Manipulating Dream Experience

Subjects: Physiology

Contributor: Serena Scarpelli , Valentina Alfonsi , Maurizio Gorgoni , Anna Maria Giannini , Luigi De Gennaro

Dreaming, or sleep mentation, is an intriguing experience occurring during any human sleep stages. It can happen many times per night and is characterized by different degrees of emotional intensity, bizarreness, visual vividness, and narrative complexity. Mental activity during sleep and wakefulness shared similar neural bases. On the other side, recent studies have highlighted that dream experience is promoted by significant brain activation, characterized by reduced low frequencies and increased rapid frequencies. Additionally, several studies confirmed that the posterior parietal area and prefrontal cortex are responsible for dream experience.

dream recall   sleep   EEG   neuroimaging   brain stimulation

1. Sensory Stimulation and Dreaming

Thus far, the researchers have looked at the available studies that made an effort in order to understand the neural correlates of sleep mentation. However, it should be mentioned that, in parallel, multiple older investigations were aimed to directly influence the ongoing dream scenario by using different kind of stimulations, i.e., visual, auditory, somatosensory or olfactory cues.

The first attempt to manipulate dreaming with pre-sleeping external stimuli was reported by Dement and Wolpert [1]. The authors deprived subjects of fluids one day prior to sleeping and obtained 5 out of 15 REM dreams, including thirst-related content. Goodenough et al. [2] used stressful films during a pre-sleep period, demonstrating that visual stimulus can increase dreams characterized by negative emotional tone. Moreover, subjects exposed to visual inverting prisms recalled more vivid dreams [3].

Visual stimuli were also applied during sleep. Rechtschaffen and Foulkes [4] presented some images during REM Sleep, while subjects' eyes were taped open. Nevertheless, no incorporation was found.

Concerning auditory stimuli, Berger [5] found that presenting personally significant names during REM sleep provoked a high rate of indirect incorporation of these stimuli into dream experience. For instance, the names were modified for assonance or in an associative manner [5]. Similarly, Hoelscher et al. [6] revealed that words with a relevant personal meaning were more frequently incorporated than other words.

Visual and auditory modalities were combined in a study that applied stimulation both during REM and stage 2 NREM sleep [7]. Interestingly, the effect was found only when the stimulation occurring in NREM sleep, after which people reported dream with more visual contents [7]. Although the authors suggested that REM sleep was not very

sensitive to visual stimuli, some researchers investigated lucid dreaming, positing that visual stimuli could be incorporated into the dream experience [8]. Indeed, a study in which participants were requested to wear a LED light-fitted mask detecting rapid eye movements and sending visual stimuli showed that sleeping subjects realized that they were currently in REM sleep stage, increasing the possibility of producing lucid dreams. Participants frequently reported a dream scenario characterized by illuminated environments or containing street lamps [8].

It should be noted that researchers also shaped dreaming by introducing specific bodily stimulus during sleep. For instance, a spray of water on the subjects' skin was applied [1], as well as a thermal stimulation [9][10]. Specifically, Dement and Wolpert by using various external stimuli (i.e., 1000-cps tone stimulus, light flashes, water spray and arousing bell) did not show remarkable effects in modifying the dream content, nevertheless cold water appeared more effective than other stimuli [1]. Some authors also tried to stimulate subjects with vestibular stimulation, for instance asking subjects to sleep in hammocks [11]. Other studies evaluated the effect of tactile stimulation by a pressure cuff to a leg, both during REM [12][13] and at sleep onset (stage 1 NREM sleep; [14]) provoking high incorporation rates, with a percentage of 40%–80%. Furthermore, the incorporation of somatosensory stimuli was obtained by electrical pulses on the wrist to stimulate muscle contractions during REM sleep [15]. Overall, these kinds of stimulations increased vividness and higher bodily sensations in the oneiric contents.

More recently, olfactory stimulation was successfully used to modulate dreams' emotional tone during REM sleep [16]. Indeed, the authors showed that pleasant scent (e.g., rose) were associated with positive dream experience, while unpleasant smell (e.g., eggs) with more negative dream experiences [16]. Furthermore, it was demonstrated that using an odor presented during REM sleep and previously associated with an image during waking state induced subjects to report a dream experience containing the related image [17].

The findings of the impact of external stimuli on dream contents are mixed, and no compelling explanation about these phenomena was reported. In fact, the results on dream incorporation are discordant between studies and/or stimuli often fail to be incorporated in the content of dreams directly [4][5][18]. Moreover, the method used to classify the incorporation is quite different among studies. The judgment of whether a stimulus had been actually represented into the dream scenario or not was often subjective (e.g., [1]) and only few studies tried to assess, by an objective method, the presence/absence of incorporation and themes/emotional contents of dreams by identifying defined categories and requiring rating to two independents judges (e.g., [5][17]). However, a systematic and reliable method to study the incorporation is still lacking.

To some extent, these studies showed that the sleeping brain is able to perceive and process much information integrating them in an oneiric narrative. However, some authors suggested that stimuli incorporation into dreams cause a sort of micro-arousals that slightly awaken the sleeping subject so that they perceive it, but not enough to wake them up [19]. This view seems to be relatively compatible with the activation-hypothesis, however only scarce evidence about neural correlates is available.

2. Brain Stimulation and Dreaming

A very innovative line of research is aimed to manipulate dreaming by modulating brain activity directly. This method is based on non-invasive brain stimulation techniques and may be considered complementary to the earlier mentioned protocols influencing dream contents.

Specifically, Transcranial Direct Current Stimulation (tDCS) can induce focal changes in cortical excitability by a constant low-intensity current [20]. It is well-established that during wakefulness tDCS can alter the activation of motor [21], somatosensory [22], prefrontal [23] and visual cortices [24]. Additionally, tDCS can impact on cognitive functions, namely working memory [25] or tactile perception [26]. In recent years, a growing number of studies have investigated the effects of these techniques in the context of sleep and vigilance [27][28][29][30][31][32].

Starting from this knowledge, some investigations assessed tDCS effects on dreaming, intending to explore the involvement of different cortical areas in the oneiric experience. In a pioneering study, the stimulation was applied during Stage 2 NREM sleep over frontal (cathodal) and right posterior parietal (anodal) cortex [33]. The authors found a greater number of visual imagery reports after tDCS than sham condition, but the same was revealed for the two control conditions (i.e., reversed polarity and other-cephalic tDCS). Hence, the effects seem to be independent of tDCS polarity and the higher visual dream frequency appears to be elicited by a general arousing effect, rather than depending on the specific stimulation of cortical areas [33]. Moreover, no effect was observed during REM sleep or SWS [34][35]

Bihemispheric tDCS has been recently applied during REM sleep to investigate the potential interference of tDCS over the sensorimotor cortex with movement and bodily sensations of dream experience [36]. The study showed that subjects awakening after stimulation had a lower rate of reports including movements (especially repetitive actions), while tactile and vestibular sensations were not affected by tDCS. Hence, the authors suggested that sensorimotor cortex is responsible for generating dream movement, confirming that the neural bases of peculiar dream contents are shared between sleep and waking state.

The absence of awareness, and the lack of voluntary control during dream experience are both intriguing issues for dream scientists. In this regard, the researchers started becoming interested in modulating the level of consciousness during sleep, namely, inducing lucid dream experiences [37][38][39]. Hobson et al. [40] proposed that lucid dreaming may stem from the reactivation of dorsolateral prefrontal cortex that, as mentioned, appear deactivated during REM Sleep [41][42][43]. In this vein, Stumbrys et al. [38] applied tDCS stimulation over the dorsolateral prefrontal cortex during REM sleep and observed a small increase of self-reported lucid dreaming only in frequent lucid dreamers.

Further, transcranial alternating current stimulation (tACS) was applied to induce dream lucidity [37]. tACS exerts its effects by the application of an alternating current to the scalp at a specific frequency. The alternating stimulation drives the cortical network to oscillate at the given frequency, inducing periodic shifts in the transmembrane potential of underlying neurons [44]. Bearing in mind the involvement of frontal areas in dream activity [45], Voss et al. [37] used tACS for 30 s at several different frequencies over fronto-lateral regions during REM sleep. Subjects

reported lucid dreams when 25 and 40 Hz stimulation were applied. Conversely, a more recent study on lucid dreaming did not support this evidence, observing no effect of 40 Hz frontal stimulation [39].

The only one study using Transcranial Magnetic Stimulation (TMS) tried to manipulate dream experience targeting the posterior parietal cortex. TMS was applied during NREM sleep before awakening subjects and asking them about the presence/absence of dream experience [46]. The results showed that TMS induces an EEG response characterized by a larger negative deflection (similar to a larger NREM sleep slow wave) and a shorter period of phase-locking associated with non-recall compared to recall conditions [46]. Additionally, the amplitude of this deflection was negatively correlated with the total word count of dream reports. This response is typical of cortical circuits in condition of bistability between depolarized up-states and hyperpolarized down-states [47]. Notably, changes in the bistability of cerebral networks, mainly expressed in the form of slow oscillations, modulate the level of consciousness and the ability of the cortex to integrate information [46]. The authors started from the view that dreaming represents a consciousness experience during sleep. In turn, the level of consciousness corresponds to the amount of integrated information generated by a complex of elements and would only vanish during dreamless sleep or under general anesthesia [48]. In other words, slow frequencies (1–4 Hz) EEG during sleep are associated with neuronal down-states preventing the emergence of stable causal interactions among cortical areas and provoking the loss of consciousness [49][50][51].

Although the application of brain stimulation techniques in the field of sleep and dreaming represents a promising research area [52], the available evidence is far from being conclusive.

However, the direct manipulation of brain activity could give us powerful insights in understanding the neural substrates of dream recall.

References

1. Dement, W.; Wolpert, E.A. The relation of eye movements, body motility, and external stimuli to dream content. J. Exp. Psychol. 1958, 55, 543.

2. Goodenough, D.R.; Witkin, H.A.; Koulack, D.; Cohen, H. The Effects of Stress Films on Dream Affect and on Respiration and Eye-Movement Activity During Rapid-Eye-Movement Sleep. Psychophysiology 1975, 12, 313–320.

3. Corsi-Cabrera, M.; Becker, J.; García, L.; Ibarra, R.; Morales, M.; Souza, M. Dream content after using visual inverting prisms. Percept. Mot. Skills 1986, 63, 415–423.

4. Rechtschaffen, A.; Foulkes, D. Effect of visual stimuli on dream content. Percept. Mot. Skills 1965, 20, 1149–1160.

5. Berger, R.J. Experimental Modification of Dream Content by Meaningful Verbal Stimuli. Br. J. Psychiatry 1963, 109, 722–740.

6. Hoelscher, T.J.; Klinger, E.; Barta, S.G. Incorporation of concern-and nonconcern-related verbal stimuli into dream content. J. Abnorm. Psychol. 1981, 90, 88–91.

7. Conduit, R.; Bruck, D.; Coleman, G. Induction of Visual Imagery During NREM Sleep. Sleep 1997, 20, 948–956.

8. LaBerge, S.; Levitan, L. Validity established of DreamLight cues for eliciting lucid dreaming. Dreaming 1995, 5, 159–168.

9. Baldridge, B.J.; Whitman, R.M.; Kramer, M. The Concurrence of Fine Muscle Activity and Rapid Eye Movements During Sleep. Psychosom. Med. 1965, 27, 19–26.

10. Baldridge, B. Physical concomitants of dreaming and the effect of stimulation on dreams—PubMed. Ohio State Med. J. 1966, 2, 1273–1275.

11. Leslie, K.; Ogilvie, R. Vestibular dreams: The effect of rocking on dream mentation. Dreaming 1996, 6, 1–16.

12. Nielsen, T. Changes in the kinesthetic content of dreams following somatosensory stimulation of leg muscles during REM sleep. Dreaming 1993, 3, 99.

13. Sauvageau, A.; Nielsen, T.A.; Montplaisir, J. Effects of somatosensory stimulation on dream content in gymnasts and control participants: Evidence of vestibulomotor adaptation in REM sleep. Dreaming 1998, 8, 125–134.

14. Solomonova, E. The Embodied Mind in Sleep and Dreaming: A Theoretical Framework and an Empirical Study of Sleep, Dreams and Memory in Meditators and Controls. Ph.D. Thesis, University of Montreal, Montreal, QC, Canada, 2018.

15. Koulack, D. Effects of somatosensory stimulation on dream content. Arch. Gen. Psychiatry 1969, 20, 718–725.

16. Schredl, M.; Atanasova, D.; Hörmann, K.; Maurer, J.T.; Hummel, T.; Stuck, B.A. Information processing during sleep: The effect of olfactory stimuli on dream content and dream emotions. J. Sleep Res. 2009, 18, 285–290.

17. Schredl, M.; Hoffmann, L.; Sommer, J.U.; Stuck, B.A. Olfactory Stimulation During Sleep Can Reactivate Odor-Associated Images. Chemosens. Percept. 2014, 7, 140–146.

18. Nir, Y.; Tononi, G. Dreaming and the brain: From phenomenology to neurophysiology. Trends Cogn. Sci. 2010, 14, 88–100.

19. Solomonova, E.; Carr, M. Incorporation of External Stimuli into Dream Content The implication of dreaming in sleep-dependent learning View project. Dreams Underst. Biol. Psychol. Cult. 2019, 213–218.

20. Nitsche, M.; Paulus, W. Excitability changes induced in the human motor cortex by weak transcranial direct current stimulation. J. Physiol. 2000, 527, 633.

21. Boggio, P.S.; Ferrucci, R.; Rigonatti, S.P.; Covre, P.; Nitsche, M.; Pascual-Leone, A.; Fregni, F. Effects of transcranial direct current stimulation on working memory in patients with Parkinson's disease. J. Neurol. Sci. 2006, 249, 31–38.

22. Dieckhöfer, A.; Waberski, T.; Nitsche, M.; Paulus, W. Transcranial direct current stimulation applied over the somatosensory cortex–differential effect on low and high frequency SEPs. Clin. Neurophysiol. 2006, 117, 2221–2227.

23. Kincses, T.; Antal, A.; Nitsche, M.; Bártfai, O.; Paulus, W. Facilitation of probabilistic classification learning by transcranial direct current stimulation of the prefrontal cortex in the human. Neuropsychologia 2004, 42, 113–117.

24. Antal, A.; Kincses, T.; Nitsche, M.; Bartfai, O.; Paulus, W. Excitability changes induced in the human primary visual cortex by transcranial direct current stimulation: Direct electrophysiological evidence. Investig. Ophtalmol. Vis. Sci. 2004, 45, 702–707.

25. Marshall, L.; Mölle, M.; Siebner, H.R.; Born, J. Bifrontal transcranial direct current stimulation slows reaction time in a working memory task. BMC Neurosci. 2005, 6.

26. Rogalewski, A.; Breitenstein, C.; Nitsche, M.A.; Paulus, W.; Knecht, S. Transcranial direct current stimulation disrupts tactile perception. Eur. J. Neurosci. 2004, 20, 313–316.

27. Marshall, L.; Kirov, R.; Brade, J.; Mölle, M.; Born, J. Transcranial electrical currents to probe EEG brain rhythms and memory consolidation during sleep in humans. PLoS ONE 2011, 6.

28. McKinley, R.; McIntire, L.; Nelson, J.; Nelson, J. Acceleration of procedural learning with transcranial direct current stimulation (tDCS). Brain Stimul. Basic Transl. Clin. Res. Neuromodul. 2014, 7, e4–e5.

29. D'Atri, A.; Simoni, E.D.; Gorgoni, M.; Ferrara, M.; De Gennaro, L. Frequency-dependent effects of oscillatory-tDCS on EEG oscillations: A study with Better OSCillation detection method (BOSC). Arch. Ital. Biol. 2015, 153, 124–134.

30. D'Atri, A.; De Simoni, E.; Gorgoni, M.; Ferrara, M.; Ferlazzo, F.; Rossini, P.M.; De Gennaro, L. Accepted Manuscript Electrical Stimulation of the Frontal Cortex Enhances Slow-Frequency Eeg Ac-tivity and Sleepiness. Neuroscience 2016, 324, 119–130.

31. D'Atri, A.; Romano, C.; Gorgoni, M.; Scarpelli, S.; Alfonsi, V.; Ferrara, M.; Ferlazzo, F.; Rossini, P.M.; De Gennaro, L. Bilateral 5 Hz transcranial alternating current stimulation on frontoporal areas modulates resting-state EEG. Sci. Rep. 2017, 7.

32. D'Atri, A.; Scarpelli, S.; Gorgoni, M.; Alfonsi, V.; Annarumma, L.; Giannini, A.M.; Ferrara, M.; Ferlazzo, F.; Rossini, P.; De Gennaro, L.; et al. Bilateral Theta Transcranial Alternating Current

Stimulation (tACS) Modulates EEG Activity: When tACS Works Awake It Also Works Asleep. Nat. Sci. Sleep 2019, 11, 343–356.

33. Jakobson, A.J.; Fitzgerald, P.B.; Conduit, R. Induction of visual dream reports after transcranial direct current stimulation (tDCs) during Stage 2 sleep. J. Sleep Res. 2012, 21, 369–379.

34. Jakobson, A.J.; Fitzgerald, P.B.; Conduit, R. Investigation of dream reports after transcranial direct current stimulation (tDCs) during slow wave sleep (SWS). Sleep Biol. Rhythms 2012, 10, 169–178.

35. Jakobson, A.J.; Conduit, R.; Fitzgerald, P.B. Investigation of visual dream reports after transcranial direct current stimulation (tDCS) during REM sleep. Int. J. Dream Res. 2012, 5, 87–93.

36. Noreika, V.; Windt, J.M.; Kern, M.; Valli, K.; Salonen, T.; Parkkola, R.; Revonsuo, A.; Karim, A.A.; Ball, T.; Lenggenhager, B. Modulating dream experience: Noninvasive brain stimulation over the sensorimotor cortex reduces dream movement. Sci. Rep. 2020, 10, 1–19.

37. Voss, U.; Holzmann, R.; Hobson, A.; Paulus, W.; Koppehele-Gossel, J.; Klimke, A.; Nitsche, M.A. Induction of self awareness in dreams through frontal low current stimulation of gamma activity. Nat. Neurosci. 2014, 17, 810–812.

38. Stumbrys, T.; Erlacher, D.; Schredl, M. Testing the involvement of the prefrontal cortex in lucid dreaming: A tDCS study. Conscious. Cogn. 2013, 22, 1214–1222.

39. Blanchette-Carrière, C.; Julien, S.H.; Picard-Deland, C.; Bouchard, M.; Carrier, J.; Paquette, T.; Nielsen, T. Attempted induction of signalled lucid dreaming by transcranial alternating current stimulation. Conscious. Cogn. 2020, 83, 102957.

40. Hobson, J.A.; Pace-Schott, E.F.; Stickgold, R. Dreaming and the brain: Toward a cognitive neuroscience of conscious states. Behav. Brain Sci. 2000, 23, 793–842.

41. Maquet, P.; Péters, J.; Aerts, J.; Delfiore, G.; Degueldre, C.; Luxen, A.; Franck, G. Functional neuroanatomy of human rapid-eye-movement sleep and dreaming. Nature 1996, 383, 163–166.

42. Nofzinger, E.A.; Mintun, M.A.; Wiseman, M.; Kupfer, D.J.; Moore, R.Y. Forebrain activation in REM sleep: An FDG PET study. Brain Res. 1997, 770, 192–201.

43. Desseilles, M.; Thanh Dang-Vu, T.; Sterpenich, V.; Schwartz, S. Cognitive and emotional processes during dreaming: A neuroimaging view. Conscious. Cogn. 2011, 20, 998–1008.

44. Bestmann, S.; Walsh, V. Transcranial electrical stimulation. Curr. Biol. 2017, 27, R1258–R1262.

45. Solms, M. Dreaming and REM sleep are controlled by different brain mechanisms. Behav. Brain Sci. 2000, 23, 843–850.

46. Nieminen, J.O.; Gosseries, O.; Massimini, M.; Saad, E.; Sheldon, A.D.; Boly, M.; Siclari, F.; Postle, B.R.; Tononi, G. Consciousness and cortical responsiveness: A within-state study during non-rapid eye movement sleep. Sci. Rep. 2016, 6, 1–10.

47. Steriade, M.; Timofeev, I.; Grenier, F. Natural waking and sleep states: A view from inside neocortical neurons. J. Neurophysiol. 2001, 85, 1969–1985.

48. Koch, C.; Massimini, M.; Boly, M.; Reviews, G.T.-N. Neural correlates of consciousness: Progress and problems. Nat. Rev. Neurosci. 2016, 17, 307–321.

49. Massimini, M.; Ferrarelli, F.; Huber, R.; Esser, S.K.; Singh, H.; Tononi, G. Neuroscience: Breakdown of cortical effective connectivity during sleep. Science (80-) 2005, 309, 2228–2232.

50. Tononi, G.; Massimini, M. Why Does Consciousness Fade in Early Sleep? Ann. N. Y. Acad. Sci. 2008, 1129, 330–334.

51. Purdon, P.L.; Pierce, E.T.; Mukamel, E.A.; Prerau, M.J.; Walsh, J.L.; Foon, K.; Wong, K.; Salazar-Gomez, A.F.; Harrell, P.G.; Sampson, A.L.; et al. Electroencephalogram signatures of loss and recovery of consciousness from propofol. Proc. Natl. Acad. Sci. USA 2013, 110, E1142–E1151.

52. Annarumma, L.; Atri, A.D.; Alfonsi, V.; De Gennaro, L. The Efficacy of Transcranial Current Stimulation Techniques to Modulate Resting-State EEG, to Affect Vigilance and to Promote Sleepiness. Brain Sci. 2018, 8, 137.