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Default-mode network activity and its role in comprehension and management of psychophysiological insomnia: A new perspective

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ABSTRACT

Psychophysiological insomnia (PI) is a common sleep disorder in which numerous variables interact. The mechanisms responsible for the etiology and maintenance of PI, though far from completely understood, point to the existence of hyperarousal of several systems. The frequent occurrence of ruminations and worries with a self-referential component (related or not with sleep complaints) during the pre-sleep period, and daytime wakefulness, seems to relate to the functions which have been associated with default-mode network (DMN) activity. This neural network seems to be involved in introspective thinking as well as emotional and episodic memory processing, among others. In this paper, we propose that PI may be conceptualized as a disorder associated with overactivity of some brain areas of DMN. Accordingly, it is also suggested that cognitive-behavioral therapy for insomnia (CBT-I), a kind of non-pharmacological treatment, may alter the function of this network, improving symptoms of patients, and overall quality of life.

1. Introduction

Approximately 10–15% of the general population has insomnia and this is considered as being one of the most common sleep disorders with an estimated incidence of 3–5% of new cases each year (Drake & Roth, 2006). Psychophysiological insomnia (PI) is a sleep disorder with clear-cut classification criteria in terms of medical diagnosis and covers complaints in starting, maintaining sleep, or experiencing non-restorative sleep. According to the second edition of International Classification of Sleep Disorders - ICSD-2 of the American Academy of Sleep Medicine (AASM, 2005), this is a diagnosis that includes high cognitive, physiological, and emotional arousal levels associated with negative conditioning between some stimuli or spatial/temporal cues and sleep behaviors.

As suggested in the literature, insomnia (particularly conditioned insomnia) seems to be a fluctuating disorder. This is evident when we analyze the amount of pathophysiologic models that have been proposed to explain it (Bootzin, 1972; Espie, Broomfield, MacMahon, Macphee, & Taylor, 2006; Harvey, 2002; Kales, Caldwell, Preston, Healey, & Kales, 1976; Lundh & Broman, 2000; Morin, 1993; Ong, Ulmer, & Manber, 2012; Perlis, Giles,

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Mendelson, Bootzin, & Wyatt, 1997; Spielman, Caruso, & Glovinsky, 1987). All these models, mainly psychological in their origins, gave consistency to the two hypotheses explaining insomnia development and maintenance processes: hyperarousal and failure to inhibit wakefulness, respectively (Perlis, Shaw, Cano, & Espie, 2011). The hyperarousal hypothesis states that in patients with insomnia there is a widespread activation of several systems (e.g., cognitive, physiological, emotional, cortical), which consequently prevents the person to relax. The concept of hyperarousal was recognized to be of major importance in the understanding of PI. However, sleep researchers have not yet reached a consensus on which dimensions this concept covers (Riemann et al., 2010).

On the other hand, the failure to inhibit wakefulness account suggests that the difficulty in inhibiting activation typical of wakefulness period is the principal disturbing process in PI (Espie et al., 2006). In practice, it is feasible to accept the complementarity of both hypotheses (Perlis et al., 2011). It is likely that these two processes may relate to two distinct profiles of patients with insomnia. Although interesting, we do not have yet evidence to support this claim.

Many studies have concluded that bedtime is the period of day in which individuals are more available to deal with emotionally arousing cognitions (Harvey, 2005). For example, people tend to focus on the concerns regarding the organization and management of the following day, to elaborate a retrospective of the past day, to remember past traumatic events, or to anxiously anticipate the future, or generate negative expectations related to own sleep behavior, among many others (Watts, Coyle, & East, 1994). Accordingly, it is easy to understand that intrusive and dysfunctional thoughts related with the self play a key role in PI.

As already mentioned, there are many models proposed for understanding the etiology and maintenance of PI. Nevertheless, it should be noted that the behavioral or psychological models are the most studied and well-known ones, with the added advantage, but also the challenge, of integrating neurobiological, biochemical, physiological, and even immunological variables (Talbot & Harvey, 2010).

In this article, we will present some provisional ideas suggesting that the new developments in neuroscience, in particular, pertaining to the brain's default-mode network (DMN) study will bring important advances for insomnia's conceptualization and treatment.

2. The default-mode network

The function of the DMN is currently one of the most studied topics in the field of cognitive neuroscience. In general, it concerns to a relatively well-defined set of brain areas which have a higher level of activation when the subjects are not focused on a specific external task mobilizing their explicit attentional resources (i.e., goal-oriented task or attention demanding task). For this reason, it is also called a task-negative network (Raichle & Snyder, 2007). In spite of this, it is relevant to stress that DMN brain regions are also generally activated in attention demanding tasks albeit in a lesser extent (the exception is when the individuals perform tasks requiring self-referential processing).

The DMN has captured the interest of many scholars since during this “state of rest” the brain consumes identical energy resources compared with solving arithmetic problems tasks, for example (Snyder & Raichle, 2012).

Several studies using the resting-state paradigm and focused particularly in DMN have shown that there are basic psychological functions associated with this neural network. The DMN is involved in behaviors such as mind-wandering, recovery of past memories, planning/projection of future events, and consideration of perspective/point of view of other individuals (theory of mind). All of these functions activate multiple regions within the DMN (Buckner, Andrews-Hanna, & Schacter, 2008). Overall, they represent what the researchers refer to as the “internal modes of cognition”. The resting-state experiments (i.e., in which the participant is asked to simply relax with eyes closed or open, as appropriate) allow to obtain an overview of the most active brain regions that a growing number of studies have shown to be related with each other (i.e., work interdependently), when the subject is focused only on their own psychological processes (Raichle & Snyder, 2007). However, we must note that DMN constitutes just one of the many resting networks observed in the brain.

Although there is no full understanding about the functions inherent to DMN, several studies have converged in identifying the underlying brain structures. These regions include medial areas of the brain, comprising the ventral medial prefrontal cortex (MPFC), dorsal MPFC, medial temporal lobule, inferior parietal lobule (IPL), precuneus, posterior cingulate cortex (CPP)/retrosplenial cortex, and the hippocampal formation (Buckner et al., 2008). Nonetheless, it is worth noting that the current consensus is on MPFC, including anterior cingulate cortex (AAC), PCC, and IPL (Whitfield-Gabrieli & Ford, 2012).

There are some studies suggesting that the DMN, instead of representing a cohesive and coherent organization, can be divided into specific sub-organizations. In an attempt to dissociate subsystems within DMN, Andrews-Hanna, Reidler, Sepulcre, Poulin, and Buckner (2010) observed that this network can be subdivided into two main components, taking into account the self-reference and temporal orientation variables. These authors reported that one component is the *medial prefrontal cortex system* - including the dorsal prefrontal medial dorsal, the temporo-parietal junction, the lateral temporal cortex, and the temporal pole; the other component is the *temporal lobe subsystem* which includes the medial ventral prefrontal cortex, posterior inferior parietal lobe, retrosplenial cortex, parahippocampal cortex and the hippocampal formation, and is mobilized when individuals engage in decisions that require mental simulations based on memory. In future-oriented cognitions the two subsystems are simultaneously mobilized, presumably to facilitate the construction of mental models that enable people to adapt to the environment.

Since the last decade, many scholars have sought to understand the patterns of response of the DMN in various neuropsychiatric disorders such as Alzheimer's disease, autism spectrum disorders, schizophrenia, attention deficit