Dreams, emotions and brain plasticity

Schwartz, Sophie

9º Simpósio da Fundação Bial

A Fundação BIAL é uma instituição sem fins lucrativos, considerada de utilidade pública pelo Governo português, que tem como missão incentivar o conhecimento científico do Homem, tanto do ponto de vista físico como espiritual.

Constituída em 1994 pelos Laboratórios BIAL e pelo Conselho de Reitores das Universidades Portuguesas, tem os altos patrocínios do Senhor Presidente da República e da Ordem dos Médicos.

A atividade da Fundação BIAL desenvolve-se através da atribuição do Prémio BIAL, um dos maiores galardões na área da saúde em toda a Europa, e do lançamento de Bolsas de Investigação Científica na área das Neurociências.

Bianualmente, a Fundação BIAL organiza os simpósios Aquém e Além do Cérebro, um espaço de diálogo aberto que reúne alguns dos mais prestigiados especialistas mundiais nas áreas da Psicofisiologia e da Parapsicologia e os seus bolseiros.

Nestes encontros, através da exposição de posters e das sessões de comunicações orais de um conjunto de projetos, a Fundação BIAL apresenta à comunidade científica os resultados das investigações dos seus bolseiros.

O livro de atas que agora se publica é uma compilação dos textos das palestras apresentadas durante o 9º Simpósio da Fundação BIAL dedicado ao tema “Sono e Sonhos”.

The BIAL Foundation is a non-profit-making institution, considered as a public utility by the Portuguese Government. Its main objective is to encourage the scientific study of Man, from both the physical and spiritual perspectives.

Established in 1994 by the Laboratórios BIAL and by the Council of Rectors of the Portuguese Universities, the BIAL Foundation includes among its patrons the President of Portugal and the Portuguese Medical Association.

The activity of the BIAL Foundation involves the BIAL Award, one of the most important awards in the field of health in Europe, and the Bial Fellowship Programme in the area of Neuroscience.

Every two years the BIAL Foundation organizes the "Behind and beyond the brain" symposium, – a discussion forum where dialogue is most encouraged – that brings together bursary-holders and several world-renowned experts in the fields of Psychophysiology and Parapsychology.

In these symposia, through posters session and oral communications of some of its supported projects, the BIAL Foundation presents to the scientific community the results of the scientific research developed by its Fellows.

The Proceedings that are now being published include the texts of the lectures presented during the 9th Symposium “Behind and Beyond the Brain” dedicated to the theme “Sleep and Dreams”.

9º Simpósio da Fundação Bial

AQUÉM E ALÉM DO CÉREBRO
BEHIND AND BEYOND THE BRAIN

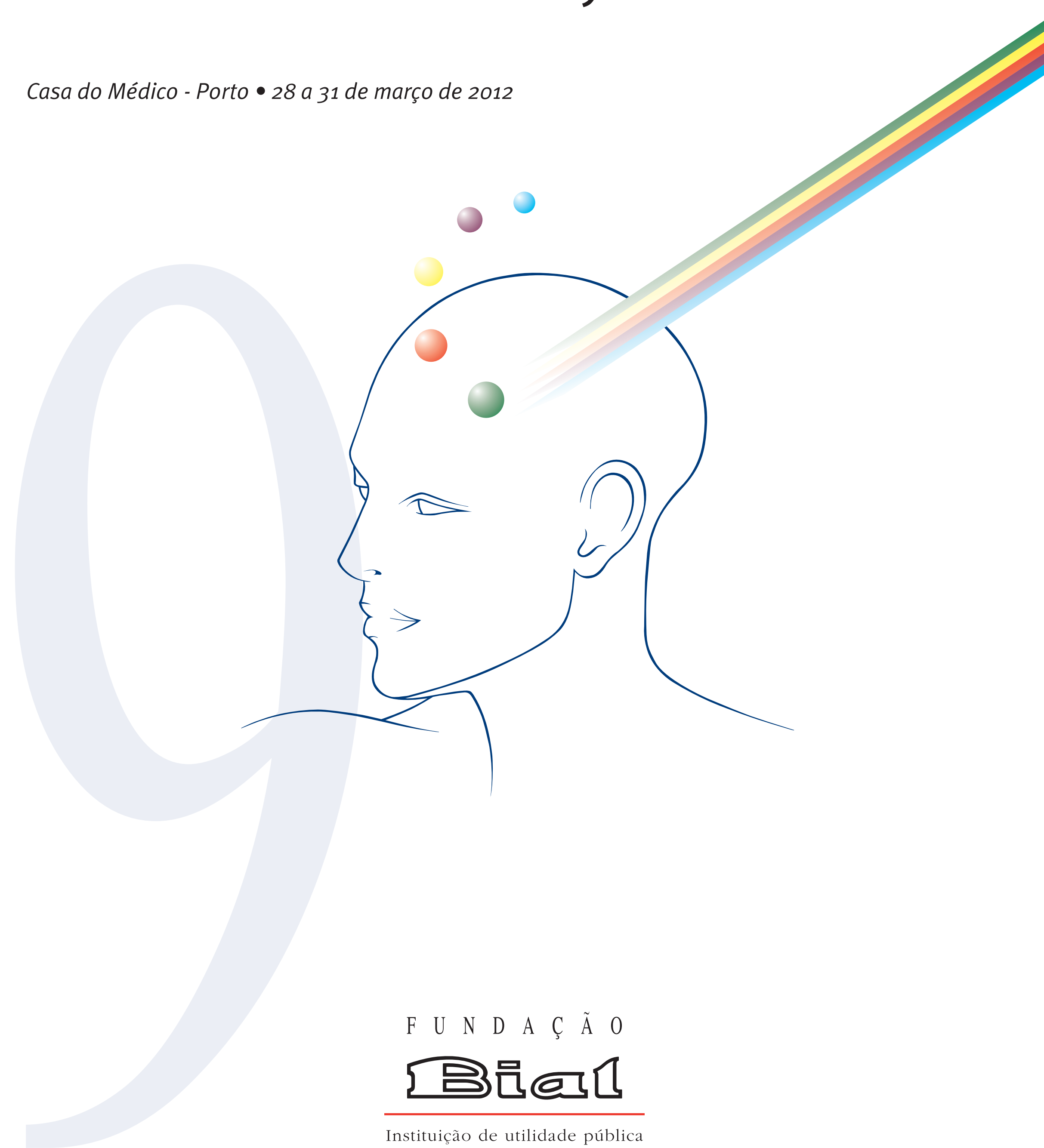
Bial

44

9º Simpósio da Fundação Bial

Aquém e Além do Cérebro
Behind and Beyond the Brain

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



FUNDAÇÃO
Bial

Instituição de utilidade pública
Institution of public utility

Sono e sonhos

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.
The texts are available at www.bial.com.

Foi publicado em 1ª edição pela Fundação Bial com uma tiragem de 2.250 exemplares.

It was published as 1st edition by Fundação Bial with a print run of 2.250 copies.

Execução Gráfica / *Printed by*: Multitema
Depósito Legal Nº 353797/13
ISBN: 978-972-99286-4-2

ÍNDICE
INDEX

SESSÃO DE ABERTURA / *OPENING SESSION*

CONFERÊNCIA INAUGURAL / *OPENING CONFERENCE*

PALESTRAS / *LECTURES*

Textos disponíveis em www.bial.com ***Texts availabe at www.bial.com***

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

* Faculty of Medicine, University of Geneva, Switzerland.

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 to 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.

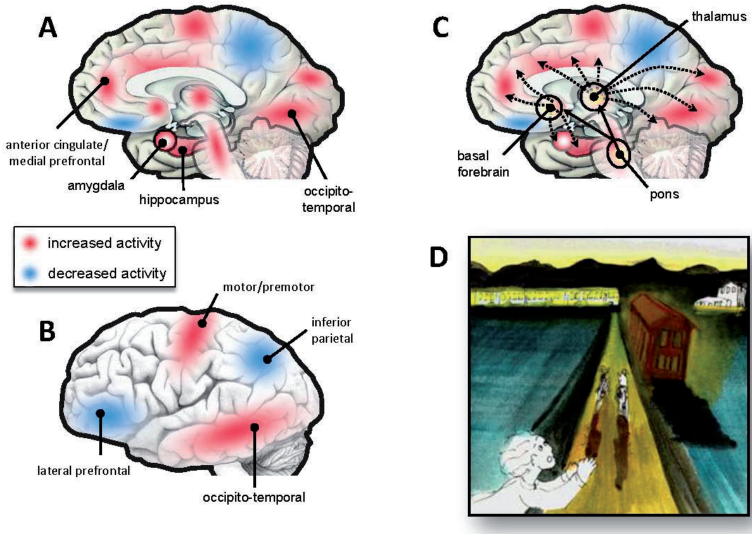


Figure 1. Distribution of activity in REM sleep and typical dream features. Regions showing increased or decreased brain activity in human brain imaging studies: (A) lateral view of the brain and (B) medial view. (B) Internally-generated activation during REM sleep: activation waves originating from 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 spontaneous 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.

Acknowledgments

This work is supported by the Swiss National Science Foundation and the Pierre Mercier Foundation.

References

1. Desseilles, M., Dang-Vu, T.T., Sterpenich, V., and Schwartz, S. (2011). Cognitive and emotional processes during dreaming: a neuroimaging view. Conscious Cogn 20, 998-1008.

2. Walker, M.P., and van der Helm, E. (2009). Overnight therapy? The role of sleep in emotional brain processing. Psychol Bull 135, 731-748.

3. Smith, M.R., Antrobus, J.S., Gordon, E., Tucker, M.A., Hirota, Y., Wamsley, E.J., Ross, L., Doan, T., Chaklader, A., and Emery, R.N. (2004). Motivation and affect in REM sleep and the mentation reporting process. Conscious Cogn 13, 501-511.

4. Valli, K., and Revonsuo, A. (2009). The threat simulation theory in light of recent empirical evidence: a review. Am J Psychol 122, 17-38.

5. Perogamvros, L., and Schwartz, S. (2012). The roles of the reward system in sleep and dreaming. Neurosci Biobehav Rev 36, 1934-1951.

6. Schwartz, S., and Maquet, P. (2002). Sleep imaging and the neuro-psychological assessment of dreams. Trends Cogn Sci 6, 23-30.

7. Hobson, J.A., Pace-Schott, E.F., Stickgold, R., and Kahn, D. (1998). To dream or not to dream? Relevant data from new neuroimaging and electrophysiological studies. Curr Opin Neurobiol 8, 239-244.

8. Schwartz, S. (2004). What dreaming can reveal about cognitive and brain functions during sleep: A lexico-statistical analysis of dream reports. Psychological Belgica 44, 5-42.

9. Maquet, P., Peters, J., Aerts, J., Delfiore, G., Degueldre, C., Luxen, A., and Franck, G. (1996). Functional neuroanatomy of human rapid-eye-movement sleep and dreaming. Nature 383, 163-166.

10. Rasch, B., and Born, J. (2007). Maintaining memories by reactivation. Curr Opin Neurobiol 17, 698-703.

11. Maquet, P. (2001). The role of sleep in learning and memory. Science 294, 1048-1052.

12. Wilson, M.A., and McNaughton, B.L. (1994). Reactivation of hippocampal ensemble memories during sleep. Science 265, 676-679.

13. Euston, D.R., Tatsuno, M., and McNaughton, B.L. (2007). Fast-forward playback of recent memory sequences in prefrontal cortex during sleep. Science 318, 1147-1150.

14. Pennartz, C.M., Lee, E., Verheul, J., Lipa, P., Barnes, C.A., and McNaughton, B.L. (2004). The ventral striatum in off-line processing: ensemble reactivation during sleep and modulation by hippocampal ripples. J Neurosci 24, 6446-6456.

15. Peyrache, A., Khamassi, M., Benchenane, K., Wiener, S.I., and Battaglia, F.P. (2009). Replay of rule-learning related neural patterns in the prefrontal cortex during sleep. Nat Neurosci 12, 919-926.

16. Lansink, C.S., Goltstein, P.M., Lankelma, J.V., McNaughton, B.L., and Pennartz, C.M. (2009). Hippocampus leads ventral striatum in replay of place-reward information. PLoS Biol 7, e1000173.

17. Lansink, C.S., Goltstein, P.M., Lankelma, J.V., Joosten, R.N., McNaughton, B.L., and Pennartz, C.M. (2008). Preferential reactivation of motivationally relevant information in the ventral striatum. J Neurosci 28, 6372-6382.

18. Peigneux, P., Laureys, S., Fuchs, S., Collette, F., Perrin, F., Reggers, J., Phillips, C., Degueldre, C., Del Fiore, G., Aerts, J., et al. (2004). Are spatial memories strengthened in the human hippocampus during slow wave sleep? Neuron 44, 535-545.

19. Maquet, P., Laureys, S., Peigneux, P., Fuchs, S., Petiau, C., Phillips, C., Aerts,

J., Del Fiore, G., Degueldre, C., Meulemans, T., et al. (2000). Experience-dependent changes in cerebral activation during human REM sleep. Nat Neurosci 3, 831-836.

20. Sterpenich, V., Albouy, G., Darsaud, A., Schmidt, C., Vandewalle, G., Dang Vu, T.T., Desseilles, M., Phillips, C., Degueldre, C., Balteau, E., et al. (2009). Sleep promotes the neural reorganization of remote emotional memory. J Neurosci 29, 5143-5152.

21. Sterpenich, V., Albouy, G., Boly, M., Vandewalle, G., Darsaud, A., Balteau, E., Dang-Vu, T.T., Desseilles, M., D'Argembeau, A., Gais, S., et al. (2007). Sleep-related hippocampo-cortical interplay during emotional memory recollection. PLoS Biol 5, e 282.

22. Maquet, P., Schwartz, S., Passingham, R., and Frith, C. (2003). Sleep-related consolidation of a visuomotor skill: brain mechanisms as assessed by functional magnetic resonance imaging. J Neurosci 23, 1432-1440.

23. Schwartz, S., Maquet, P., and Frith, C. (2002). Neural correlates of perceptual learning: a functional MRI study of visual texture discrimination. Proc Natl Acad Sci U S A 99, 17137-17142.

24. Diekelmann, S., and Born, J. (2010). The memory function of sleep. Nat Rev Neurosci 11, 114-126.

25. Waters, W.F., Adams, S.G., Jr., Binks, P., and Varnado, P. (1993). Attention, stress and negative emotion in persistent sleep-onset and sleep-maintenance insomnia. Sleep 16, 128-136.

26. Schmidt, R.E., and Van der Linden, M. (2009). The aftermath of rash action: sleep-interfering counterfactual thoughts and emotions. Emotion 9, 549-553.

27. Benca, R.M., Obermeyer, W.H., Thisted, R.A., and Gillin, J.C. (1992). Sleep and psychiatric disorders. A meta-analysis. Arch Gen Psychiatry 49, 651-668; discussion 669-670.

28. Baumann, C.R., and Bassetti, C.L. (2005). Hypocretins (orexins) and sleep-wake disorders. Lancet Neurol 4, 673-682.

29. Dang-Vu, T.T., Desseilles, M., Schwartz, S., and Maquet, P. (2009). Neuroimaging of narcolepsy. CNS Neurol Disord Drug Targets 8, 254-263.

30. Desseilles, M., Dang-Vu, T., Schabus, M., Sterpenich, V., Maquet, P., and Schwartz, S. (2008). Neuroimaging insights into the pathophysiology of sleep disorders. Sleep 31, 777-794.

31. Schwartz, S., Ponz, A., Poryazova, R., Werth, E., Boesiger, P., Khatami, R., and Bassetti, C.L. (2008). Abnormal activity in hypothalamus and amygdala during humour processing in human narcolepsy with cataplexy. Brain 131, 514-522.

32. Ponz, A., Khatami, R., Poryazova, R., Werth, E., Boesiger, P., Bassetti, C.L., and Schwartz, S. (2010). Abnormal activity in reward brain circuits in human narcolepsy with cataplexy. Ann Neurol 67, 190-200.

33. Harris, G.C., and Aston-Jones, G. (2006). Arousal and reward: a dichotomy in orexin function. Trends Neurosci 29, 571-577.

34. Ponz, A., Khatami, R., Poryazova, R., Werth, E., Boesiger, P., Schwartz, S., and Bassetti, C.L. (2010). Reduced amygdala activity during aversive conditioning in human narcolepsy. Ann Neurol 67, 394-398.

35. Levin, R., and Nielsen, T.A. (2007). Disturbed dreaming, posttraumatic stress disorder, and affect distress: a review and neurocognitive model. Psychol Bull 133, 482-528.

36. Nielsen, T., and Levin, R. (2007). Nightmares: a new neurocognitive model. Sleep Med Rev 11, 295-310.

37. Mellman, T.A., Bustamante, V., Fins, A.I., Pigeon, W.R., and Nolan, B. (2002). REM sleep and the early development of posttraumatic stress disorder. Am J Psychiatry 159, 1696-1701.

38. Wagner, U., Hallschmid, M., Rasch, B., and Born, J. (2006). Brief sleep after learning keeps emotional memories alive for years. Biol Psychiatry 60, 788-790.

39. Germain, A., Buysse, D.J., and Nofzinger, E. (2008). Sleep-specific mechanisms underlying posttraumatic stress disorder: integrative review and neurobiological hypotheses. Sleep Med Rev 12, 185-195.

40. Horne, J.A. (1993). Human sleep, sleep loss and behaviour. Implications for the prefrontal cortex and psychiatric disorder. Br J Psychiatry 162, 413-419.

41. Harrison, Y., and Horne, J.A. (2000). The impact of sleep deprivation on decision making: a review. J Exp Psychol Appl 6, 236-249.

42. Dinges, D.F., Pack, F., Williams, K., Gillen, K.A., Powell, J.W., Ott, G.E., Aptowicz, C., and Pack, A.I. (1997). Cumulative sleepiness, mood disturbance, and psychomotor vigilance performance decrements during a week of sleep restricted to 4-5 hours per night. Sleep 20, 267-277.

43. Yoo, S.S., Gujar, N., Hu, P., Jolesz, F.A., and Walker, M.P. (2007). The human emotional brain without sleep--a prefrontal amygdala disconnect. Curr Biol 17, R877-878.

44. McKenna, B.S., Dickinson, D.L., Orff, H.J., and Drummond, S.P. (2007). The effects of one night of sleep deprivation on known-risk and ambiguous-risk decisions. J Sleep Res 16, 245-252.

45. Venkatraman, V., Huettel, S.A., Chuah, L.Y., Payne, J.W., and Chee, M.W. (2011). Sleep deprivation biases the neural mechanisms underlying economic preferences. J Neurosci 31, 3712-3718.

46. Venkatraman, V., Chuah, Y.M., Huettel, S.A., and Chee, M.W. (2007). Sleep deprivation elevates expectation of gains and attenuates response to losses following risky decisions. Sleep 30, 603-609.

47. Chee, M.W., and Chuah, L.Y. (2008). Functional neuroimaging insights into how sleep and sleep deprivation affect memory and cognition. Curr Opin Neurol 21, 417-423.

48. Gujar, N., Yoo, S.S., Hu, P., and Walker, M.P. (2011). Sleep deprivation amplifies reactivity of brain reward networks, biasing the appraisal of positive emotional experiences. J Neurosci 31, 4466-4474.

49. Holm, S.M., Forbes, E.E., Ryan, N.D., Phillips, M.L., Tarr, J.A., and Dahl, R.E. (2009). Reward-related brain function and sleep in pre/early pubertal and mid/late pubertal adolescents. J Adolesc Health 45, 326-334.

50. Haber, S.N., and Knutson, B. (2010). The reward circuit: linking primate anatomy and human imaging. Neuropsychopharmacology 35, 4-26.

51. Wagner, U., Gais, S., and Born, J. (2001). Emotional memory formation is enhanced across sleep intervals with high amounts of rapid eye movement sleep. Learn Mem 8, 112-119.

52. Payne, J.D., Stickgold, R., Swanberg, K., and Kensinger, E.A. (2008). Sleep preferentially enhances memory for emotional components of scenes. Psychol Sci 19, 781-788.

53. Wamsley, E.J., and Stickgold, R. (2010). Dreaming and offline memory processing. Curr Biol 20, R1010-1013.

54. Wamsley, E.J., Tucker, M., Payne, J.D., Benavides, J.A., and Stickgold, R. (2010). Dreaming of a learning task is associated with enhanced sleep-dependent memory consolidation. Curr Biol 20, 850-855.

55. Mancia, M. (2004). The dream between neuroscience and psychoanalysis. Arch Ital Biol 142, 525-531.

56. Cartwright, R., Agargun, M.Y., Kirkby, J., and Friedman, J.K. (2006). Relation of dreams to waking concerns. Psychiatry Res 141, 261-270.

57. Schredl, M. (2010). Characteristics and contents of dreams. Int Rev Neurobiol 92, 135-154.

58. Nofzinger, E.A., Mintun, M.A., Wiseman, M., Kupfer, D.J., and Moore, R.Y. (1997). Forebrain activation in REM sleep: an FDG PET study. Brain Res 770, 192-201.

59. Revonsuo, A. (2000). The reinterpretation of dreams: an evolutionary hypothesis of the function of dreaming. Behav Brain Sci 23, 877-901; discussion 904-1121.

60. Valli, K., Revonsuo, A., Palkas, O., Ismail, K.H., Ali, K.J., and Punamaki, R.L. (2005). The threat simulation theory of the evolutionary function of dreaming: Evidence from dreams of traumatized children. Conscious Cogn 14, 188-218.

61. Revonsuo, A., and Valli, K. (2008). How to test the threat-simulation theory. Conscious Cogn 17, 1292-1296; discussion 1297-1301.

62. Maloney, K.J., Mainville, L., and Jones, B.E. (2002). c-Fos expression in dopaminergic and GABAergic neurons of the ventral mesencephalic tegmentum after paradoxical sleep deprivation and recovery. Eur J Neurosci 15, 774-778.

63. Lena, I., Parrot, S., Deschaux, O., Muffat-Joly, S., Sauvinet, V., Renaud, B., Suaud-Chagny, M.F., and Gottesmann, C. (2005). Variations in extracellular levels of dopamine, noradrenaline, glutamate, and aspartate across the sleep--wake cycle in the medial prefrontal cortex and nucleus accumbens of freely moving rats. J Neurosci Res 81, 891-899.

64. Dahan, L., Astier, B., Vautrelle, N., Urbain, N., Kocsis, B., and Chouvet, G. (2007). Prominent burst firing of dopaminergic neurons in the ventral tegmental area during paradoxical sleep. Neuropsychopharmacology 32, 1232-1241.

65. Dzirasa, K., Ribeiro, S., Costa, R., Santos, L.M., Lin, S.C., Grosmark, A., Sotnikova, T.D., Gainetdinov, R.R., Caron, M.G., and Nicolelis, M.A. (2006). Dopaminergic control of sleep-wake states. J Neurosci 26, 10577-10589.

66. Carter, R.M., Macinnes, J.J., Huettel, S.A., and Adcock, R.A. (2009). Activation in the VTA and nucleus accumbens increases in anticipation of both gains and losses. Front Behav Neurosci 3, 21.

67. Delgado, M.R., Li, J., Schiller, D., and Phelps, E.A. (2008). The role of the striatum in aversive learning and aversive prediction errors. Philos Trans R Soc Lond B Biol Sci 363, 3787-3800.