I'm lucid. Then I stood up and ripped all my electrodes off, cause I was like, I don't need them now, because I am dreaming anyways. […] I was kind of scared, but then I felt you were stimulating again, but then I woke up.

3.3.2 Participant 4

Participant 4 is a 25-year-old male with between two and three lucid dreams per month. The spontaneous SVLD was observed at 02:51 during REM sleep, followed by trial initiation. Two trials of two-way communication were performed. In a first trial, the participant was stimulated twice, followed by no-response. In a second trial, the participant was stimulated twice again followed by no-response. Participant 4 reports doing a reality check as well as giving the lucidity signal. In addition, he reports perceiving the stimulations and responding with eye movements. Unfortunately, this was not verified by the PSG data. The participant reported that the stimulus in the dream felt warm and tingly, however, less profound in comparison with the waking state. In this case, EMS stimulation did not produce any visible artifacts in the PSG data, thus no figure of the two trials with participant 4 is available.

[…] Then, I did this nose reality check and realized, oh this is a dream. I could breathe through my nose even though I had it closed and then I immediately did the left-right-left-right movement. […] After the left-right-left-right, I just did another left-right. I thought it [stimulation] was only once. Because it felt like it was a longer feeling and it was difficult for me to analyze if there was more than only one impulse. […] [The stimulus] was actually like the impulse we had tried earlier, but it wasn't this "tickle", but it was really a suppressed feeling, it wasn't so easy to recognize [...] and it was a bit warm and suppressed compared to the real impulse.

4. Conclusion and Discussion

4.1. Conclusion

The results presented have confirmed that it is possible to communicate with a lucid dreamer by stimulating the physical body using electrical muscle stimulation. Out of a total of 11 two-way communication trials, five were successful (45.5%). From the dream reports, it appears that all four participants recognized the EMS stimulus in their lucid dreams, but their perceptions differed from each other. For participant 1, the stimulation in the dream felt exactly the same as in the waking state. Moreover, he reported that his dream hand moved equivalently to how his hand would move in real life upon stimulation. He managed to distinguish the different stimulations from each other and to count the number of stimuli.

Participant 2 reported feeling the stimulation not only on her arm but also on her neck, leading to an unpleasant sensation and anxiety. Notably, she found the stimulation very uncomfortable when awake, even though the EMS device was set to a level that other participants did not perceive. This suggests that sensitivity to stimuli in the waking state could affect perception in dreams. Increased pain sensitivity might cause the unpleasant sensation to spread to other body parts, inducing stress and amplifying discomfort. This mirrors the vicious cycle of stress and pain seen in wakefulness, where heightened focus on pain exacerbates symptoms (Whibley et al., 2019). Participant 2's stress likely influenced her perception of the stimulus. Despite the discomfort, she was able to distinguish individual stimulations.

Participant 4 did not succeed in distinguishing between individual stimuli. Instead, he perceived them as a single warm and tingly sensation. The reported temperature change is particularly interesting. This perception can potentially be explained by the metabolic activity associated with muscle contractions. When muscles contract, they undergo metabolic processes that produce heat as a byproduct (Loiselle et al., 2016). Even during artificial muscle contractions induced by electrical muscle stimulation (EMS), this heat production can occur, or at least the sensation of heat can be perceived (Knibbe et al., 2018). The perception of warmth and tingling during EMS might also be linked to increased blood flow and localized muscle activity, which can enhance the sensation of heat (Fortin et al., 2017). This phenomenon indicates that the sensory experience during a dream can be influenced by the physiological responses of the body to external stimuli. These observations highlight the complexity of sensory incorporation into dreams and suggest that individual differences in sensitivity and perception can significantly affect how external stimuli are experienced during lucid dreaming. While some participants might experience clear and distinct sensations, others may perceive them as blended or altered, such as participant 4's experience of a warm, merged sensation. Unfortunately, due to the small number of dream reports in which participants refer in detail to EMS stimulation, little data could be collected on how EMS stimulation affects dream content in general. One major limitation of the trial of participant 4 is the lack of artifacts following stimulation, which might indicate that there was a problem with the stimulation presentation at that timepoint.

The described findings support the conclusions of Konkoly et al. (2021) that it is possible to communicate with sleeping individuals to gain insights about their dreams. Furthermore, the study confirmed that lucid dreamers can respond to a trial while remaining asleep. The collected data confirm the previous findings about two-way communication during sleep and help forming the basis for future scientific exploration of two-way communication in lucid dreaming. Furthermore, the present study provides us with a unique insight into the lucid dream body and how muscle sensations are translated into the dream body.

4.2. Limitations

One major limitation of this study is the small sample size, which restricts the generalizability of the findings. Additionally, the absence of a control condition without stimulation introduces potential biases, as it is unclear how the absence of stimulation might have affected the participants' experiences. Another limitation is the limited communication system employed in the study, which relied on a counting task to interact with the participants. Despite these limitations, the study provides valuable insights into the feasibility of using electrical muscle stimulation for communication in lucid dreams. Future research that addresses these limitations—by including a larger sample size, incorporating control conditions, and exploring more advanced communication methods—will build on these promising findings and further advance the field.

Another significant challenge in two-way communication during lucid dreaming is identifying the ideal method for communication that achieves the highest possible response rate. This challenge can be framed within the context of two main factors: the dream incorporation of a stimulus (input to the dreamer) and the methods used by the dreamer to communicate (output of the dreamer). Optimizing both input and output is crucial for successful communication.

The stimulus must be strong enough for the dreamer to notice it but not so strong that it causes arousal from sleep. In this study, all four participants noticed the electrical muscle stimulation (EMS) in their lucid dreams. Only one participant woke up due to EMS stimulation, and this occurred only during the second counting trial. To optimize the EMS stimulation threshold, we used the lowest value that produced a hand movement and avoided stronger stimuli during sleep. However, we did not conduct a wake threshold arousal trial, which could have helped fine-tune the stimulus to prevent arousal from sleep. Managing arousal levels is thus critical. Effective communication relies on maintaining an optimal balance where the stimulus is perceptible without being disruptive. Future studies could benefit from utilizing personalized arousal threshold algorithms based on polysomnographic (PSG) data (Pavlou, 2024). These algorithms could dynamically adjust the intensity of the stimuli to individual participants' arousal thresholds, enhancing the likelihood of successful communication without waking the dreamer. Incorporating these personalized adjustments could significantly improve response rates and the reliability of two-way communication in lucid dreaming research. Additionally, refining these methods may reduce the variability in participants' responses, leading to more consistent and interpretable data.

Despite the challenges, having five successful trials out of eleven counting trials (45.5%) demonstrates that electrical muscle stimulation is highly suitable for two-way communication. This success rate compares favorably with the study by Konkoly et al. (2021), which achieved a 53.8% success rate in their best method—a counting trial where participants counted taps on their right hand (7 out of 13 trials). In the current study, the use of electrical muscle stimulation (EMS) proved similarly effective. Both tapping and EMS are reliable methods for accessing the physical body during sleep without causing arousal. These somatosensory stimuli can be seamlessly integrated into the dream, making them suited for communication in lucid dreaming. The findings suggest that somatosensory stimulation, such as tapping and EMS, are effective for establishing two-way communication in lucid dreams. Future studies can build on these promising results by further exploring somatosensory stimulation, either by collecting additional data using the outlined methods or by testing new, similar approaches. The development of more complex communication signals based on these preliminary findings could by-pass the problems of distorted and fragmentary dream reports and obtain real-time information about a dream (Konkoly et al., 2021).

Building on the study's findings, it is worth considering how electrical muscle stimulation (EMS) could be utilized to create more complex input signals, facilitating richer communication during lucid dreaming. While this study primarily employed EMS for simple counting, future research could explore more sophisticated and creative stimulation patterns to convey a broader range of information. For example, varying the frequency, intensity, or location of EMS could encode different types of messages or commands. By establishing a system where each pattern corresponds to a specific response, participants could learn to interpret these patterns and respond accordingly.

The output of the dreamer, in our case eye movements, is the second important factor in the two-way communication process. With the communication methods studied so far, it is not possible to exchange a lot of information quickly. Methods used, such as counting trials, morse codes, simple yes/no questions, allow only a minimal exchange of information.

One way to enhance the nuance of communication in lucid dreaming is by using counting to rate an experience. For instance, participants could use a predetermined number of eye movements on an agreed-upon scale to describe specific aspects of the dream as it unfolds. This method allows for a more detailed, in-the-moment description of the dream. Eye movements as an output mechanism can be expanded further, as shown by Appel (2023), who is exploring new methods for complex message transmission in lucid dreams. One such approach uses horizontal and vertical eye movements, recorded via electrooculography (EOG), to reconstruct 2D patterns, allowing dreamers to "draw" or "write" with their eyes. Another technique, the "swEYEpe" method—modeled after smartphone swipe keyboards—enables dreamers to spell words by moving their gaze over an imagined keyboard. Although these methods require practice and rely on algorithmic interpretation, they point to the increasing sophistication of communication during lucid dreaming.

Recent studies reveal that lucid dream communication can utilize more than just eye movements. Raduga et al. (2023) introduced facial surface electromyography (EMG) as a proof of concept for enabling the decoding of speech in lucid dreams. They developed a system called Remmyo, which translated EMG signals into sounds and letters, ultimately vocalizing English phrases in real-time. The study demonstrated that with further development, individuals could verbally communicate while in lucid dreams. Despite software limitations and some mispronunciations, the researchers decoded and translated dream speech, suggesting that dreamers could potentially convey more complex and nuanced messages in the future. This study was built on the notion that speech muscle activity during REM sleep correlates with the recall of speech in dreams (Shimizu & Inoue, 1986).

Additionally, Mallett (2020) explored using brain-computer interfaces (BCIs) to control external devices through mental commands in lucid dreams. In this pilot study, participants trained on a mental motor command while awake, then attempted to perform the same action during a lucid dream. In two cases, the dreamer's mental commands were successfully translated into computer actions. This breakthrough indicates that BCIs, typically used to interpret mental imagery in waking life, could also be used to enhance communication during dreams, offering exciting possibilities for more sophisticated interaction.

While these advancements are promising, some challenges remain. Translating physiological signals—whether through EMG, eye movements, or BCIs—into accurate and nuanced communication is still complex. Issues such as software interpretation errors, training requirements, and the limitations of current technology pose obstacles. However, these studies illustrate that communication from within dreams is becoming increasingly viable and intricate, moving beyond simple, one-dimensional signals. Above all, this is a call for creativity, inviting researchers to explore and innovate the dream communication and engineering field.

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