The Involvement of the Prefrontal Cortex in Lucid Dreaming: A Review

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Introduction

Many studies have examined lucid dreaming and the role that the brain plays in this phenomenon. There have been many discoveries about the similarities and differences between lucid dreaming and regular REM sleep, including areas in the brain that are activated in one versus the other. This review will be using some major findings regarding lucid dreaming and the areas of the brain that are affected by it to draw conclusions that tie together the similarities and contradictions between the studies. This goal of this review is to give an in-depth analysis of the localities of the brain that are involved with lucid dreaming and what this means for future research.

The first study being examined is from Tadas Stumbrys, Daniel Erlacher, and Michael Schredl at the Institute of Sports and Sports Sciences, Heidelberg University, in Germany. They conducted their study by testing the involvement of the prefrontal cortex in lucid dreaming. It was published on March 12, 2013 in *Consciousness and Cognition*. In the article, Stumbrys, Erlacher, & Schredl (2013) start off by introducing the topic of lucid dreaming by defining it as a special kind of dreaming where the person is aware of being in a dream and can even control the dream often times. They go on to explain that during REM sleep, the dorsolateral prefrontal cortex (DLPFC) becomes deactivated, which may play a role in lucid dreaming.

In the article, the authors bring up past research related to their topic of lucid dreaming. Hobson (2009) showed that lucid dreaming is related to consciousness. Laberge (1990) stated that lucid dreaming mainly occurs during REM sleep. Hobson, Pace-Schott, & Stickgold (2000) concluded that thought and awareness is made possible during lucid dreaming by the DLPFC being activated during REM sleep, where it would usually be deactivated. A shift in EEG power in the frontal brain regions during lucid dreaming was discovered in a study (Voss, Holzmann, Tuin & Hobson, 2009). Another study used fMRI to observe cerebral regional activation occurring during lucid dreaming and found that many regions of the brain activate during this phenomenon, including the prefrontal cortex (Dresler et al., 2012).

The authors of this study explain that in order to stimulate frontocortical areas of the brain while participants are sleeping, transcranial direct current stimulation (tDCS) must be used because it does not wake the participants. The authors of this article want to manipulate the activation of the prefrontal cortex in order to make causal claims about the relationship between this brain area and lucid dreaming, which is what this paper will be examining. The previous research that was cited only produced correlational data, so the authors of this study wanted to perform some experimentation to produce causal data. The hypothesis for this study is such that when the DLPFC is activated by anodal tDCS by modulating cortical excitability, there should be an increase in dream lucidity in the participants.

A different study, conducted at Max Planck Institute of Psychiatry and published in *Sleep*, completed by Dresler, et al. (2012) had had a similar point of interest as Stumbrys, Erlacher, & Schredl (2013). The goal was to observe the brains of lucid dreamers while they sleep to examine the activated brain areas during lucid REM sleep compared with non-lucid REM sleep. The authors introduce their topic by referencing Maquet et al. (1996) who concluded that the reason people do not have full cognitive ability, such as awareness of being within a dream, during dreaming is the deactivation of the dorsolateral prefrontal cortex. They also discussed a major difference between non-lucid and lucid dreaming, which is that brains during lucid dreaming show signs of waking and dreaming (Voss, Holzmann, Tuin & Hobson, 2009). Using this previous research, the authors highlighted their interest in providing functional imaging of brains during lucid dreaming to observe what areas are being activated. They did not specify a hypothesis, but just stated that they aimed to contrast brain activity during non-lucid and lucid REM sleep.

Related to the above study, Neider, et al. (2010) conducted a study at Briarcliff High School in New York that was published in *Consciousness and Cognition* on January 19, 2010. This study also focused on the brains of lucid dreamers as the above two studies, and sought to examine whether lucid dreamers had better ventromedial or dorsolateral prefrontal task performance or if there was no difference from non-lucid dreamers. In the article, the authors start off by stating that dreaming is a special case of consciousness that is similar in some ways to waking consciousness. They explain that the main difference between dreaming and waking consciousness is the awareness that comes from being awake. This is where they introduce the concept of lucid dreaming, which they define as the awareness of being within a dream. The authors express their desire to provide the first neuroimaging data that shows brain activity during lucid dreaming.

Neider et al. (2010) included past research to come to the assumption that the frontal cortex, specifically the frontolateral and ventromedial prefrontal regions, is more activated during lucid dreaming than normal REM sleep. They cited Braun et al. (1998) for discovering that frontolateral regions were found in PET studies to be deactivated during all stages of the sleep cycle. Pace-Schott (2005) is referenced for finding that this deactivation of the frontolateral regions can cause a lack of lucidity in dreams because one cannot compare experiences within the dream. The authors use this research to predict that the frontolateral region of the brain could be more activated during lucid dreaming because one is able to compare experiences within the dream. The authors use a study by Nofzinger, Mintun, Wiseman, Kupfer, & Moore (1997) to explain that the ventromedial prefrontal region reactivates during REM sleep and can even become more active than during waking. They use this article to support their prediction that the ventromedial prefrontal region becomes even more activated during lucid dreaming than REM sleep.

This study sought to find out if individuals that more often experience lucid dreaming differed in the use of their frontolateral and ventromedial prefrontal regions with individuals that do not often have lucid dreams. They hypothesized that lucid dreamers would show better performance on cognitive tasks that require the use of the frontolateral and ventromedial prefrontal regions of the brain, which would imply that these regions of the brain are involved with meta-awareness and consciousness.

Corlett et al. (2014) conducted a study that built off the findings of Neider et al. (2010) at Yale University and was published in *Cognitive Neuropsychiatry* on June 4, 2014. The purpose of this study was to examine the relationship between dream awareness and reality monitoring errors. The authors were interested in whether high dream awareness would cause those people to have trouble discerning reality from fantasy while they were awake, which could give some implications about certain locations in the brain lucid dreaming affects.

They used prior research that concluded that prediction error signaling is signaled by dopamine neurons in the orbitofrontal cortex (OFC) and striatum (Schultz & Dickinson, 2000). Schnider (2001) claimed that since the OFC and striatum is involved in prediction error signaling, the disconnection of the two can cause spontaneous confabulation. The authors cited Neider et al. (2010) for finding that those that experience lucid dreams more often performed better on a cognitive task that activates the OFC. Using these research findings, Corlett et al. (2014) hypothesized that more dream awareness would be associated with more reality monitoring errors.

Methods and Materials

The study by Stumbrys, Erlacher, & Schredl (2013) was sponsored by the BIAL Foundation, Portugal. Psychology students and known lucid dreamers were emailed for recruitment, 23 of whom responded and participated. The study called for participants who had average dream recall, slept well, had no health problems, and higher frequency of lucid dreaming. Nineteen of the twenty-three participants completed the study.

Participants slept three nights in the laboratory consecutively. Before the first night's sleep, the participants reported their lucid dream frequency. The first night was to gauge if the participants had any sleep disorders or were too sensitive to the tDCS stimulation. Three participants were removed from the study during the first night because of sensitivity to tDCS. During the second and third nights, each participant received tDCS stimulation one night and sham stimulation the other night, which was randomly determined. If the participants experienced lucid dreaming, they were instructed to move their eyes left and right repeatedly. When they awoke, they were asked to describe the dream in detail. Stimulation was delivered during REM sleep, and two minutes after the stimulation ended the participants were woken up by an intercom to describe the dream.

Dresler et al. (2012) did not have a sponsor for their study. The researchers recruited four participants, all male aged 27, 29, 31, and 32 years, that reported that they had lucid dreams more than once a week.

The participants slept in an MRI scanner for 2 to 6 nights depending on their availability. When they achieved dream lucidity, they were instructed to move their eyes back and forth and clench their hand. This helped the researchers to identify when the lucid dreaming occurred in the participants. If the participants did not signal for 40 seconds after their last signal, they were awoken and asked questions to confirm the lucidity of the dream. fMRI and EEG data was collected early in the morning because this is when REM sleep is the most expected.

The study conducted by Neider et al. (2010) was sponsored by the National Center for Research Resources. The study included twenty-eight high school students aged fourteen to eighteen. The participants were required to have kept a regular bedtime for the month before being selected for the study and were excluded if they had smoked cigarettes recently or were taking medication that could affect sleep or cognition.

The authors used the Pittsburg Sleep Quality Index to measure the quantity and quality of the participants' sleep over the past month. They used the Baseline Lucidity Assessment to measure lucidity and control of dreams. The IOWA Gambling Task (IGT) was used to activate the ventromedial prefrontal cortex and assess the cognitive performance of this brain region. This task requires the participants to virtually select cards to gain money from either decks that amount to an overall net loss or decks that amount to an overall net gain. The more cards selected from the net gain decks in comparison to the net loss decks results in better performance on the task. The Wisconsin Card Sort Task (WCST) activates the frontolateral regions and assesses its performance. In this task, participants were to virtually sort cards by different factors, but were not told which factors to sort by. The sorting factor is changed once the participants complete it, requiring them to figure out the new factor. The number of trials reflects the performance on this task. For 7 days participants were instructed to complete activities that promote dream lucidity, and they completed the Morning Lucidity Assessment (MLA) each morning for the 7 days.

In the study conducted by Corlett et al. (2014) there were 57 participants (22 males and 35 females). This study was sponsored by the Mind Science Foundation.

They used the BLA over the phone to assess the participants dream awareness levels. Based on their score on this scale, the participants would be separated into two groups of high dream awareness and low dream awareness. The authors then used a memory selection task that measured the participants' ability to determine if a picture quickly shown on a computer screen relates to the current reality or not. The researchers were interested in analyzing two types of errors, which are described as the participants identifying a picture from a previous trial as one from the current trial or the participants claiming that pictures that had been seen before in that trial were new.

Results

In the study done by Stumbrys, Erlacher, & Schredl (2013), the median reported value for dream recall was "several times a week" and lucid dreaming was reported to occur "about once a month." Because participants woke frequently during tDCS stimulation, there were fewer intercom awakenings in the tDCS condition. Only one participant reported a lucid dream during REM sleep by moving her eyes left and right. In the tDCS condition, dreams were reported to be significantly longer than those in the sham condition, and dreams were rated to be more lucid in the tDCS condition as well. There were no significant differences found in self-reported emotional tone of the dreams or metacognitive activities within the dreams. There was no association between self-reported lucidity and dream report length, awakening clock time, or time since sleep onset. There was, however, an association found between longer dream reports and more externally-focused metacognition. Dreams from the tDCS nights were found to be more lucid and more bizarre. Post-hoc tests showed that participants in the tDCS condition were more aware of objects and people in their dreams being fictional as well as their bodies being asleep.

Of the four subjects in the study by Dresler et al. (2012), two showed signs of REM sleep when the fMRI and EEG data was collected, and one had two long and stable lucid dreams. fMRI analysis of these two instances of lucid dreaming showed significant activity contrasting with non-lucid REM sleep. Many areas of the brain showed activation including the bilateral precuneus, bilateral inferior and superior parietal lobules, left frontopolar cortex, and dorsolateral prefrontal cortex.

Neider et al. (2010) had conflicting results showing that there was no statistical difference between high and low lucidity groups (measured by the MLA) in the WCST, which was used to assess the cognitive performance of the frontolateral region of the brain. There was, however, a statistical significance between high and low lucidity groups in the IGT, which assessed cognitive performance of the ventromedial prefrontal cortex. Specifically, the high lucidity group performed better in the IGT than the low lucidity group.

Corlett et al. (2014) found that there was no significant difference between the groups defined as false alarm rate and miss rate with those high or low in dream awareness. There was a difference found in the response criteria. Those in the high dream awareness group were more likely to accept that a picture was familiar even if it was not.

Conclusion

Stumbrys, Erlacher, & Schredl (2013) found that the tDCS stimulation of the DLPFC during REM sleep did in fact have an effect on the participants' dreaming experience. Their hypothesis was confirmed in that there was an increase in dream lucidity according to self-rating of the participants in the tDCS condition. The authors also explain that the results were not very strong and were shown to happen only in frequent lucid dreamers. Stumbrys, Erlacher, & Schredl (2013) came to the conclusion that in order to induce lucidity in dreams, stimulation of a wider variety of brain areas may be necessary. Previous studies have shown an increase in lucid dreams in other areas of the brain, not only the prefrontal cortex (Dresler et al. 2012). Dresler et al. (2012) provided functional imaging that confirmed the reactivation of the dorsolateral prefrontal cortex, as well as many other brain regions. This study only analyzed one participant because he was the only to have long and stable lucid dreams, which is a concern because of such a small sample size. The results, however, still support the results of Stumbrys, Erlacher, & Schredl (2013), and help to verify the role of the prefrontal cortex in lucid dreaming. Neider et al. (2010) found that lucid dreamers showed better performance on tasks that activated the prefrontal cortex, but not specifically the dorsolateral prefrontal cortex. Instead the researchers observed better performance in the IGT, which assessed the ventromedial prefrontal cortex. This does not disprove the involvement of the dorsolateral prefrontal cortex since this study only reflected behavioral measures, but it does point to the possibility of select people having more of an inclination toward lucid dreaming. This study showed that lucid dreamers can be better at performance of a specific part of their brain, so they either have further developed their brain through lucid dreaming or have naturally more developed areas of their brain that give them a stronger ability to achieve dream lucidity.

One could argue that the results of the study by Corlett et al. (2014), showing that participants high in dream awareness made more errors of false familiarity of new items than those low in dream awareness, contradict the results of the other studies discussed here. One might say that since those high in dream awareness made more confabulatory errors, they could not be said to have more development in the frontal cortex, involved with decision-making. This argument can be contested with the possibility of the orbitofrontal cortex being more active in lucid dreamers, which causes those participants to believe that the item they saw was new and confuse their reality. The over stimulation of the orbitofrontal cortex could actually be inhibiting the performance of the participants. Lucid dreamers can safely be assumed to be activating their prefrontal cortex during lucid dreaming, as well as many other regions of the brain.

Stumbrys, Erlacher, & Schredl (2013) reasoned that the tDCS application might have increased arousal in the participants, which in turn resulted in more dream lucidity. This would mean that it was not only the prefrontal cortical stimulation that caused the results, but a confounding factor. The stimulation level of the prefrontal cortex was also brought up, for the authors considered that there may be more stimulation of this cortical area needed to reach a threshold where dream lucidity occurs.

These studies are a precursor for future studies examining the areas of the brain causally related to lucid dreaming. They introduce and provide some evidence that supports the idea that the prefrontal cortex is activated during lucid dreaming, and experienced lucid dreamers show signs of having more engaged and better performing areas of the prefrontal cortex even during waking. Training in lucid dreaming may be a way to train certain areas of the prefrontal cortex resulting in better performance on tasks requiring the engagement of those areas. More engagement of the orbitofrontal cortex, however, may be connected with reality monitoring errors. Future studies could examine if lucid dreamers on a wider scale have trouble with reality monitoring and what areas of the brain are associated with those errors.

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