Transcranial cortex stimulation as a novel approach for probing the neurobiology of dreams: Clinical and neuroethical implications

Commentary on "The neurobiology of consciousness: Lucid dreaming wakes up" by J. Allan Hobson

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Summary. In the last two decades considerable progress in brain imaging techniques have led to increasing interest into the neurobiology of sleep stages and dream contents. However, this fascinating research field poses several methodological challenges. The aim of this article is to discuss these challenges and to suggest novel approaches for probing the neurobiology of dream contents. Most of all, I suggest (i) to overcome the correlative limitations of neuroimaging techniques by applying transcranial direct current stimulation (tDCS) during different sleep stages in order to provide causal evidence for the role of specific brain regions in different dream contents, (ii) to control for possible perceptual and cognitive biases in dream reports such as hindsight bias, (iii) to combine computer assisted qualitative data analyses of dream reports with quantitative psychometric scales by applying logistic regression analyses and (iv) to consider possible implications for psychotherapy and neuroethics.

keywords: Lucid dreaming, dream content, consciousness, transcranial direct current stimulation (tDCS), qualitative and quantitative data analyses, psychotherapy, neuroethics

1. Introduction

Although in classical psychoanalyses according to Freud (1900) dream analyses had a pivotal role in psychotherapeutic treatment, in contemporary behavioral therapy dream reports have – if at all – only a minor role. A main reason for the lack of attention to dream reports in current cognitive-behavioral interventions is that in the Freudian approach psychometric measures of reliability and validity of the supposed dream interpretations are missing. Some authors even argue that psychoanalyses in general and particularly Freudian dream interpretations are rather "unscientific" (for a review: Birbaumer, 2002; Fischer & Greenberg, 1996; Amelang & Bartussek, 2001).

However, in the last two decades remarkable progress in brain imaging techniques such as positron emission tomography (PET) and functional magnetic resonance imaging (fMRI) have led to increasing interest into the neurobiology of sleep stages and dream reports (Muzur et al., 2002; Maquet et al., 2005). Moreover, the relevance of dream reports (and their neural correlates) for psychotherapy is being currently readdressed (cf. Hobson, 2009; Schwarz & Maquet, 2002). Dream reports may include fascinating phenomena, which sometimes resemble neuropsychiatric conditions, such as distortion of time perception, perceived distortion of body parts, bizarre illogical situations, prominence of negative emotions, anxiety and fear, and misidentification syndromes such as the Frégoli syndrome (an unknown person's face is erroneously recognized as a familiar person despite the lack of any obvious physical resemblance). It has been suggested that these phenomena result from hyper- or hypoactivity of specific neural networks (for a review see Schwartz & Maquet, 2002). For example the Frégoli syndrome has been shown to result from temporal and frontal lesions (Forstl et al., 1991; Young et al., 1990; Schwarz & Maquet, 2002). Predominance of fear has been related to hyperactivity of the Amygdala (Maquet et al., 1996) and illogical bizarre thinking has been related to prefrontal deactivation during REM sleep (Muzur et al., 2002; Hobson, 2002). Interestingly, reciprocal inhibition between frontal and limbic areas has been hypothesized to be involved in the etiology of depression and schizophrenia (Kahn & Hobson, 2005). Thus, REM-sleep dreaming might be a normal physiological state of the brain that is analogous to psychopathological conditions in which limbic hyperactivation is combined with frontal hypoactivation (Schwarz & Maquet, 2002). Recent neuroimaging studies have indeed demonstrated that in sleep there are brain regions that become selectively deactivated compared to waking such as the dorsolateral prefrontal cortex (DLPFC) and the precuneus, whereas other brain regions

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become more activated such as the limbic and paralimbic systems (Braun et al., 1997; Maquet et al., 1996; 2000).

In a recent highly interesting article Hobson (2009) pointed out the relevance of so called lucid dreaming to the study of consciousness. Lucid dreaming has been defined as a rare but robust awareness that we are dreaming and that we are not really awake. Lucid dreamers even often claim, that they can gain control over the course of the dream. Lucid dreamers can then "decide" to fly, make love to whom ever they please or conduct any other preferable behaviour. Kahn and Hobson (2005) have proposed that during the lucid state the previously deactivated DLPFC becomes reactivated. This reactivation would allow directed thought, metacognition and awareness of being in a dream. Preliminary empirical evidence for this hypothesis has been obtained from a very recent study by Voss et al. (2009) in which student volunteers had been trained by pre-sleep autosuggestion to become lucid. Their findings indicate that when subjects become lucid, they shift their EEG power, especially in the 40-Hz range and especially in frontal brain regions. Moreover, in lucid dreaming also EEG coherence is largest in frontolateral and frontal areas. In an other study, which has used fMRI to study brain regional activation in lucid dreams, it has been shown that in lucid dreams not only frontal but also temporal and occipital regions show higher activation compared to non-lucid dreams (s. Wehrle et al., 2005; 2007).

Although these findings and hypotheses concerning the neurobiology of dreams are intriguing, this fascinating research field poses several methodological challenges. In the following I would like to discuss some of these challenges and suggest novel approaches for probing the neurobiology of dream contents.

2. The subjective nature of dream reports and the challenge of cognitive-perceptual biases

In classical psychophysics the perception of visual, auditory or tactile stimuli can be investigated by manipulating the physical properties of the stimuli and assessing the corresponding change in subjective perception (cf. Green & Swets, 1966). Several studies based on signal detection theory have shown that some subjects might perceive physically identical stimuli as different and other subjects might perceive physically different stimuli (e.g., two tones with different volumes or frequencies) as identical. Moreover, based on the assigned pay-of-matrix[1] subjects will adopt involuntarily more liberal or conservative criteria to judge if they perceived something or not, and if they perceived difference between two stimuli or not (for a review see Gardner, 1997; Green & Swets, 1966).

Concerning dream reports, at least currently, we can only rely on the subjective perception of the dream and do not have any independent validation of what the subject "really" experienced. However, possible biases in reporting subjective experiences could be systematically assessed.

First of all, when asking about specific dream contents, the experimenter should avoid any remarks or non-verbal signals which might have a rewarding effect on the subject (e.g., when a subject reports that he or she could control the course of dream, the experimenter reacts in an enthusiastic way). Studies on signal-detection theory have shown that such a selective feedback can involuntarily bias the subject's report (s. Green & Swets, 1966). Thus, whatever the subject reports, the reaction of the experimenter should be in a standardized manner. Another interesting and well-documented cognitive bias is the so called hindsight bias effect. Here is a typical example for this effect:

A subject is asked before an election to forecast the probability of a party X to win the elections. The subject says for example 30%. After the elections the subject is told that the party has actually received 50% of the votes. Now the subject is asked to recall the forecast he/she gave before the elections. Although the subject actually forecasted 30%, the subject is convinced that he/she said 40%. This difference to the original forecast is called hindsight bias. In his pioneering article, Fischhoff (1975) has shown that hindsight knowledge influences the recall of predictions unconsciously, and that hindsight judges cannot accurately recall their foresight state-of-mind (see also Agans & Shaffer, 1994; Hoffrage & Pohl, 2003). Concerning dream reports the effect of hindsight bias might even be stronger in sleeping subjects than in awake subjects. A lucid dreamer could for instance claim that a specific dream experience has occurred exactly as he/she forecasted it before it had happened. However, such claims could be merely due to the hindsight bias effect. Thus, in future studies it would be interesting to investigate the effect of sleep on hindsight bias. Voss et al. (2009) have shown that it is possible to train volunteers to become lucid and to signal lucidity through a pattern of horizontal eye movements. If this method is reliable then lucid dreamers could be asked to forecast through a specific number of eye movements how many times a specific action will take place (e.g. kicking a ball) and then compare the dream report with the original forecast.

3. Therapeutic relevance of dream reports

Several studies have also shown that psychological features such as self-efficacy expectation[2] according to Bandura (1977) or learned helplessness according to Seligman (Seligman et al., 1968; 1984) can induce perceptual and cognitive biases in everyday life. It is plausible to assume that such psychological features will also have an effect on the sleeping mind and might result in specific dream reports with a rather high or low magnitude of self-efficacy expectations within the dream. Deficits in self-efficacy and depression might also result in a lack of control over the course of dream experiences. Therefore, from a therapeutic point of view, I argue to investigate the impact of psychological features, measured by standardized psychometric scales, on dream content. By means of modern computer-assisted qualitative data analyses (such as MAXQDA, Kuckartz, 2001) specific categories of dream experiences could be derived from the dream reports. Afterwards, based on a logistic regression analyses these categories could be treated as dichotomous outcome variables and the psychometric scales and other relevant variables (such as age, education or gender) can be treated as predictor variables. Such a regression analyses could reveal the relative impact of psychological features on dream content. It would be most interesting to investigate, if in the course of cognitive-behavioral interventions not only perception, cognition and behavior change in awake patients but also in the dreaming mind.

Moreover, it is plausible to assume that between the awake and the dreaming mind there is a reciprocal relationship, meaning that not only cognition and self-perception in the awake mind has an effect on the dreaming mind, but also that the dreaming mind has an impact on the awake mind. In this sense, if it is possible to directly change dream experience and dream cognition, this could have therapeutic effect on the awake patient. Hobson and colleagues (Hobson, 2009; Voss et al., 2009) have argued that pre-sleep autosuggestion might affect dream cognition. Here, I suggest a further novel approach, namely the direct modulation of specific brain regions in REM-sleep by transcranial direct current stimulation (tDCS). This method will be discussed in the following section.

4. Neuroimaging studies only allow correlative statements

A general problem in neuroimaging methods such as EEG, MEG, PET, fMRI and NIRS is that they only allow correlative statements about the brain regions involved in a specific behavior (here dream cognition and perception). Causal relevance can be obtained in humans either based on patients with brain lesions or based on methods allowing a transient modulation of cortical activity such as transcranial direct stimulation (tDCS) (for a discussion of other cortical stimulation techniques see the commentary of Noreika et al. in this issue). Several studies have demonstrated that cerebral excitability was diminished by cathodal stimulation, which hyperpolarizes neurons, whereas anodal stimulation resulted in increased cortical excitability (Bindmann et al., 1964; Creutzfeldt et al., 1962; Gartside, 1968). These tDCS induced effects have been observed in several cortical regions such as the motor (Nitsche & Paulus, 2000), visual (Antal et al., 2001), somatosensory (Rogalewski et al., 2004) and the prefrontal cortex (Karim et al., 2006; 2010). In 2004, Marshal and colleagues demonstrated for the first time that tDCS can be reliably applied during sleep without waking up the subjects. Moreover, they found that repeated application of anodal tDCS over frontocortical areas during slow wave sleep (SWS) improved declarative memory consolidation.

In order to go beyond the limited investigation of the neural correlates of dreaming, I suggest applying tDCS for probing the neurobiology of dream contents. TDCS induced modulation of cortical excitability in different sleep stages could test widely assumed, but to date unverified, hypotheses concerning the function of specific brain regions in sleep and dreaming. For instance, concerning the prefrontal hypotheses of lucid dreaming, anodal tDCS could be applied during REM-sleep to activate the DLPFC and test if this external modulation of cortical excitability increases lucid dreams. Conversely, inhibiting the DLPFC during REM-sleep should prevent or at least lead to a significant decrease of the lucid state in trained lucid dreamers. Such findings would give for the first time causal support to recent correlative data obtained by neuroimaging studies indicating a predominant role of the DLPFC in lucid dreaming. Moreover, the variation of stimulation polarity and induction of opposite effects would show if activation of the DLPFC in REM-sleep is a necessary and sufficient condition for lucid dreaming. If, for example, inhibition of the DLPFC in REM-sleep would impede lucid dreams in trained volunteers, but activation of the DLPFC would *not* induce lucid dreams then this would indicate that activation of the DLPFC is a *necessary but not a sufficient condition* for lucid dreams. However, if inhibition of the DLPFC would impede lucid dreams, and activation of the DLPFC would facilitate lucid dreams, then this finding would indicate that activation of the DLPFC is a *necessary and a sufficient condition* for lucid dreams. The same rational could also be applied to other neurobiological assumptions of dream contents, such as the Frégoli syndrome and other phenomena in dream reports which resemble neuropsychiatric symptoms.

5. Neuroethical implications

The possibility to alter dream content and dream cognition by transcranial DC stimulation of specific cortical regions may help us to understand the neurobiology of dream contents and provide new perspectives for psychotherapeutic interventions, such as increasing self-efficacy and perceived control over the course of the dream or reducing anxiety and bizarre phenomenon which might occur during nightmares.

However, tDCS induced modulation of dream contents would also entail several neuroethical considerations. Concerning the current debate on emerging ethical issues in neuroscience (cf. Farah, 2002), interdisciplinary research and communication are needed to address the following question: If neuroscientific research can demonstrate that dream content and dream cognition are not only associated with the activation of specific brain areas, but may even be modulated by non-invasive stimulation of these areas, what implications will such findings have on our concept of autonomy and personal authenticity? Moreover, under which conditions should it be allowed or forbidden to modulate dream content and dream cognition by brain stimulation techniques, especially if applied outside a medical-therapeutic context?

6. Epilogue and Acknowledgments

In October 2006 the Volkswagen Foundation has invited around 50 young researchers from around Europe to launch the 1. European Platform for Mind Sciences, Life Sciences and the Humanities. At this event I met several distinguished colleagues among them Valdas Noreika from the sleep laboratory at the Centre of Cognitive Neuroscience in Turku, Finland and Jennifer Windt from the Department of Philosophy at the University of Mainz, Germany who are interested in studying the neurobiology of dream contents. There I suggested for the first time to investigate the causal relevance of the assumed cortical regions in dream contents by applying transcranial direct current stimulation (tDCS) in REM-sleep. We then wrote a research grant which was later joined by the following colleagues: Nicolas Langlitz, Bigna Lenggenhager, Tonio Ball and Isabella Mutschler. This research grant has been funded by the Volkswagen Foundation and preliminary results were presented at the VW-Symposium in Osnabrück, Germany (Noreika et al., 2009). Our results will be published soon as a journal article. I would like to thank my colleagues for participating in this fascinating research field. Moreover, I gratefully thank for funding: the Volkswagen Foundation and Fundaco BIAL.

Notes

[1] In perceptual experiments volunteers can be assigned to different pay-of-matrices, e.g., by rewarding a volunteer for detecting a signal or for detecting difference between two stimuli. However, for a false alarm the volunteer will not be punished. In such a case the volunteer will adopt relatively liberal criteria for detection. Conversely, a volunteer could be punished for a false alarm but is not rewarded for detecting a signal or detecting difference between two stimuli. In such a case the volunteer will adopt rather conservative

criteria for detection.

[2] Self-efficacy has been described as the belief that one has the capabilities to execute the courses of actions required to manage prospective situations. The facilitation of self-efficacy plays a crucial role in cognitive behavior therapy of several psychological disorders such as depression or anxious avoidant personality disorders.

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