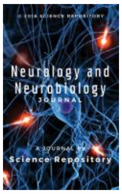

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Research Article

Cognitive Neuroscience of Conscious Dreaming: Investigating Methodological Approaches to Detect Dream Lucidity in Sleep Studies

Berenika Maciejewicz*

Department of Biomedical Engineering, Einstein Medical Institute, Florida, USA

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ABSTRACT

Background: It is uncommon for dreamers to be aware of their dreaming status while being inside their own dream. Yet, it is possible to become mindful and conscious of the fact that one is dreaming. This fairly rare phenomenon is called lucid dreaming. Cognitive functions are preserved while sleeping, and in the case of trained and experienced lucid dreamers, this also permits them to manage and influence their own dream environment, characters present, own actions, and the progression and plot of the dream itself. The neuroscience of lucid dreaming is novel but started to gain interest across a broad spectrum of interdisciplinary fields, including neurology, psychotherapy, philosophy, and sports sciences.
Aim of the Study: To evaluate approaches currently practiced during dream lucidity sleep experiments, as well as to suggest new methodologies and protocols that can be adopted to detect the emergence of self-awareness during sleep.
Materials and Methods: Analysis and evaluation of some of the existing methods was performed and combined with their own methodological and theoretical insights. Analysed were selected sleep studies and medical literature.
Results: Neuroimaging employing electroencephalography, electrooculogram and sleep polysomnography simultaneously can be effective in objectively measuring and validating dream lucidity. Agreed-upon sequence patterns involving a left-right-left-right eye movement as a cue from a lucid dreamer signaling, they have entered an awareness state in parallel with polysomnography data can be effectively employed.
Conclusion: Further studies are vital for investigating the clinical and non-clinical applications of lucid dreaming. Dream lucidity, becoming conscious of dreaming while dreaming, might be therapeutically beneficial in various biological and psychological applications, including as a therapy for nightmares or narcolepsy. Diagnostic indications of emerging self-awareness based on more accurate neuroimaging protocols could also be therapeutically applicable to conditions like anaesthesia awareness and locked-in syndrome.

Introduction

Lucid dreaming is a term describing a recognition that one is dreaming while dreaming. It was believed that dreaming takes place only when the dreamer experiences the Rapid Eye Movement (REM) phase of sleep. More recent studies reveal that dreamers tend to have vivid dreams while they are in Non-Rapid Eye Movement (NREM) sleep as well [1]. Nevertheless, it is believed that REM sleep arousals correlate with 74-80% of dream memory, whereas NREM sleep correlates with 7-9% [2, 3]. NREM dreams seem to be more common, particularly during the early half of the night [4]. Memory of the details of NREM dreams is frequently compromised compared to REM dreams [5]. While vivid experiences of perception and emotions are frequent characteristics of dreams, they are also frequently characterized by a variety of cognitive abnormalities, including atypical imaginative perceptions and hindered free will.

Correspondence to: Berenika Maciejewicz, Department of Biomedical Engineering, Einstein Medical Institute, 842 US Highway 1, North Palm Beach, Florida, 33408 USA; Tel: +14084797607; E-mail: office@drberenikamaciejewicz.com

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The sleep-wake cycle shows dramatic variations in conscious awareness. While awake, humans are alert, aware of both internal and external stimuli, capable of self-reflection on their perceptions, feelings, and thoughts, and able to act freely in accordance with their intentions. The majority of these qualities diminish as someone goes to sleep, yet, when someone dreams, consciousness resurfaces in a different capacity. Various types of awareness and personality expression can exist during sleep, including feelings and abstract thinking functions [6]. Sensations during sleep and waking hours can be very different from one another. The surreal illusions that emerge in mind during sleep are convincing to dreamers who assume them as real. People can feel intense emotions while asleep, can lose willpower, or become disoriented about their whereabouts and other people in their dreams.

Dream lucidity tends to happen almost exclusively during rapid eye movement phases of sleep, as opposed to non-lucid dreaming, which happens throughout the whole sleep cycle [7]. In general, dream lucidity is an uncommon occurrence, and only about 23% of people experience this phenomenon during their lifetime [8]. The frequency of lucid dreams does not seem to depend on gender or age [9]. More than 80% of lucid dreamers claim to have engaged in self-indulgent activities such as flying, having sex, or other activities at least once, according to a survey conducted interviewing 301 lucid dreamers [7]. In contrast to non-lucid REM dreams, lucid dreaming has been linked to a stronger activation of the autonomic nervous system, including higher breathing frequency, heart rate, and skin conductance [10].

Materials and Methods

Due to their rarity, lucid dreams are challenging to investigate; sleep research often involves recording weeks' worth of sleep to record sufficient amounts of dream lucidity data. As a result, participants in most lucid dreaming sleep laboratory experiments are chosen based on how frequently they have lucid dreams, influencing the likelihood that the laboratory will record a lucid dream on a given night. It's challenging to identify subjects that regularly have lucid dreams and invite such volunteers for a dream lucidity study which may involve extensive work in advertising, recruiting, traveling and extensive costs associated. Methodologically, implemented are complex procedures required to conduct a multi-factorial sleep study, such as polysomnographic measurement of the brain activity including electroencephalogram (EEG), eye movements by electrooculography (EOG), muscle activity by electromyography (EMG), oxygen level measurements, leg movement measurements and skin conductance responses. To objectively identify whether a subject is awake or asleep, as well as which of the several stages of sleep the dreamer is in, a multi-stage polysomnographic recording might be required. For this study, analysis and evaluation of existing methods was performed and combined with own methodological and theoretical insights.

Results

Investigating conscious dreaming is inevitably interlinked with examining the very nature and definition of what makes us describe anything as conscious in the first place. Consciousness and working memory appear to be interconnected but not synonymous. While we may be conscious only of one thing at a time, a number of objects can be held in working memory simultaneously. Working memory is believed to be based on the prefrontal cortex. Experiments show that for something to be stored within working memory for more than a second or so, we must be conscious of it. Thus, it appears that multistep algorithmic computations in our brains require our consciousness to complete.

If an event never gets stored in memory, the person can't report it because they would have never remembered about it. This shows the role of memory in consciousness. For example, if someone doesn't remember a dream, they cannot tell if they were conscious during it. This indicates a notable difference between access consciousness and what can be called phenomenal consciousness. In one interesting experiment, Sperling flashed a 3 by 3, or 3 by 4 array of random letters for 50 milliseconds to participants [11]. When directly asked to report as many letters from the array as they can, most subjects were only able to report three to five of them, consistent with limitations on working memory. However, if they were given a row soon afterward and asked to report all the letters in that row, most subjects were able to do so. Sperling claimed this supported the existence of an iconic memory in addition to working memory which has a much higher capacity. Nevertheless, iconic memory only lasts very shortly and rapidly fades away. There's a similar effect existing for sounds involving echoic memory.

Working memory appears to store information in a more coarse-grained manner than phenomenal consciousness. For instance, we appear to be able to consciously distinguish over thousands of colours and shades but working memory can only distinguish eleven to seventeen different colours. Working memory is believed to consist of four things: a phonological loop, a visuospatial sketchpad, an episodic buffer and a central executive [12]. The phonological loop stores a sequence of sounds temporarily, but only for a limited time and with a limited capacity. And unless the person rehearses it, the memory in the phonological loop fades away quickly. Also, the order of the sounds is stored separately from the sounds themselves, which are believed to be stored in parallel in the brain. The visuospatial sketchpad appears to operate independently from the phonological loop. The sketchpad allows people to store the location of objects. All of the independent features of an object are stored simultaneously in the sketchpad. The capacity of the sketchpad depends upon the number of objects or sequences and not the number of features. The episodic buffer combines information from various modalities, like the phonological loop, the visuospatial sketchpad, and long-term memory. To retrieve an item from the episodic buffer, it appears that one needs to be consciously aware of it.

In this context, the brain can be described as a parallel information processor, meaning that it can process a lot of different information, all at the same time. However, not all of this information is processed equally. Some of it is selected for further processing while the rest is ignored. This process is another way to describe attention. Attention seems to be related to consciousness. Some researchers, such as Prinz, argue that consciousness and intermediate-level attention are the same thing [13]. Sensory information is processed through a hierarchy of low-level, intermediate-level and high-level systems. For vision, low-level processing is similar to a pixel map. Intermediate-level processing is vision from a particular vantage point, while high-level processing is vantage-independent. Consciousness in this interpretation is associated with the intermediate-level attention.

However, other researchers like Montemayor and Haladjian claim that these two phenomena are dissociated, meaning that they are two separate things. Single dissociation theories claim that consciousness requires attention but not vice versa [14]. Double dissociation theories claim that neither consciousness nor attention requires the other. Blindsight can be considered an example of subconscious attention without conscious awareness. Experiments have shown that if an object is flashed subliminally at a given location, the brain becomes primed for further activity at that location; that is, we have attention without consciousness. Experiments on inattentional blindness suggest that if we don't give any attention to an object, we can't be conscious of it, seemingly ruling out double dissociation. However, people are able to report the summary of a photograph unexpectedly flashed to them for 30 milliseconds, as described by Koch and Tsuchiya [15]. There appears to be too little time for top-down attention to take effect. This is opposed to bottom-up attention.

In dual-task experiments, subjects are asked to focus on one object while another object is flashed at a different location. They are able to determine if the other object contains a vehicle or a known shape like an animal, but they can't distinguish objects' further patterns like red-green vs. green-red [16]. This suggests that consciousness is present even when top-down attention is not. However, dual-task experiments don't necessarily mean that we can be conscious of more than one object at the same time. Instead, bottom-up attention might jump from one object to another in a fraction of a second or be diffused. We can either pay attention to something based on its features (bottom-up and feedforward) or based on our viewing objectives (top-down and feedback). Feature-based attention is a bottom-up process where a particular feature is chosen to select the object of attention. The pop-out effect is a type of bottom-up process where attention is automatically captured because of certain salient features. Bottom-up processing is conducted in parallel over all the sensory information. Object-based attention is when attention is drawn towards the features of a particular object. If an object is extended in space, features within the object are more likely to be detected than those outside the object.

In their dual-task experiment, Reddy and Koch gave a highly attention-demanding task to subjects at their research center; while an image was flashed at a random moment at the periphery, subjects were more likely to be able to recognize the image if it was a human face, over a coloured pattern [17]. This might be considered evidence of consciousness with limited attention, but it's possible that the human face caused a pop-out bottom-up capture of attention for a split second, while the coloured pattern did not. It's also possible that the attention was diffused. Spatial attention can be focused narrowly, like a spotlight, or diffused more broadly to take in many objects at once. On the other side of science, some mystics would say that there are meditative states where attention can be given to everything simultaneously. The above-mentioned studies suggest that there are multiple types of attention, and consciousness may only be related to some of them. It also appears that an object needs to be attended to first before it can get stored in a working memory. For example, if there are two overlapping shapes in view at the same time, but attention is only paid to one of them, only the shape that was attended to is remembered. It also seems to be much harder to pay attention when working memory is full.

Lucid dreams are investigated in sleep laboratories working with individuals who have previously experienced frequent lucid dreams and are trained in this regard. Before the individuals are sent to bed in the sleep lab, the experiment may require several hours of preparation, including fitting the 128 EEG electrodes and measuring their positions and orientations [18]. The dreamers can be asked to carry out particular tasks while dreaming as well as to make indications of starting and finishing cues of certain tasks in the dream using their eye movements within the experimental procedures adopted for observing lucid dreams. Hence, this approach ensures a practical method of capturing the relationship between conscious experience and physiologically recorded changes while asleep [19]. Electroencephalography data can then investigate if lucid REM sleep exhibits different brain activity from non-lucid REM sleep [20].

Mnemonic induction of lucid dreams (MILD) was among the first successful cognitive strategies deployed for inducing lucid dreams. Some studies indicate that occurrence of lucid dreams can be effectively increased by the MILD [21]. A number of recent studies have also investigated non-invasive brain stimulation techniques to generate lucid dreams. One investigation looked at whether frontal cortex-targeted transcranial direct current stimulation (tDCS) would enhance lucid dreaming, but the experiments need further confirmation [22]. In addition to that, consistent meditation practice was suggested to support and be supplemental to lucid dreaming techniques [23]. No mechanism has yet been discovered to reliably and securely produce lucid dreams on demand for everyone and on every desired night, in spite of multiple attempts from various research fields as diverse as psychology, electrical engineering, or even pharmacology, where certain natural substances or drugs like galantamine are proposed to potentially correlate with induction and frequency of dream lucidity [2].

During the actual sleeping sessions, sleeping participants do not hold the equipment on their body in stillness, but they naturally move around a lot, move their hands, press them into the pillow, pull cords, and alike. In contrast to daytime EEG research, where the subject typically remains immobile in front of a computer screen, this poses technical challenges and errors and often involves the need to repeat sessions. As a result, lucid dreaming researchers typically have to stay awake throughout the night to monitor the recording quality continually and to take action in case of poor signal transmission [2].

As soon as lucid dreamers become aware of their dreaming state, or become conscious within their dream, the methodologically suggested procedure is to instruct them ahead of falling asleep, to use pre-agreed signals and move their eyes in a predetermined left-right-up-and-down or left-right-left-right (LRLR) pattern. The LRLR eye signal is to formally confirm that the individual has just started a lucid dream. The signaling of eye movements can be then seen on the electrooculogram, being a clear mark differentiating from normal REM sleep eye movements [24]. Numerous experiments have confirmed these protocols as effective, allowing for precise timing and objective measures of dream lucidity [10]. Lucid dreamers are awakened or wake up on their own after a predetermined period of time (or after indications that the subject lost dream lucidity). Just after waking up, they are given a report to fill out the details about their dream to avoid overlooking and forgetting important elements. Before the individual falls back to sleep for another try at lucid dreaming, questionnaires on levels of lucidity are filled out as well, along with other specific questions about the experiments carried out within the lucid dream itself [2]. Recordings finish when the subject says they can't sleep anymore in the morning, and depending on the experiment, it typically takes another hour or two to let the person complete more questionnaires, disinfect EEG caps and other equipment. The entire experimental process of recording one night, including setup and follow-up forms, could take from 8 pm until 11 am the following day to collect all the relevant data.

Some studies were conducted on possible EEG spectrum alterations in sleep subjects, investigating alpha-band (8-12 Hz) in one EEG channel by comparing periods of lucid REM sleep with non-lucid REM cycle [25]. Unfortunately, the phases of two highest and lowest alpha signals were waking up the dreamers so the results were inconclusive. Higher alpha activity was reportedly seen in several of the early EEG investigations during lucid REM sleep, but these findings were not sustained in subsequent studies [26]. Other investigations reported increased beta-1 activity (13-19 Hz) over parietal regions or reduced delta activity over frontocentral parts during lucid REM sleep, yet these findings have not been validated by other studies involving more participants [27]. It was also suggested that frontolateral scalp areas' gamma-band (40 Hz) EEG power was elevated during lucid REM sleep, as well as the cortical region [28]. Recent neuroimaging studies have also connected parietal brain regions activity to the phenomenon of lucidity [29]. A number of other cognitive processes connected to lucid dreaming, such as self-reflection, episodic memory, and agency, have also been linked to this region, which provides a number of additional possible interpretations of such findings [30].

As per the discoveries of another study, 35 lucid dreams were observed and only 3 lucid dreams occurred between NREM Stage I phase and NREM Stage II; whereas other 32 instances were observed during REM sleep phase [31]. This suggests that lucid dreaming typically, but not always, occurs during REM sleep. The results of studies conducted in numerous other laboratories add credibility to this hypothesis [32]. According to LaBerge, one of the pioneers in this area of research, he generally becomes lucid between early morning hours, approximately 5 a.m. – 8 a.m. LaBerge analysed 212 of his lucid dreams' times and discovered that their frequency pattern closely matched the typical cyclic distribution of REM episodes [33]. NREM dreams are frequently reported to be more contemplative, less emotive, or aesthetically vivid. This does not indicate that becoming lucid in NREM sleep is not possible. Occurrence of lucid dreams in the last, deepest stage 3 of NREM has not been reported to date [22].

Conclusion

Initially, the community of researchers had some degree of scientific mistrust towards lucid dreaming. Due to their rarity, lucid dreams are challenging to investigate, yet patients can be trained to induce them and experience them on a regular basis. Dream lucidity, becoming conscious of dreaming while dreaming, might be therapeutically beneficial in various biological and psychological applications, including as a therapy for nightmares or narcolepsy. Diagnostic indications of emerging self-awareness based on more accurate neuroimaging protocols could also be therapeutically applicable to conditions like anaesthesia awareness and locked-in syndrome. Clinical applications already in use include employing conscious dreams as a potential solution for continuous, traumatizing and debilitating nightmares, including those of children. Employing lucid dreams effectively to alleviate nightmares is currently studied and tested. Waking up one's awareness amidst a nightmare might provide the dreamer needed help to realize the nightmare is not real, and maybe even to take control of the dream itself after sufficient training at doing so, which may lead to easing the tension and fear. Narcolepsy patients are reported to have longer, more intricate, and vivid dreams as well as higher frequency of nightmares than healthy people.

Furthermore, narcoleptic patients seem to have a higher frequency of lucid dreams for reasons that are not yet identified. Thus, the potential benefits of gaining self-awareness during traumatic, recurring nightmares could be investigated for its therapeutic usage to ease suffering of narcoleptic patients as well. Other clinical applications of neuroscience of lucid dreaming that could be further tested and implemented is for post-traumatic stress disorder (PTSD), and even in schizophrenia lucid dreaming could be proposed as an experimental therapeutic method of approach. The treatment of phobias through exposure and desensitization therapy, similar to virtual reality exposure therapy, is another potential clinical use for lucid dreaming training. On the other hand, some lucid dreamers claim that they have effectively deployed their lucid dreams in non-clinical settings as well, to improve their real-life results or help with problem-solving and creative thinking. Conducting further studies with more subjects involved will be important for statistical procedures to enable between-subject comparisons and vital for investigating the effectiveness of various clinical and non-clinical applications. Lastly, diagnostic indications of emerging self-awareness based on more accurate neuroimaging protocols derived from dream lucidity studies could also be therapeutically applicable to conditions like anaesthesia awareness and locked-in syndrome.

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Conflicts of Interest

None.

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