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Review

Dreaming and the default network: A review, synthesis, and counterintuitive research proposal

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ABSTRACT

This article argues that the default network, augmented by secondary visual and sensorimotor cortices, is the likely neural correlate of dreaming. This hypothesis is based on a synthesis of work on dream content, the findings on the contents and neural correlates of mind-wandering, and the results from EEG and neuroimaging studies of REM sleep. Relying on studies in the 1970s that serendipitously discovered episodes of dreaming during waking mind-wandering, this article presents the seemingly counterintuitive hypothesis that the neural correlates for dreaming could be further specified in the process of carrying out EEG/fMRI studies of mind-wandering and default network activity. This hypothesis could be tested by asking participants for experiential reports during moments of differentially high levels of default network activation, as indicated by mixed EEG/fMRI criteria. Evidence from earlier EEG/fMRI studies of mind-wandering and from laboratory studies of dreaming during the sleep-onset process is used to support the argument.

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1. Introduction and overview

The general outlines of the neural correlates of dreaming, which are putative indices of the neural substrate that supports dreaming, have been known since the late 1990s due to the unexpected convergence of findings from two very different types of studies: neuroimaging studies of REM sleep on the one hand, and neurological examinations and CT scans of patients with alterations in their dreaming on the other (e.g., Braun et al., 1997; Maquet et al., 1996; Nofzinger, Mintun, Wiseman, Kupfer, & Moore, 1997; Solms, 1997). The neuroimaging and neurological literatures were then synthesized with the literatures on dream content and on the gradual development of frequent and complex dreaming in children to create a neurocognitive theory of dreaming (Domhoff, 2001, 2003, Chapter 1). Around the same time, a serendipitous discovery showed that a "default" network of brain regions is spontaneously active during restful states, and supports mind-wandering and daydreaming during waking (e.g., Addis, Wong, & Schacter, 2007; Andrews-Hanna, Reidler, Huang, & Buckner, 2010; Christoff, Gordon, Smallwood, Smith, & Schooler, 2009; Dixon, Fox, & Christoff, 2014; Gusnard & Raichle, 2001; Kucyi & Davis, 2014; Mason et al., 2007). Not only is the default network activated during *waking* daydreaming; recent findings show that many hubs of the default network are even more active during REM sleep than at rest, augmented by secondary visual and sensorimotor cortices that support sensorimotor imagery (Chow et al., 2013; Fox, Nijeboer, Solomonova, Domhoff, & Christoff, 2013).

It is also possible that this augmented default network could support episodes of dreaming during the complex and multifaceted sleep-onset process and into Stage 2 of NREM, before Stages 3 and 4 occur (e.g., Horovitz, 2008; Larson-Prior et al., 2009; Laufs, 2008, for a review; Laufs, Walker, & Lund, 2007; Sämann et al., 2011; Tagliazucchi et al., 2013). Based on the similarity of dream reports after spontaneous morning awakenings from REM and NREM 2 (Cicogna, Natale, Occhionero, & Bosinelli, 1998), and the higher level of general brain activation in the early morning hours (Antrobus, Kondo, & Reinsel, 1995; Wamsley et al., 2007), it seems likely that the putative neural network for dreaming is active during NREM 2 at this time as well (Domhoff, 2011b, pp. 1168–1169, for a review of the evidence). However, due to the difficulties of investigating the full sleep cycle with noisy brain scanning equipment, no neuroimaging study has yet examined NREM 2 in the early morning.

Despite the progress in outlining a general pattern of brain activity during dreaming, further advances in specifying the neural correlates of dreaming may be slow, for at least two reasons. First, cognitive neuroscientists interested in the functioning of the default network are rightly focused on many other issues, including the role of this network in social-affective cognition and in various neurodegenerative, neurodevelopmental, and psychiatric conditions, such as Alzheimer's, autism, and schizophrenia (e.g., Amft, Bzdok, Laird, Fox, & Schilbach, 2014; Andrews-Hanna, 2012; Andrews-Hanna, Smallwood, & Spreng, 2014, for overviews). Second, the type of studies of the default network and its relationship to ongoing mentation that are needed (namely, combined EEG/fMRI studies) are more difficult to conduct during sleep because of the noise of the fMRI scanner, the fact that it takes an entire night to adapt to sleeping in a laboratory in the best of circumstances, and the relatively time-consuming process of awakening participants from sleep and having them attempt to recall often hazy mental experiences. Adding to the difficulty of studying dreaming during sleep or sleep onset in conjunction with EEG/fMRI, participants in these studies are usually sleep deprived or instructed to shorten their normal sleeping period for several days beforehand, which reduces functional connectivity in the default network and may alter the production and recall of dreams (De Havas, Parimal, Soon, & Chee, 2012).

Given these and other problems, it seems likely that new approaches compatible with the primary interests of neuroimaging researchers are needed for studies of the neural correlates of dreaming. It is the purpose of this article to suggest one such approach. This approach is counterintuitive because it involves studying dreaming during brief episodes of dreaming during mind-wandering in the waking state, a phenomenon that was accidentally discovered in the 1970s (Foulkes & Fleisher, 1975; Foulkes & Scott, 1973). More specifically, the necessary EEG/fMRI studies might be done as part of larger studies of the default network carried out for other purposes.

2. What is dreaming and when does it occur?

There is no consensus on the definition of dreaming. For example, dreaming is sometimes considered to be a type of hallucinatory activity, which is defined very generally as perceiving something that isn't there, or as the perception of sights and sounds with no reality basis. This view is often adopted in neurophysiological theories of dreaming, which leads to the idea that dreaming is a form of psychosis. For example, psychiatrist J. Allan Hobson (2002, pp. 98–99) asserts, "psychosis is, by definition, a mental state characterized by hallucinations and/or delusions," so it follows that dreaming is "as psychotic a state as we ever experience while awake." Similarly, the Freudian theorists Mark Solms and Oliver Turnbull (2002, p. 213) argue that "the functional anatomy of dreaming is almost identical to that of schizophrenic psychosis," which is characterized by frequent hallucinatory activity. On the other hand, dreaming sometimes is defined very broadly as any form of mental activity during sleep, which can range from thoughts and isolated images to the more story-like experiences that are recalled upon awakening; in still other studies, ordinal scales are used to rate mentation reports as to the degree that they are like canonical definitions of dreaming, which can bring about considerable agreement concerning the amount of dreaming that was found in a wide range of studies (e.g., Nielsen, 2000; Pagel et al., 2001; Zadra & Domhoff, 2011, for further discussion).