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Aquém e Além do Cérebro

Behind and Beyond the Brain

Casa do Médico - Porto • 28 a 31 de março de 2012



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Sleep and dreams

O livro “Aquém e Além do Cérebro” contém as atas do 9º Simpósio da Fundação Bial, realizado na Casa do Médico, de 28 a 31 de março de 2012, tendo como membros da Comissão Organizadora os Senhores Professores Fernando Lopes da Silva, Dick Bierman, Miguel Castelo-Branco, Alexandre Castro-Caldas, Axel Cleeremans, Rui Mota Cardoso, Mário Simões e Caroline Watt. Os textos estão disponíveis em www.bial.com.

The book “Behind and Beyond the Brain” includes the texts of the Bial Foundation’s 9th Symposium, held at Casa do Médico, from the 28th to the 31st March 2012, having as members of its Organizing Committee the following Professors: Fernando Lopes da Silva, Dick Bierman, Miguel Castelo-Branco, Alexandre Castro-Caldas, Axel Cleeremans, Rui Mota Cardoso, Mário Simões and Caroline Watt.

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DREAMS, EMOTIONS AND BRAIN PLASTICITY

Sophie Schwartz *

1. Introduction

“The scariest place was a neighborhood with sinuous paths. I was worried. Leaving the neighborhood, I saw a lot of lizards. I was looking for my girlfriend but could never find her. Sometimes, I was completely lost. At some point, shots were fired in my direction but I do not know if I was touched. The dream was very unpleasant. I was not comfortable.”

This dream report was written by a young man just after waking up. It reveals several typical features of dream experiences such as complex perceptions (seeing places and animals), spatial navigation (moving from one place to the other), intentions or goals (looking for someone), confusion or amnesia (uncertain about being wounded), as well as particularly intense emotions, including high anxiety. One simple question that I would like to discuss here is why strong emotional experiences are so common in dreams. I will review psychological and neurophysiological data indicating that affective and motivational processes as well as underlying dedicated brain circuits are activated during sleep. I will also suggest that information that is highly relevant for the individual is prioritized for reprocessing during sleep. Moreover, emotions that we experience in dreams may subsequently promote adapted waking emotional reactivity and decision making [1, 2]. More generally, in the present paper, I provide support for the hypothesis that emotional or motivation factors exert a continuous influence on mental and neural activity across distinct brain states. Such affective effects during both wakefulness and sleep would thus guide (or bias) the selection of information that will gain access to conscious representation.

While we dream, the brain is not at rest. This is evidenced by measures of brain activity acquired during sleep using various techniques such as for

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example electroencephalography (EEG), positron emission tomography (PET), and functional magnetic resonance imaging (fMRI). During rapid-eye movement (REM) sleep, brain activity measured by EEG resembles that observed during resting wakefulness. Moreover, during REM sleep, the virtual world that we experience in dreams is perceptually very veridical. Yet, dream experiences are no replicates of real life experiences: objects or characters that populate the dreams may often seem familiar although they differ from their real-life equivalents; perceptual representations are often bizarre, with distortions of size, texture, or color, for example; upon awakening, the dream plot may appear rather illogical; the dreamer is usually unaware of being in a dream; etc. Related to our initial question and as illustrated in the dream reported above, another key feature in dream reports is the high prevalence of strong emotions (especially for REM dreams) [3, 4], more negatively-loaded than those experienced in real life, and frequently related to fear or anxiety.

How can we relate the content of the dreams with underlying neural activity during sleep? The specific pattern of regions activated during REM sleep in humans is consistent with some main features of dreaming experience [1, 5-9] (Figure 1). In particular, widespread activity along occipital-temporal visual regions and motor regions is consistent with the highly visual and motor content of the dreams. Conversely, hypoactivation of lateral prefrontal cortices during REM sleep may cause disorientation, illogical thinking, and prevent supervisory control functions so that bizarre elements in dreams are not recognized as incompatible with our conception of the real world and of ourselves. Concerning strong (particularly negative) emotions in dreams, they may be facilitated by a net increase in amygdala activity, in particular during REM sleep [9]. Finally, we also recently proposed that the activation of the hippocampus and mesolimbic dopaminergic system (ML-DA) reward system (including the medial prefrontal cortex and in the dopaminergic ventral tegmental area) during sleep contributes to memory processes and to the generation and the motivational content of dreams [5]. Accordingly, the engagement of ML-DA and associated limbic structures would prioritize information with high emotional or motivational relevance for (re)processing during sleep and dreaming.

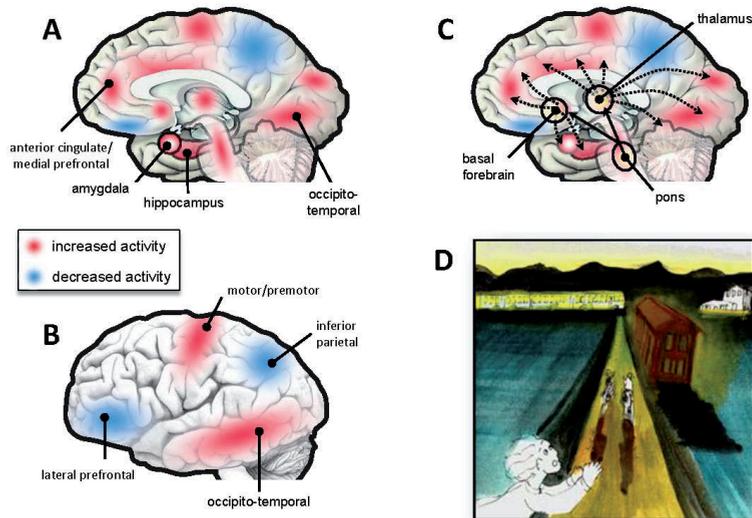


Figure 1. Distribution of activity in REM sleep and typical dream features. Regions showing increased or decreased brain activity in human brain imaging studies: (A) lateral view of the brain and (B) medial view. (B) Internally-generated activation during REM sleep: activation waves originating from the pontine tegmentum generate widespread cortical activation via the thalamus and the basal forebrain. (C) Illustration of a dream involving strong fear-related emotions: terrified by some danger (not shown), the dreamer runs away from it hoping to catch the yellow train at the end of the road. Such frightening experiences in dreams are evocative of increased amygdala activation during REM sleep. The drawing comes from a dream diary extensively analyzed elsewhere (S. Schwartz, Doctoral thesis).

Below I first review some recent research on the role of sleep in memory functions, with a special emphasis on brain imaging studies in humans. I then report convergent clinical, neuroimaging, and dream data showing that sleep and emotion interact to optimize daytime functioning.

2. Sleep and memory processes

While waking brain function is critical to cognition, sleep contributes to equally essential and complementary operations. In particular, evidence has accumulated to show that sleep is implicated in the active

consolidation of memory [10, 11]. Strong support for the role of sleep in memory comes from the observation that patterns of neuronal activity associated with a recently-trained waking behavior may be spontaneously replayed during later periods of sleep (or quiet wakefulness) [12-17]. In animals, this replay can be found across several brain areas (e.g. hippocampus, ventral striatum, and neocortex) and directly contributes to learning processes through a mechanism of synaptic strengthening. Similarly, human brain imaging data have shown that regions activated during waking experiences are spontaneously reactivated during sleep, leading to long lasting changes in brain activity and connectivity [10, 18-23]. In sum, these recent data suggest that sleep fosters the consolidation of newly acquired information in memory [24].

Yet, the factors influencing the selection of freshly encoded information for further consolidation during sleep remain largely unknown. Here, I hypothesize that our brains prioritize information with high emotional relevance in the competition for subsequent reprocessing during sleep.

3. Sleep and emotional processing

Insufficient sleep and sleep disorders are typically accompanied by daytime complaints, several of them suggesting some form of emotional dysregulation [25-27]. Similarly, narcolepsy with cataplexy (NC), which is a major sleep disorder due to a deficiency in hypocretin/orexin (HCRT), presents with a striking emotional component: cataplexy (sudden loss of muscle tone) in NC is triggered by emotions, most often by laughing, joking, playing games [28-30]. In our functional magnetic resonance imaging (fMRI) studies on NC, we showed increased amygdala response to emotionally-positive situation, i.e. watching humorous pictures and winning at games [31, 32]. We also found altered responses in mesolimbic reward circuits and medial prefrontal cortex (mPFC), supporting a link between the HCRT system and the expression of motivated behaviors and addiction [33], and consistent with the fact that HCRT-deficient NC patients rarely become addicted to highly-addictive treatments. In addition, we demonstrated impaired emotional learning in NC patients, expressed by the lack of amygdala modulation by conditioned stimuli, and an abnormal functional coupling between the amygdala and mPFC

[34]. Altogether, these findings suggest that the processing of emotional signals engages neurotransmitters and neural pathways that are also critically involved in the maintenance of sleep-wake states.

3.1. Sleep alterations in emotion disorders

The vast majority of psychiatric disorders, especially those involving emotional dysregulation, are associated with sleep abnormalities [27]. Post-traumatic stress disorder (PTSD) is an important psychiatric condition with major sleep disturbances, characterized by frequent nightmares and insomnia due to recurrent, unwanted re-experiencing of the traumatic event [35, 36]. Moreover, insomnia and REM sleep alterations in the acute aftermath of trauma (including increased amygdala activity) could relate to the subsequent development of PTSD [37-39].

3.2. Effects of sleep deprivation on emotional and reward processing

Reduced emotional control is frequently observed after sleep-deprivation in the form of irritability, impulsivity, childish humor, disregard of normal social conventions, and inappropriate interpersonal behaviors [40, 41]. Emotional processing might actually be more affected by sleep deprivation than cognitive or motor performance [42, 43]. For example, insufficient sleep is associated with changes in reward-related decision making: people take greater risks [41, 44], are less concerned with negative consequences [45-47], and overestimate positive emotional experiences [48]. In 2009, Holm et al. showed that in both reward anticipation and outcome phases of a card-game, adolescents with fewer minutes asleep and later sleep onset time exhibited less caudate activation [49], a structure implicated in linking reward to behavior and learning [50]. Collectively, these recent data suggest that less sleep may impact on neural systems involved in emotional and reward processing in ways that exacerbate behavioral problems (e.g. increased risk-taking), and may thus have major health implications in both adolescents and adults.

3.3 Consolidation of emotional memory during sleep

Behavioral studies suggest that REM sleep enhances the consolidation of enduring emotional memories [38, 51] or emotional components of scenes [52]. Very few studies have started to reveal the cerebral mechanisms underlying sleep-related emotional memory consolidation. Using fMRI, Sterpenich et al. showed that sleep during the first post-encoding night critically enhances the long-term consolidation of emotional memory by modulating amygdala-mPFC functional connections [20, 21]. These data support our proposal that emotional significance may boost sleep-related memory consolidation. Whether dreaming plays an active role in memory consolidation was investigated by Bob Stickgold and his collaborator Erin Wamsley [53, 54] who elegantly showed that dreaming about elements of a recently trained task led to an improvement in performance for this task, when compared to subjects who did not report dream content related to the task. This observation is also consistent with the idea that dreams are influenced by waking emotional concerns of the sleeper [36, 55-57].

4. Emotions in dreams

Dream research has brought support to the traditional belief that dreams are highly emotional: dream reports contain a high proportion of fear- or anxiety-related emotions (compared to real-life emotion spectrum) [4]. An elevated intensity of emotions in dreams might relate to high amygdala activity during REM sleep, since the amygdala responds to emotional stimuli, stressful situations, and novelty [6, 9]. It has been proposed that normal dreaming could allow an adaptive extinction of fear memories by activating some features of those memories without their pairing with the unpleasant unconditioned stimulus [35, 36]. The suggested cathartic function of dreaming might also be mediated by the persistence of activity in mPFC cortex during REM sleep [9, 58], a region (particularly its ventral part) that is known to send inhibitory feedbacks to the amygdala. While mental health depends on the successful extinction of the terror associated with traumatic memories, it may be equally essential for the individual's survival to maintain memories for

life-threatening information. In this respect, PTSD might be seen as an undesirable consequence of a useful threat-detection neural apparatus. Consistent with this interpretation, Revonsuo and Valli recently proposed that dreaming might serve to simulate responses to threatening events in a totally secure environment, and ultimately promote adapted and efficient reactions to dangerous real-life events [4, 59]. Accordingly, dreams may serve important biological and psychological functions [60, 61].

In a recent proposal, we extended this view by suggesting that activation of the ML-DA reward system during sleep creates an internal environment of high exploratory excitability and elevated novelty-seeking [5]. Sustained activation of the ML-DA reward system (in particular the VTA) during REM sleep [62-65] may thus favor the activation of stimulus representations or behaviors of high motivational relevance, which would induce approach and avoidance behaviors. For example, pleasant and positive content of a dream (e.g. winning a game or having sex) would constitute a rewarding (approach-prone) stimulus, whereas threat-related content (e.g. being chased or attacked) would be an aversive (avoidance-prone) stimulus. NAcc and VTA may actually be activated independently of the emotional valence of the dream content, because both structures are found to be activated during both reward and punisher anticipation [66, 67]. Motivational and emotional content may be more prominent in REM than in NREM dreaming [3]. This is consistent with the finding that several limbic and ML-DA regions are selectively activated during REM, with amygdala activity and burst firing in the VTA being significantly higher in REM compared to NREM. Importantly, because dreams offer a virtual reality platform for an acquaintance of the dreamer with diverse stimuli, including stimuli of high emotional and/or motivational value from the recent past, activation of the ML-DA reward system during sleep and dreaming may contribute to adaptive memory processes, leading to subsequent performance improvement during wakefulness.

5. Conclusions

The main aim of this review was to demonstrate that sleep and dreaming, in particular emotions in dreams, serve vital functions by fostering adapted reactions to potential psychological (and physical)

threats (or rewards), and can thus jointly contribute to the optimization of waking functioning. Accordingly, emotional relevance would guide the selection of information to be further processed and consolidated in memory, yielding a continuous remodeling of memory networks and reshaping of future goals and behaviors. This emerging view is based on the integration of data generated at different levels of organization, from the basic neurobiology of reward and sleep to affective and cognitive levels encompassing dreaming and consciousness in humans. Such an integrated framework for the study of human sleep and dreaming is particularly necessary to accommodate the diversity and increasing sophistication of modern neuroimaging research. Actually, a fundamental objective for future studies will be to systematically investigate changes in brain activity and mental content across all sleep-wake states, and thus obtain a detailed characterization of the neural determinants of human conscious experience. These studies will be especially important because sleep curtailment emerges as a major health problem, with disastrous socioeconomic and public safety consequences. Thus, providing scientific evidence that sleep affects learning and emotion regulation is highly valuable to promote measures to prevent sleep restriction and its consequences, particularly in the most vulnerable populations, such as for example psychiatric patients or children.

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