Experimental research on dreaming: state of the art and neuropsychoanalytic perspectives

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Dreaming is still a mystery of human cognition, although it has been studied experimentally for more than a century. Experimental psychology first investigated dream content and frequency. The neuroscientific approach to dreaming arose at the end of the 1950s and soon proposed a physiological substrate of dreaming: rapid eye movement sleep. Fifty years later, this hypothesis was challenged because it could not explain all of the characteristics of dream reports. Therefore, the neurophysiological correlates of dreaming are still unclear, and many questions remain unresolved. Do the representations that constitute the dream emerge randomly from the brain, or do they surface according to certain parameters? Is the organization of the dream's representations chaotic or is it determined by rules? Does dreaming have a meaning? What is/are the function(s) of dreaming? Psychoanalysis provides hypotheses to address these questions. Until now, these hypotheses have received minimal attention in cognitive neuroscience, but the recent development of neuropsychoanalysis brings new hopes of interaction between the two fields. Considering the psychoanalytical perspective in cognitive neuroscience would provide new directions and leads for dream research and would help to achieve a comprehensive understanding of dreaming. Notably, several subjective issues at the core of the psychoanalytic approach, such as the concept of personal meaning, the concept of unconscious episodic memory and the subject's history, are not addressed or considered in cognitive neuroscience. This paper argues that the focus on singularity and personal meaning in psychoanalysis is needed to successfully address these issues in cognitive neuroscience and to progress in the understanding of dreaming and the psyche.

Keywords: dream, neurophysiological correlates of dreaming, dream functions, unconscious, personal meaning, neuroimaging, psychoanalysis

The word "dream" is commonly used to express an unattainable ideal or a very deep and strong desire:

> I have a dream that my four little children will one day live in a nation where they will not be judged by the color of their skin, but by the content of their character.
>
> Martin Luther King

In dream reports, however, one often notices banal situations, strange scenes, or even frightening events. Why is there such a contrast between the popular meaning of the word "dream" and the content of dream reports? Why are some dream scenes so bizarre? Are dreams built from images that arise randomly from the sleeping brain? Or is the emergence and organization of dream images controlled by currently unknown parameters? Does dreaming have a function?

Answering these questions is not easy because dreaming is elusive. We still do not know when it happens during the night, how long it lasts, whether we can recall its entire content, or how to control it. For more than a century, such limited understanding of dreaming has seriously hampered experimental investigations. Nonetheless, scientific research has managed to produce considerable information about the phenomenology and physiology of dreaming and has improved our understanding of this fascinating phenomenon.

EXPERIMENTAL RESEARCH ON DREAMING
DREAMING AND EXPERIMENTAL PSYCHOLOGY
Dream content

Dreaming was first investigated on an experimental level in the nineteenth century. Calkins (1893) published the first statistical results about dreaming and argued that some aspects of dream content could be quantified. Later, questionnaires and automatic analysis of the lexical content of dream reports allowed psychologists to show that dream content has some precise phenomenological characteristics. According to psychological studies (Hall and Van de Castle, 1966; Schwartz, 1999), visual imagery occurs more frequently in dreams than imagery of other senses (audition, olfaction, touch, and taste); the dream drama is mostly lived by the dreamer from a first-person perspective; some elements of real-life events previously experienced by the dreamer often contribute to the scene of the dream; most often, the dream sequence is not within the dreamer's voluntary control (i.e., the dreamer

may be convinced during the dream that the dream's story is really happening); temporal and spatial incoherencies can occur in the dream story; the dream report is often full of people interacting with each other (e.g., discussions, fights, pursuit, sexuality); and finally, the dream report often contains strong emotions.

Substantial variability of content exists, however, among the same individual's dreams and among the dreams of different individuals. Further, psychological studies have shown that many internal and external parameters can influence dream content. For example, males report more aggression and violence in their dreams than do females (Nielsen et al., 2003; Schredl et al., 2004). External stimulation perceived by the dreamer can be incorporated into dreams (Koulack, 1969; Saint-Denys, 1867; Hoelscher et al., 1981), as illustrated by the famous Dali painting *Dream Caused by the Flight of a Bee around a Pomegranate a Second before Awakening*. The current concerns of the subject may also be found in the content of his/her dreams (Schwartz, 1999; Domhoff and Schneider, 2008), and many aspects of the subject's daily life were found to influence dream content, including news events (Bulkeley and Kahan, 2008), musical practice (Uga et al., 2006), religious beliefs (Domhoff and Schneider, 2008), chronic pain (Raymond et al., 2002), mood (Cartwright et al., 1998a), or a violent living environment (Valli et al., 2005). By contrast, congenital or acquired malformations do not seem to significantly influence dream content (Voss et al., 2010; Saurat et al., 2011).

Based on these results, two opposing hypotheses were formulated: the continuity hypothesis (Schredl and Hofmann, 2003) and the discontinuity hypothesis (Rechtschaffen, 1978; Kahn et al., 1997; Stickgold et al., 2001). The former relies on results showing that the themes of an individual's thoughts during waking life and dreaming are similar; the latter focuses on the fundamentally different structures of thoughts during waking life and dreaming. Voss et al. (2010) stressed in their recent paper that these hypotheses represent oversimplified approaches to dream analysis and argued that waking and dreaming thoughts were related but structurally independent; in other words, she argued in favor of merging the continuity and discontinuity hypotheses.

Dream report frequency

Dream report frequency (DRF) can vary within subjects and varies substantially among subjects. In a study of 900 German subjects with a large age range from various socioprofessional categories, the mean DRF was approximately 1 dream report per week (Schredl, 2008). This result shows that the dream experience is common and familiar to everyone. Psychological studies have demonstrated that many parameters covary with DRF and may thus influence it.

Sleep parameters.   First, DRF varies according to the sleep stage preceding awakening (e.g., Dement and Kleitman, 1957b; Nielsen, 2000, for a review). More dream reports are obtained after an awakening during rapid eye movement (REM) sleep than after an awakening during non-REM (NREM) sleep. These results inspired the REM sleep hypothesis of dreaming (see the section Dreaming and Neuroscience). Second, DRF increases with the number of awakenings during sleep, according to retrospective self-evaluations of awakenings (Cory and Ormiston, 1975; Schredl

et al., 2003). Such studies showed that the more the subjects tended to awaken during sleep, the higher their DRF. These results support the hypothesis of Koulack and Goodenough (1976), which proposes that nocturnal awakenings facilitate the encoding of the dream in memory and thus facilitate dream recall upon awakening. However, this hypothesis has not been tested by measuring awakenings with polysomnographic recordings in healthy subjects with various DRFs. Finally, DRF varies according to the method of awakening. Abrupt awakenings lead to more dream reports than gradual awakenings (Shapiro et al., 1963, 1965; Goodenough et al., 1965).

Physiological and environmental parameters.   Dream report frequency deceases with age (e.g., Schredl, 2008) and tends to be slightly higher among females than males (e.g., Schredl, 2008; Schredl and Reinhard, 2008). Remarkably, Schredl's (2008) results revealed that DRF also varied according to the size of the subject's place of residence.

Psychological parameters.   First, increased professional stress or interpersonal stress resulted in an increase in DRF (for a review, see Schredl, 1999). Second, an interest in dreams or a positive attitude toward dreams clearly covaries with DRF (Hill et al., 1997; Schredl, 1999; Schredl et al., 2003). The greater an individual's interest in dreams, the higher his/her DRF. Third, several cognitive abilities have been found to covary with DRF. Contradictory results have been reported for the correlation between DRF and memory abilities (short-term, long-term, visual, verbal, implicit, and explicit; significant positive correlation: Cory and Ormiston, 1975; Belicki et al., 1978; Butler and Watson, 1985; Schredl et al., 1995; Solms, 1997; no significant correlation: Cohen, 1971; Belicki et al., 1978; Schredl et al., 1995, 1997, 2003; Solms, 1997) and the correlation between DRF and visual imagery (*significant positive correlation*: Hiscock and Cohen, 1973; Richardson, 1979; Okada et al., 2000; *no significant correlation*: Hill et al., 1997; Okada et al., 2000). However, several studies have consistently shown that DRF is positively correlated with creativity (Fitch and Armitage, 1989; Schredl, 1999; Schredl et al., 2003) and intelligence scales (multiple-choice vocabulary test, Schonbar, 1959; Shipley Intelligence Scale, Connor and Boblitt, 1970). Finally, many authors have reported a correlation between DRF and personality traits. Subjects with a high DRF are more likely to have a personality with thinner boundaries (Hartmann described people with thin boundaries as being open, trustworthy, vulnerable, and sensitive; Hartmann, 1989; Hartmann et al., 1991; Schredl et al., 2003), to be more anxious (Schonbar, 1959; Tart, 1962), to have a higher level of absorption (the absorption scale measures the capacity to become absorptively involved in imaginative and esthetic experiences; Hill et al., 1997; Schredl, 1999; Schredl et al., 2003), to be more open to experience (Hill et al., 1997; Schredl et al., 2003), and to be less alexithymic (alexithymia is a personality variable that incorporates difficulty identifying and describing feelings, difficulty distinguishing between feelings and the physical sensation of emotional arousal, limited imaginative processes, and an externally oriented cognitive style; De Gennaro et al., 2003; Nielsen et al., 2011) compared to subjects with a low dream recall frequency. However, those results have not always been reproducible (e.g., Schredl, 2002 for

openness to experience; Cory and Ormiston, 1975; Hill et al., 1997 for anxiety; Nielsen et al., 1997 for alexithymia) and, according to the recent review by Blagrove and Pace-Schott (2010), it is difficult to draw conclusions about a possible link between personality traits and DRF.

In conclusion, numerous parameters have been identified that covary with DRF. Schredl stressed in many of his papers that the studied parameters usually explain only a small percentage of the total variance (e.g., Schredl, 2008). Thus, the DRF variation profile suggests that the production, encoding and recall of dreams are influenced by numerous parameters that probably interact with each other.

DREAMING AND NEUROSCIENCE

The neuroscientific approach to dreaming arose at the end of the 1950s with the discovery of REM during human sleep by the American physiologist Nathaniel Kleitman and his team (Aserinsky and Kleitman, 1953; Dement and Kleitman, 1957a). During these sleep episodes with saccades, the researchers noticed a decrease in voltage and an increase in frequency in the EEG, accompanied by an increase in cardiac frequency variability and a decrease in body movements. They concluded that these physiological modifications indicate a particular sleep stage, which they called REM sleep. A few years later, the French team led by neurobiologist Michel Jouvet discovered that the lack of movement during REM sleep in cats was due to a general muscular atonia, controlled notably by the locus coeruleus α in the brainstem (Jouvet and Michel, 1959; Berger, 1961 later showed that muscular atonia during REM sleep also occurs in humans). Interestingly, the inability to move during REM sleep indicates deep sleep and paradoxically, the fast EEG activity of REM sleep resembles EEG activity in wakefulness. Jouvet concluded that this particular physiological state is associated with a "third state" of the brain (in addition to the brain states associated with wakefulness and NREM sleep) which he called "paradoxical sleep" instead of "REM sleep" (Jouvet et al., 1959; Jouvet, 1992). Several years later, Fisher et al. (1965) discovered another physiological characteristic of REM sleep: the penile erection.

During the same period, the American team noticed that a subject awakened during REM sleep very often reported a dream (80% of awakenings in REM sleep vs. 6% of awakenings in NREM sleep are followed by a dream report, according to Dement and Kleitman, 1957b). Researchers concluded that dreaming occurs during REM sleep. The eye movements of REM sleep would allow the dreamer to scan the imaginary scene of the dream (the scanning hypothesis); the cerebral cortex activation revealed by the rapid EEG would allow intense cognitive activity, creating the complex stories of a dream; and the lack of muscle tone would prevent the dreamer from acting out his dreams. From that time on, researchers investigated REM sleep to obtain answers about dreaming.

In the 1990s, researchers used functional neuroimaging techniques such as positron emission tomography (PET) to investigate brain activity during REM sleep in humans. This new approach enabled researchers to demonstrate that the functional organization of the brain during REM sleep is different from the functional organization of the brain during wakefulness (Maquet et al., 1996;

Braun et al., 1998). In comparison to wakefulness, brain activity during REM sleep is decreased in some brain regions (e.g., in the dorsolateral prefrontal cortex; Braun et al., 1998) and increased in other regions (e.g., in the occipital and temporal cortex, the hippocampus and parahippocampus, the anterior cingulate, the precentral and postcentral gyri, the superior parietal cortex, and the pons; Braun et al., 1998; Maquet et al., 2000). Looking more generally for brain activity correlating with REM sleep (the vigilance states considered included wakefulness, slow-wave sleep, and REM sleep), Maquet et al. (1996) found negative correlations in the precuneus, posterior cingulate cortex, temporoparietal junction, and dorsolateral prefrontal cortex and positive correlations in the amygdala, anterior cingulate, postcentral gyrus, thalamus, and pons (see Schwartz and Maquet, 2002; Maquet et al., 2005; Nir and Tononi, 2010 for reviews). Based on these results, researchers argued that the particular functional organization of the brain during REM sleep could explain the phenomenological characteristics of dream reports (Hobson and Pace-Schott, 2002; Schwartz and Maquet, 2002; Maquet et al., 2005; Nir and Tononi, 2010). They considered that brain activity increases and decreases during REM sleep could be interpreted on the basis of what we know about brain activity during wakefulness. In this context, the increased occipital cortex activity during REM sleep could explain the visual component of dream reports because neuroimaging results during wakefulness showed that visual imagery with the eyes closed activates the occipital cortex (Kosslyn and Thompson, 2003). The decreased activity in the temporoparietal junction during REM sleep may explain why dreams are mainly experienced in the egocentric coordinates of the first-person; indeed, during wakefulness, activity in the temporoparietal junction was reported to be greater for allocentric vs. egocentric representation (e.g., Ruby and Decety, 2001; Zacks et al., 2003) and for third- vs. first-person perspective (e.g., Ruby and Decety, 2003, 2004). The increased activity in the hippocampus during REM sleep could explain why dreams are often composed of known images or characters, as the hippocampus is known to be associated with the encoding and retrieval of lived events during wakefulness (e.g., Piolino et al., 2009). The decreased activity in the lateral prefrontal cortex during REM sleep could explain why dream stories lack consistency, why the dreamer's perception of time is altered, why the dream story is beyond the control of the dreamer and why the dreamer is convinced that the dream story is really happening. Indeed, during wakefulness, the lateral prefrontal cortex is involved in executive function, cognitive control, and working memory (Petrides, 2005; Koechlin and Hyafil, 2007). The increased activity in the medial prefrontal cortex during REM sleep could explain the attribution of thoughts, beliefs, and emotions to the characters in the dream because, during wakefulness, the medial prefrontal cortex is known to participate in mind reading (Ruby et al., 2007, 2009; Legrand and Ruby, 2009). The increased activity in the motor cortex (precentral gyrus) during REM sleep could explain the movements of the characters' bodies in the dream because, during wakefulness, motor imagery, and the imagination of someone's action from the third-person perspective involve the precentral gyrus (Decety et al., 1994; Ruby and Decety, 2001). Finally, the amygdala's activity during REM sleep could explain why emotions, especially fear, are often mentioned in dream reports; indeed, the amygdala is

involved in the processing of emotional stimuli during wakefulness (Adolphs, 2008).

In conclusion, results from experimental psychology and neuroscience allow us to better understand the phenomenology of dreaming and the cerebral correlates of some characteristics of dream reports. Still, what do they tell us about the role of dreaming? What are the current hypotheses about dream function(s)?

HYPOTHESES ABOUT DREAM FUNCTION(S)
No function
At the end of the twentieth century, the neurologist Alan Hobson, who was profoundly anti-psychoanalysis, proposed a theory that deprived dreaming of any function. Hobson argued that dreaming is an epiphenomenon of REM sleep: "Because dreams are so difficult to remember, it seems unlikely that attention to their content could afford much in the way of high-priority survival value. Indeed, it might instead be assumed that dreaming is an epiphenomenon of REM sleep whose cognitive content is so ambiguous as to invite misleading or even erroneous interpretation" (Hobson et al., 1998).

Psychological individualism
In contrast, other teams, like Michel Jouvet's, believed that dreaming serves a vital function. In 1979, Jouvet's team blocked muscular atonia during REM sleep in a cat by damaging the locus coeruleus α in its brainstem. This lesion resulted in the appearance of movements during REM sleep. Movies from the Jouvet lab show sleeping cats performing complex motor actions (with altered control and coordination) resembling those of wakefulness, such as fur licking, growling, chasing prey, mastication, and fighting. From these videos, the authors concluded that the cat was acting out its dream, and they called this non-physiological state "oneiric behavior" (Sastre and Jouvet, 1979). These results led Jouvet to propose that dreaming plays a role in reinforcing a species' typical behavior. Later in his career, Jouvet moved toward a hypothesis focusing on the role of dreaming in the individual dimension. He speculated that dreams (note that, for Jouvet, dreams and paradoxical sleep were equivalent) could be involved in psychological individualism and in the stability of the dreamer's personality (Jouvet, 1991, 1992, 1998). According to Jouvet, "the brain is the sole organ of homeotherms that do not undergo cell division. We thus have to explain how certain aspects of psychological heredity (found in homozygote twins raised in different surroundings) may persist for a whole life (psychological individuation). A definitive genetic programming during development (by neurogenesis) is unlikely due to the plasticity of the nervous system. That is why we have to consider the possibility of an iterative genetic programming. The internal mechanisms (synchronous) of paradoxical sleep (SP) are particularly adapted to such programming. This would activate an endogenous system of stimulation that would stimulate and stabilize receptors genetically programmed by DNA in some neuronal circuits. The excitation of these neurons during SP leads to oniric behaviors that could be experimentally revealed – the lists of these behaviors are specific to each individual and indirect data suggest a genetic component of this programming. Amongst the mechanisms allowing the iterative programming of SP, sleep is particularly important. Security – and hence the inhibition of

the arousal system – is a *sine qua non-condition* for genetic programming to take place. In that sense, sleep could very well be the guardian of dreaming" (Jouvet, 1991). In other words, Jouvet's hypothesis is that paradoxical sleep restores neuronal circuitry that was modified during the day to preserve the expression of the genetic program that codes for psychological characteristics. This process would ensure the stability of personality across time.

The threat simulation theory
The Finnish psychologist Antti Revonsuo recently proposed a hypothesis called threat simulation theory, which explains the fearful characteristics of dream content (Revonsuo, 2000; Valli and Revonsuo, 2009). According to this theory, dreams serve as virtual training places to improve threat avoidance or threat fighting ability. The theory postulates that such nocturnal training makes the dreamer more efficient at resolving threatening situations during wakefulness.

Emotional regulation
Cartwright et al. (1998a,b) defended the idea that dreaming is involved in emotional regulation. Her team showed that, in healthy subjects, the depression level before sleep was significantly correlated with affect in the first REM report. Her team also observed that low scorers on the depression scale displayed a flat distribution of positive and negative affect in dreams, whereas those with a depressed mood before sleep showed a pattern of decreasing negative and increasing positive affect in dreams reported from successive REM periods (Cartwright et al., 1998a). These results led Cartwright's team to suggest that dreaming may actively moderate mood overnight in normal subjects. The team strengthened this hypothesis by showing that among subjects who were depressed because of a divorce, those who reported more negative dreams at the beginning of sleep and fewer at the night's end were more likely to be in remission 1 year later than subjects who had fewer negative dreams at the beginning of sleep and more at the end of the night (Cartwright et al., 1998b). The researchers concluded that negative dreams early in the night may reflect a within-sleep mood regulation process, whereas those that occur later may indicate a failure in the completion of this process.

Memory consolidation
Finally, a current mainstream hypothesis in cognitive neuroscience credits sleep and dreaming with a role in memory consolidation (for a recent review, see Diekelmann and Born, 2010). Numerous studies have shown that brain activity during training is replayed during post-training sleep (e.g., using a serial reaction time task Maquet et al., 2000, demonstrated replay during REM sleep; using a maze exploration task Peigneux et al., 2004, demonstrated replay during slow-wave sleep). Decreased performance during the post-training day in sleep-deprived subjects further suggested that the replay of brain activity at night contributes to memory consolidation (e.g., Maquet et al., 2003). Only recently, however, have experimental results in humans argued in favor of a role of dreaming *per se* in memory consolidation. In one study, subjects were trained on a virtual navigation task before taking a nap. Post-nap tests showed that subjects who dreamed about the task performed better than subjects who did not dream (note that only 4 out of 50 subjects dreamed about the task in this study;

Wamsley et al., 2010). Using a different approach, Nielsen and colleagues provided additional arguments supporting a link between dreams and memory (Nielsen et al., 2004; Nielsen and Stenstrom, 2005). This team demonstrated that dreams preferably incorporate events that the dreamer lived the day before and events that the dreamer lived 7 days before the dream (U shaped curve). Animal studies have shown that after associative learning, the excitability of hippocampal cells increases (which leads to an increase in neuronal plasticity) and then returns to baseline 7 days after training (Thompson et al., 1996). The similarity between the delay of episodic event incorporation into dreams and the delay of post-training cellular plasticity in the hippocampus led the Canadian team to suggest a link between dreaming and episodic memory consolidation.

In summary, the preceding section describes the current state of the art on dreaming, its phenomenology and cerebral correlates and hypotheses about its functions. Some substantial advances have been made, but much remains to be understood.

UNRESOLVED ISSUES

THE LINK BETWEEN ONEIRIC BEHAVIORS AND DREAM REPORTS

A piece of evidence in favor of a strong link between REM sleep and dreaming is the oneiric behavior (the appearance of complex motor behaviors when motor inhibition is suppressed during REM sleep) discovered by Sastre and Jouvet (1979) in cats and reproduced by Sanford et al. (2001) in rats. Researchers interpreted these results as the animal acting out its dream. However, as animals do not talk, the link between oneiric behavior and dream recall cannot be tested experimentally. This limitation seriously hampers our understanding of dreaming. In humans, complex motor behaviors (e.g., talking, grabbing, and manipulating imaginary objects, walking, and running) can also occur during REM sleep in a pathological context. This syndrome is called REM sleep behavior disorder (RBD). It can be caused by substance withdrawal (e.g., alcohol, Nitrazepam) or intoxication (e.g., caffeine, tricyclic antidepressants) or by various diseases (e.g., Parkinson's and Alzheimer's diseases, pontine neoplasms). According to physicians experts on this syndrome, some patients report dreams that are consistent with their behaviors in REM sleep (Mahowald and Schenck, 2000). According to the literature, however, such matches seem to be loose and not systematic. Only one study has tested whether observers can link dream content to sleep behaviors in RBD (Valli et al., 2011). In this study, each video recording of motor manifestations was combined with four dream reports, and seven judges had to match the video clip with the correctly reported dream content. The authors found that reported dream content can be linked to motor behaviors at a level better than chance. However, only 39.5% of video-dream pairs were correctly identified. Note, however, that because the authors obtained only movements and not behavioral episodes for many RBD patients, the link between videos and dream reports was unfairly difficult to make.

It is important to note that motor behavior during sleep can happen outside of REM sleep. Sleepwalking and sleep terrors, which occur during NREM sleep, are usually not considered dream enactments. However, we know that dreams can happen during NREM sleep, and many patients report dreamlike mentation after awakening from sleepwalking or sleep terrors (71%, according to Oudiette et al., 2009). In addition, Oudiette et al. (2009) reported that the dreamlike mentation can correspond with the sleep behavior in NREM sleep. Consequently, the authors concluded that sleepwalking may represent an acting out of corresponding dreamlike mentation.

Recent research suggests that any kind of motor behavior during sleep can be considered an oneiric behavior. One of the challenges for future research is to test the strength of the link between these oneiric behaviors and dream reports in a controlled and systematic way.

NEUROPHYSIOLOGICAL CORRELATES OF DREAMING

Despite the numerous neuroimaging studies of sleep in humans, the neurophysiological correlates of dreaming remain unclear.

Indeed, dreaming can happen during NREM sleep, and although NREM brain activity differs substantially from REM sleep brain activity (Maquet et al., 2000; Buchsbaum et al., 2001), some NREM dreams are phenomenologically indistinguishable from REM dreams (Hobson, 1988; Cavallero et al., 1992; Cicogna et al., 1998; Wittmann et al., 2004). This phenomenon is difficult to understand given what we currently know about the sleeping brain and about dreaming. One explanation may rely on the possibility that brain activity during sleep is not as stable as we think.

Brain activity during REM sleep in humans is considered to be well understood (Hobson and Pace-Schott, 2002; Schwartz and Maquet, 2002; Nir and Tononi, 2010), but several results question this notion. First, contrary to the common belief that dorsolateral prefrontal cortex activity decreases during REM sleep, several studies have reported increased activity in the dorsolateral prefrontal cortex during REM sleep (Hong et al., 1995, 2009; Nofzinger et al., 1997; Kubota et al., 2011). Second, brain activity during REM sleep is heterogeneous. The mean regional cerebral blood flow during 1 min of REM sleep (e.g., as reported in Maquet et al., 1996) and the regional cerebral blood flow associated with the rapid eye movements of REM sleep (Hong et al., 2009; Miyauchi et al., 2009) highlight different brain regions. Finally, few congruencies have been noted in the results of studies investigating brain activity during REM sleep (Hong et al., 1995, 2009; Maquet et al., 1996, 2000; Braun et al., 1997, 1998; Nofzinger et al., 1997; Peigneux et al., 2001; Wehrle et al., 2005; Miyauchi et al., 2009; Kubota et al., 2011), even between studies using the same technique and the same contrasts (e.g., Braun et al., 1998; Maquet et al., 2000), or between studies investigating the same REM event (e.g., brain activity associated with rapid eyes movements, as in Peigneux et al., 2001; Wehrle et al., 2005; Hong et al., 2009; Miyauchi et al., 2009). Furthermore, few brain regions are consistently reported across the majority of the studies. This inconsistency suggests great intra- and intersubject variability in brain activity during REM sleep in humans. A challenge for future research will be to find out whether the variability in brain activity during REM sleep can be explained by the variability in dream content.

Because dream reports can be collected after awakenings from any sleep stage, one may hypothesize that the brain activity that subserves dreaming (if such brain activity is reproducible across dreams) is quite constant throughout the night and can be observed during all sleep stages. Some results have supported

this hypothesis and encouraged further attention in this direction. Buchsbaum et al. (2001), for example, reported that metabolism in the primary visual areas and certain parts of the lateral temporal cortex does not fluctuate much across REM and slow-wave sleep. Similarly, Nielsen's team found that dream recall (vs. no dream recall) was associated with decreased alpha (8–12 Hz) power in the EEG preceding awakening, regardless of the sleep stage (Stage 2 or REM sleep; Esposito et al., 2004). Interestingly, some authors have suggested that decreased power in the alpha band during wakefulness reflects search and retrieval processes in long-term memory (for a review, see Klimesch, 1999).

PROCESSES OF SELECTION AND ORGANIZATION OF DREAM REPRESENTATIONS

Nielsen's team found that episodic events from the 1, 7, and 8 days before a dream were more often incorporated into the dream than were events from 2 or 6 days before the dream (Nielsen et al., 2004; results reproduced by Blagrove et al., 2011). This result tells us that internal processes control and shape dream content and thus help us to constrain and shape hypotheses about the function and biological basis of dreaming.

At the end of the nineteenth century, Saint-Denys (1867) showed that a sensory stimulus (e.g., the scent of lavender) presented to a sleeping subject without his or her knowledge could induce the incorporation of an event associated with the stimulus (e.g., holidays spent near a lavender field) into the dream, regardless of the delay between the dream and the association stimulus/events (lavender scent/holidays). The author demonstrated that the external world can influence dream content in a direct or indirect way.

Finally, it appears that both external and internal parameters can shape or govern dream content. Nonetheless, few of these parameters are known, and some regularities in the phenomenology of dreams suggest that more influencing parameters remain to be discovered. For example, some individuals experience recurring themes, characters, or places in their dreams. In line with this observation, Michael Schredl's team showed that the content and style of a person's life strongly influence dream content (Schredl and Hofmann, 2003). However, the rule(s) governing which lived events are incorporated into dreams remain unknown. Do the representations constituting the dream emerge randomly from the brain, or do they surface according to certain parameters? Similarly, is the organization of the dream's representations chaotic, or is it determined by rules? Does dreaming have a meaning? What is/are the function(s) of dreaming?

DREAMING, PSYCHOANALYSIS, AND NEUROPSYCHOANALYSIS

Psychoanalysis, which was developed by the neurologist Sigmund Freud in the beginning of the twentieth century, proposes answers to the questions raised above. Indeed, his theory of the human mind comprises hypotheses about the rules of selection and organization of the representations that constitute dreams.

At the beginning of the twentieth century, Freud presented the concept of the unconscious. He proposed that a part of our mind is made up of thoughts, desires, emotions, and knowledge that we are not aware of, but that nevertheless profoundly influence and guide our behaviors. In his books (e.g., Freud, 1900, 1920), Freud proposes that the unconscious mind comes out in slips and dreams. Its expression, however, is coded within dreams (the work of dream), and unconscious thoughts are distorted before they emerge in the conscious mind of the sleeping subject (manifest content of the dream). As a consequence, the dreamer is not disturbed by repressed and unacceptable thoughts (latent content of the dream) and can continue sleeping (this is the reason why Freud considered dreams the guardians of sleep). Hence, according to Freud, decoding dreams' latent content provides an access to the unconscious mind.

In Freud's theory of the mind, unconscious thoughts and feelings may cause the patient to experience life difficulties and/or maladjustment, and free unconscious thoughts can help the patient gain insight into his/her situation. As a consequence, Freud developed techniques to decode dreams and provide a way for an analyst to look inside the words and unconscious images of the patient, and to free them through patient insight. One of these techniques is called free association, and is regarded as an essential part of the psychoanalytic therapy process. In order for an analyst to get to the latent content of a dream, he requires the patient to discuss the dream's manifest content and encourage free association about the dream. Free association is the principle that the patient is to say anything and everything that comes to mind. This includes decensoring his/her own speech so that he/she truly expresses everything. Over time, the therapist or analyst will draw associations between the many trains of uncensored speech the patient shares during each session. This can lead to patient insight into their unconscious thoughts or repressed memories, and the accomplishment of their ultimate goal of "freedom from the oppression of the unconscious" (Trull, 2005).

Hence, Freud considered that dreams, as well as slips, have a meaning and can be interpreted, so that one is justified in inferring from them the presence of restrained or repressed intentions (Freud, 1900, 1920). Note that, in Freud's theory of the mind, the words "meaning" and "intention" are closely linked: "Let us agree once more on what we understand by the 'meaning' of a psychic process. A psychic process is nothing more than the purpose which it serves and the position which it holds in a psychic sequence. We can also substitute the word 'purpose' or 'intention' for 'meaning' in most of our investigations" (Freud, 1920).

In other words, according to Freud, decoding dreams with the free association method provides an access to what makes each of us so special, uncovering the forces that guide one's behavior. It gives access to an unknown dimension of ourselves that is fundamental in understanding who we are. It provides access to personal meaning.

This hypothesis, attributing significant importance and meaning to dreams, has rarely been considered by neuroscientists who often consider Freud's work and theory unscientific.

However, this situation may change as the relationship between psychoanalysis and neuroscience evolves. The starting point was the creation of the International Society for Neuropsychoanalysis in 2000. It was founded by neuropsychologist and psychoanalyst Mark Solms with the intention to promote interactions and collaborations between psychoanalysis and neuroscience. The challenge was serious, as illustrated by neuroscientist Alan Hobson's

aggressiveness in the famous dream debate (Alan Hobson vs. Mark Solms) entitled "Should Freud's dream theory be abandoned?" held in Tucson, Arizona, in 2006 during the *Towards a Science of Consciousness* meeting (scientific arguments can be found in Solms, 2000 and Hobson et al., 2000). Alan Hobson tried to convince the assembly that Freud was 100% wrong and that Freud's dream theory was misguided and misleading and should be abandoned. He aimed to demonstrate that Freud's dream theory is incompatible with what we know about how the brain works. He added that Freud's dream theory was not scientific because it was not testable or falsifiable. Finally, he presented his model of dreaming, the *activation-synthesis* hypothesis (Hobson and McCarley, 1977; Hobson et al., 2000): "The Activation-Synthesis model of dream construction proposed that the phasic signals arising in the pontine brainstem during REM sleep and impinging upon the cortex and limbic forebrain led directly to the visual and motor hallucinations, emotion, and distinctively bizarre cognition that characterize dream mentation. In doing so, these chaotically generated signals arising from the brain stem acted as a physiological Rorschach test, initiating a process of image and narrative synthesis involving associative and language regions of the brain and resulting in the construction of the dream scenarios." In contrast, Mark Solms demonstrated that what is currently known about the dreaming brain is at least broadly consistent with Freud's dream theory. He argued that it is generally accepted that brain stem activation is necessary, but not sufficient, to explain the particular characteristics of dream consciousness. What does explain the particular characteristics of dream consciousness, according to Solms, are the following features of brain activity during REM sleep (Braun et al., 1997): the activation of core forebrain emotion and instinctual drive mechanisms, i.e., the limbic and paralimbic brain areas (the anterior cingulate, insula, hippocampus, parahippocampal gyrus, and temporal pole), and of the posterior perceptual system (the fusiform gyrus, superior, inferior and middle temporal gyrus, and angular gyrus) and the deactivation of executive dorsolateral frontal control mechanisms (the dorsolateral prefrontal cortex). He further argued that his lesion studies (Solms, 1997) are congruent with neuroimaging results because they showed that a total cessation of dreaming results from lesions in the medial part of the frontal lobe and in the temporoparietal junction (whereas no cessation of dreaming was observed for core brainstem lesions or for dorsolateral prefrontal lesions). Finally he emphasized that the activation of motivational mechanisms (such as drives and basic emotions) and of posterior perceptual system associated with deactivation of the executive control (i.e., reality oriented regulatory mechanism) during REM sleep, is broadly consistent with Freud's dream theory which claims that our instinctual drive states (notably appetitive and libidinal drive system) are relatively disinhibited during sleep. Note that experimental results demonstrating the existence of unconscious representations that guide behavior (e.g., Shevrin and Fritzler, 1968; Bunce et al., 1999; Arminjon, 2011, for a review) could also have been cited in support of Freud's dream theory. This debate was a success for Mark Solms and neuropsychoanalysis. Indeed, at the end of the debate, approximately 100 people voted "no" (i.e., "Freud's dream theory should not be abandoned"), approximately 50 people voted "yes" and 50 voted "I don't know".

Solms' (1997, 2000) approach to dreaming and his experimental results fundamentally challenged our current understanding of dreaming. He proposes that dreaming and REM sleep are controlled by different brain mechanisms. According to Solms, REM sleep is controlled by cholinergic brain stem mechanisms, whereas dreaming is mediated by forebrain mechanisms that are probably dopaminergic. This implies that dreaming can be activated by a variety of NREM triggers. Several experimental results support this hypothesis.

First, behavioral studies have demonstrated that the link between REM sleep and dream reports is lax. Subjects awakened during NREM sleep can recall dreams at a high rate (Foulkes, 1962: 74% of awakenings in NREM sleep were followed by dream reports; Cavallero et al., 1992: 64%; Wittmann et al., 2004: 60%); dreams can be recalled after a nap consisting only of NREM sleep (Salzarulo, 1971; Palagini et al., 2004); and some individuals never recall dreams, even when awakened from REM sleep (Pagel, 2003). In addition, in healthy subjects with a normal dream recall frequency (around 1 dream recall per week, Schredl, 2008), dream recall after an awakening during REM sleep is not systematic: 5–30% of awakenings in REM sleep are not followed by a dream recall, according to the literature (e.g., Dement and Kleitman, 1957a,b; Foulkes, 1962; Hobson, 1988). Finally, 5–10% of NREM dreams cannot be distinguished from REM dreams based on their content (Hobson, 1988; Cavallero et al., 1992; Cicogna et al., 1998; Wittmann et al., 2004).

Second, as Solms (2000) argued, the amount of dream recall can be modulated by dopamine agonists (Scharf et al., 1978; Nausieda et al., 1982) without concomitant modification of the duration and frequency of REM sleep (Hartmann et al., 1980). Dream recall can be suppressed by focal brain lesions (at the temporo-parieto-occipital junction and ventromedial prefrontal cortex; Solms, 1997, 2000). These lesions do not have any appreciable effects on REM frequency, duration, or density (Kerr et al., 1978; Michel and Sieroff, 1981). Finally, some clinical studies suggest that a dream can be triggered by nocturnal seizures in NREM sleep, i.e., by focal brain stimulation. Some cases of recurring nightmares caused by epileptiform activity in the temporal lobe have indeed been reported (Solms, 2000).

CONCLUSION: COLLABORATION BETWEEN NEUROSCIENCE AND PSYCHOANALYSIS WOULD BENEFIT DREAM RESEARCH

Considering the issues that remain unresolved (e.g., neurophysiologic variability, parameter(s) influencing the emergence of representations in dreams, the meaning of dreams), a psychoanalytic perspective would certainly benefit dream research by providing new directions/leads and helping to reach a comprehensive understanding of dreaming.

On the one hand, psychological research has demonstrated that dream content is influenced by one's personal life, especially personal concerns (Schwartz, 1999; Schwartz and Maquet, 2002; Schredl and Hofmann, 2003), and some neuroscientists have hypothesized that dreaming is involved in psychological individualism. Thus, both psychology and neuroscience have provided results and hypotheses that validate the possibility that dreaming has something to do with personal and meaningful issues. On the other hand, Freud argued that the unconscious, which guides

behaviors and desires, express itself during dreams. The two disciplines' (cognitive neuroscience and psychoanalysis) convergence on dreaming thus seems obvious; however, very little collaboration has occurred to date.

Note that some experimental studies in psychology have considered the psychoanalytic perspective. For example, Greenberg et al. (1992) attempted "a research-based reconsideration of the psychoanalytical theory of dreaming." They evaluated the presence of problems (defined as an expression of negative feeling or any situation evoking such feeling or requiring some change or adaptation) during dreaming and pre- and post-sleep wakefulness in two subjects. They showed that problems occurred very frequently in the manifest dream content and that these problems were nearly systematically related to the problems noted during pre-sleep wakefulness. In addition, they observed that effective dreams (i.e., dreams that presented some solution to the individuals' problems) were followed by a waking state in which the impact of the problems was diminished, whereas ineffective dreams were followed by the persistence of the problems. This study thus confirmed that personal concerns influence dream content. In addition it provided new results suggesting that dreaming may have some psychological problem-solving function (this result recalls the neuroscientific findings that sleep has a cognitive problem-solving function associated with brain reorganization; e.g., Wagner et al., 2004; Darsaud et al., 2011). Greenberg et al.'s (1992) study managed to quantify personal issues and clearly broadened the cognitive neuroscience perspective on dreaming. To proceed further, approaches integrating psychoanalysis and neuroscience must now be developed. Several subjective issues at the core of the psychoanalytic approach, such as the concept of personal meaning, the concept of unconscious episodic memory and the subject's history, are not addressed or considered in cognitive neuroscience. This limitation hampers the understanding of psychological and neurophysiological functioning in humans. These issues must be addressed, and the expertise of psychoanalysts in singularity and personal meaning is needed to do so in neuroscience and to further the understanding of dreaming and of the psyche.

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