The Multifunctionality of Dreaming and the Oblivious Avatar

A Commentary on Revonsuo & Colleagues

Martin Dresler

Sleep and dreaming do not serve a single biological function, but are multifunctional. Their functions include memory consolidation and integration, emotion regulation, creativity and problem solving, and preparation for waking life. One promising level of description is that of dreaming as a virtual reality: The dreamer interacts with a simulated environment including other simulated avatars. While dreaming can be considered a multifunctional general reality simulator, the threat simulation and social simulation functions of dreaming are unique among other dream functions in their ability to explain a striking feature of dream phenomenology: obliviousness towards the true state of mind.

Keywords
Avatars | Creativity | Dream | Dreaming | Emotion regulation | Function | Lucid dreaming | Memory | Multifunctional general reality simulator | REM sleep | Simulation | Sleep | Social simulation theory | Threat simulation theory | Virtual reality

Commentator

Martin Dresler
martin.dresler@donders.ru.nl
Radboud Universiteit Medical Center
Nijmegen, Netherlands

Target Authors

Antti Revonsuo
antti.revonsuo@utu.fi
Högskolan i Skövde, Skövde, Sweden
Turun yliopisto, Turku, Finland

Jarno Tuominen
jarno.tuominen@utu.fi
Turun yliopisto
Turku, Finland

Katja Valli
katval@utu.fi
Turun yliopisto, Turku, Finland
Högskolan i Skövde, Skövde, Sweden

Editors

Thomas Metzinger
metzinger@uni-mainz.de
Johannes Gutenberg-Universität
Mainz, Germany

Jennifer M. Windt
jennifer.windt@monash.edu
Monash University
Melbourne, Australia

1 Introduction

Sleep is an almost ubiquitous phenomenon within the animal kingdom, existing in all higher and many lower species. The specific function of sleep, however, is still an enigma:

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sleep helps an organism to save energy through extended periods of inactivity, yet at the same time leaves it in a potentially dangerous state of non-responsiveness. While several possible functions of sleep have been discussed in recent years (Frank 2006; Vassalli & Dijk 2009), the function of dreaming might be seen as an even bigger mystery: the hyper-realistic imagery experienced during dreaming does not inform the organism about its current environment, and the virtual motor activity processed in interaction with these hallucinations is not executed to affect the external world—or even worse, in pathological conditions like REM sleep behavior disorder it is, thereby threatening the health of the dreamer and his bed partner. After awakening from a dream, the often emotionally-toned preoccupation with the dream narrative can confuse the dreamer and distract his from potentially dangerous conditions in the real world.

An increasingly widespread idea is that the function of dreaming consists in the simulation of waking life. In a variation of their threat simulation theory (TST; Revonsuo 1995, 2000), Revonsuo et al. (this collection) now propose a social simulation theory of dreaming (SST), according to which dream function could best be characterized as simulating social reality. Considering the social nature of most of our dreams, SST is an intuitively plausible approach, and Revonsuo et al. review a number of studies that provide support for SST. Nevertheless, several questions remain to be clarified: is the prime function of dreaming threat simulation or social simulation—or something completely different? What is the relationship between the various proposed functions of sleep and dreaming, including TST and SST? If the TST and SST turn out not to be the sole or even prime functions of dreaming, do they nevertheless provide unique insights into the function of dreaming?

In this commentary, I shall review several widely propagated functions of sleep and dreaming. I shall then compare these functions with the social and threat simulation functions of dreaming, and finally discuss why and in which regard these two functions might be special. I shall argue that the merit of TST and SST is not the conclusive explanation of the function of dreaming—which I consider a multi-functional state—, but that they are the only candidates among the variety of dream functions that are capable of explaining a striking feature of most dreams: obliviousness towards the current state of mind.

2 Sleep physiology and the function of dreaming

When speculating about the function of dreaming, some clarifications about the level of explanation are necessary. By definition (e.g., Windt 2010), dreaming is a phenomenon occurring during sleep. In an account of biological realism (Revonsuo 2006), the function of dreaming cannot be discussed independently from the neurophysiology of sleep. Even if the phenomenology of dreaming serves a function that can be conceptually (and maybe evolutionarily) differentiated from the original function realized by its physiological correlates, this function is not independent from the neurophysiology of sleep and its specific functions: if the neurophysiological functions change their mechanisms, this would also affect the phenomenological aspects of dreaming—philosophically speaking, phenomenal properties of dreaming supervene on neurophysiological properties of sleep. However, neither can the function of dreaming be equated with the function of sleep, since there are functions of sleep for which it is rather unlikely that any phenomenological aspects play a role, e.g., myelin sheath proliferation (Bellesi et al. 2013); synaptic downscaling (Tononi & Cirelli 2006); metabolite clearance (Xie et al. 2013); or general metabolic (Morselli et al. 2012) and immunological functions (Besedovsky et al. 2012). There are also functions of sleep that might be described conceptually without referring to phenomenal aspects, but in fact happen to be biologically associated with dream mentation, e.g., physiological microprocesses underlying memory consolidation (see below). And in these cases, one can differentiate dream phenomenology and sleep physiology on a conceptual, but not biological level—unless one adopts a radically dualistic approach, that is. Hence, speaking of the

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function of dreaming —in contrast to the function of sleep more generally—always implies both phenomenological and physiological aspects.

When considering the neurophysiology of dreaming, coarse sleep stages as defined by classical polysomnography have been the prime targets of investigation. Among these, REM sleep harbors the most prototypical dreams, with a story-like dream narrative including interactive visuomotor hallucinations and often intense emotions. In addition, REM sleep dreams can be most elegantly related to their neurophysiological correlates (Hobson & Pace-Schott 2002). Nevertheless, dream-like mentation can be found in in all sleep stages (Nielsen 2000), and hence also the neurophysiology of other sleep stages has to be taken into account when investigating the function of dreaming. In conclusion, when speculating about the function of dreaming, all those REM and NREM sleep functions have to be considered that can reasonably be expected to be associated with phenomenal aspects. In the following, I will highlight four clusters of such sleep functions.

3 Dream function 1: Memory consolidation and integration

In recent years, the most widely discussed function of sleep and dreaming concerns the consolidation of declarative memory, including semantic, episodic, and autobiographical information; and procedural memory including perceptual and motor skills (Rasch & Born 2013). In particular the role of REM sleep in memory consolidation has been studied for several decades. While many studies from the 1970s have been criticized for being heavily confounded by too stressful REM sleep deprivation procedures (Horne & McGrath 1984), research in the 1990s raised interest in the role of REM sleep for memory consolidation: Karni (1994) demonstrated that a basic visual discrimination task improved after a normal night's sleep, but not after selective REM sleep deprivation. Following this, a leading research aim in the field has been to identify which memory systems benefit from which sleep stages: it was demonstrated that early deep sleep benefits declarative memories, while late REM-rich sleep supports procedural skills (Plihal & Born 1997). Further support for the role of REM sleep in procedural memory consolidation came from studies showing that REM sleep intensity (total number of REMs and REM densities) increased following procedural-task acquisition (Smith et al. 2004) and improvements in procedural memory performance after a night of sleep were proportional to time spent in REM sleep (Fischer et al. 2002). Moreover, brain areas activated during a procedural learning task were more active during REM sleep in subjects who were trained at the task (Maquet et al. 2000; Peigneux et al. 2003).

More recent studies, however, speak against a prominent role of REM sleep in the consolidation of procedural motor skills or other forms of non-emotional memories, and instead emphasize non-REM sleep processes (Genzel et al. 2014). On the neurophysiological level, it has been suggested that dreaming represents the phenomenological reflection of a neural replay of activation patterns associated with recent learning experiences (Wilson & McNaughton 1994; Wamsley & Stickgold 2011; Wamsley 2014). Although memory reactivations have been observed in REM sleep as well (Louie & Wilson 2001), the most advanced models of sleep-related memory consolidation propose that neural replay is orchestrated by an interaction of non-REM sleep microprocesses, including slows oscillations and sleep spindles (Genzel et al. 2014).

Events and episodes from waking life are sometimes incorporated into dreams, either as classical day-residues the following night or after a “dream lag” of about 5–7 days (Nielsen & Powell 1989; Nielsen et al. 2004). Supporting the idea that such dream incorporations reflect processes of memory consolidation, items that were incorporated into dreams have been observed to lead to better memory retention (de Koninck et al. 1990; Cipolli et al. 2004). While an actual episodic replay of waking events was found in no more than 1–2% of the dream reports (Fosse et al. 2003), with NREM-sleep dreams appearing to include more identifiable episodic memory sources than REM-sleep dreams (Baylor & Cavallero 2001), it has been suggested that particularly engaging learning experiences have a more robust influence on dream content relative to more passive experiences (Wamsley 2014).

In contrast to recent episodes, incorporations of autobiographical memory features could be identified in the majority of dreams (Malinowski & Horton 2014). This suggests that dreaming might serve to assimilate recent memory fragments into autobiographical memory schemas and thus supports autobiographical self-model maintenance (Metzinger 2013). For semantic memories, evidence of a relationship between dreaming and neural memory reactivations stems from studies of declarative memory that present memory cues during sleep: these cues, when associated with the pre-sleep learning session, induce associated dream imagery (Schredl et al. 2014) and enhance post-sleep memory retrieval (Rasch et al. 2007). For procedural memories, learning of an engaging visuomotor task led to integration of task-related imagery into dream-like activity during non-REM sleep (Wamsley et al. 2010a), and such dream-incorporations of recent learning experiences were associated with later memory performance (Wamsley et al. 2010b). This memory-enhancing re-experience reminds us of motor imagery training during wakefulness, which has been repeatedly demonstrated to improve motor skills (Driskell et al. 1994; Schuster et al. 2011).

Recently it has been suggested that instead of consolidating memories, REM sleep serves as a state of elaborative (re-)encoding, during which the hippocampus integrates recent episodic memory fragments into remote episodic memories (Llewellyn 2013). It has been proposed that this process relies upon principles that also underlie the mnemonic encoding strategies of ancient orators, such as vivid, complex and often bizarre associative imagery, narratives with embodiment of oneself, and associations with known locations, later serving as retrieval cues. Subjectively, this process would be experienced as the typical dream mentation with its hyper-associative and bizarre imagery. However, despite being intuitively appealing, several theoretical considerations and empirical findings are inconsistent with the idea of mnemonic encoding strategies acting during dreaming (Dresler & Konrad 2013).

To sum up, a first important function of sleep and dreaming is memory consolidation and integration, including the rehearsal of procedural motor skills, replay of episodic and semantic memories, and integration of memory episodes into autobiographical memory schemas.

4 Dream function 2: Emotion regulation

Converging evidence suggests that the regulation of emotional processes is an important function of sleep and dreaming. Early content analyses of REM sleep dreams showed that many dreams are highly emotional, with unpleasant emotions prevailing (Hall & Van de Castle 1966; Snyder 1970). This is in line with neuroimaging studies of REM sleep, demonstrating that neural areas involved in emotion regulation like the amygdala, medial prefrontal cortex, and anterior cingulate cortex are highly activated during REM sleep (Nir & Tononi 2010). Several REM-sleep characteristics differ between healthy subjects scoring low in depression scales and those with higher but still subclinical depression scores (Cartwright et al. 1998). After highly emotional life events, REM sleep changes can be observed in those subjects that react with symptoms of depression (Cartwright 1983), and dreams of depressed subjects differ from patients in remission (Cartwright et al. 2006). Likewise, in depressed patients the distribution of rapid eye movements in REM sleep differs in nights after which mood is estimated better than in the preceding evening compared to nights after which mood is unchanged (Indursky & Rotenberg 1998). It was therefore proposed that REM sleep dreaming serves as a mood regulation system and that a disturbance of this process might play a role in the development of affective disorders (Cartwright 2011). Changes in REM sleep are symptomatic of affective disorders and the sleep-memory relationship is altered in these diseases (Dresler et al. 2014). In healthy subjects, the consolidation of emotional texts

(Wagner et al. 2001) or pictures (Hu et al. 2006; Nishida et al. 2009) is enhanced through REM sleep, an effect that has been shown to last for several years (Wagner et al. 2006).

While at first sight it might look as if REM sleep unequivocally strengthens emotional memory processes, some studies suggest a more complex picture: referring to the fact that emotional experiences are remembered better than neutral ones, however their emotional tone during retrieval decreases with time, it was proposed that REM sleep serves an emotional decoupling function: we sleep to remember emotionally-tagged information yet at the same time to forget the associated emotional tone (Walker & van der Helm 2009). While some studies support this model (Hu et al. 2006; Nishida et al. 2009), others suggest that the affective tone of emotional memories is preserved rather than reduced during REM sleep (Groch et al. 2013).

Besides negative emotions, sleep and dreaming have also been associated with positive affects. Recent dream report analyses suggest that positive emotions in dreams have been underestimated in previous studies and might be even more common than negative emotions (Malcolm-Smith et al. 2012; Sikka et al. 2014). In addition, the processing of reward has been associated with REM sleep and dreaming. For example, the expectancy of a reward enhances memory consolidation processes during sleep (Fischer & Born 2009), and reactivations of neural activity related to a reward-searching task have been observed in reward-related brain regions such as the ventral striatum during sleep (Pennartz et al. 2004). Instead of a simulation of purely aversive content such as threats, according to this account sleep favors the activation of representations of high emotional and motivational relevance in general (Perogamvros & Schwartz 2012, 2014).

In summary, a second important function of sleep and dreaming is the regulation of emotions, including both an enhancement of emotionally-tagged information and a decoupling of this information from its associated emotional tone.

5 Dream function 3: Creativity and problem solving

Anecdotal reports on scientific discovery, inventive originality, and artistic productivity suggest that creativity can be triggered or enhanced by sleeping and dreaming. Several studies confirm these anecdotes, showing that sleep promotes creative problem-solving compared to wakefulness. For example, when subjects performed a cognitive task that could be solved much faster through applying a hidden rule, after a night of sleep more than twice as many subjects gained insight into the hidden rule as in a control group staying awake (Wagner et al. 2004). Similarly, subjects benefited in a creativity task from an afternoon nap but not from staying awake (Cai et al. 2009; Beijamini et al. 2014), and the likelihood of solving a problem encountered before sleep can be increased by cued reactivations during sleep (Ritter et al. 2012).

According to the classical stage model of creativity, creative insights may be described by a process consisting of several stages, of which the incubation phase appears to be most intimately associated with sleep and dreaming (Dresler 2011, 2012; Ritter & Dijksterhuis 2014). The most common psychological approaches support this view: psychoanalytical models of creativity emphasize the primary process concept, which denotes free-associative and dream-like thinking, compared to the more rational and analytical secondary-process thinking (Kris 1952). Cognitive models propose that a state of defocused attention facilitates creativity (Mendelsohn 1976)—creative individuals seem to have less narrowly-focused attention than uncreative ones, which leads to unorthodox connections of remote ideas that might eventually lead to creative cognitions. In a similar vein, creative individuals are thought to have relatively flat association hierarchies (i.e., more, yet weaker associations between cognitive elements), which accounts for the ability to make remote associations; whereas uncreative individuals are thought to have relatively steep association hierarchies (Mednick 1962). Physiological models emphasize the level of cortical arousal as an important variable influencing creativity: both a lower level of cortical arousal—particularly in the prefrontal cortex—and a higher variability in cortical arousal levels are expected in creative compared to uncreative individuals, depending on specific phases of the creative process (Martindale 1999). In addition, low levels of norepinephrine are thought to facilitate creativity, shifting the brain toward intrinsic neuronal activation with an increase in the size of distributed concept representations and co-activation across modular networks (Heilman et al. 2003). The prefrontal cortex seems to be of particular importance for creative processes; however there is evidence that both prefrontal activation and prefrontal deactivation facilitate creativity—maybe depending on the specific phase of the creative process. Brain areas showing selective activation for insight events are—besides the prefrontal cortex—the visual cortices, the hippocampus, and in particular the anterior cingulated cortex, which is thought to be involved in breaking the impasse that marks the critical step of insight into a problem (Dietrich & Kanso 2010).

Both theoretical models and empirical neuroscience of creativity suggest that sleep and dreaming provide an ideal environment for creative incubation: primary-process thinking is explicitly conceptualized as dream-like, and the hyper-associative nature of dreams can be considered a prime example of a flat associative hierarchy. Defocused attention is a phenomenal feature of most dreams, physiologically probably caused by prefrontal cortex deactivation. And daydreaming has the potential to increase creativity (Lewin 1989), while the level of engagement in such mind-wandering in contrast to explicitly directed thoughts is associated with creative performance (Baird et al. 2012). The sleep cycle provides the brain with highly alternating arousal levels, and the chaotic activation of the cortex in REM sleep through brain stem regions in absence of external sense data leads to a much more radical renunciation of unsuccessful problem solving attempts, leading to co-activations of cognitive data that are highly remote in waking life (Kahn et al. 2002a). These co-activations, woven into a dream narrative in a self-organizing manner, repeatedly receive further innervations by the brainstem, leading to bizarre sequences of loosely associated dream topics that might eventually activate particular problem-relevant cognitions or creative cognitions in general (Hobson & Wohl 2005). In addition, in REM sleep, which is characterized by low levels of norepinephrine, visual cortices, the hippocampus, and the anterior cingulate cortex have all been shown to be strongly activated, potentially facilitating insight events. In conclusion, the phenomenological and neural correlates of sleeping and dreaming provide ideal conditions for the genesis of creative ideas and insights.

In summary, a third important function of sleep and dreaming is the association of remote cognitive elements in order to facilitate creativity and problem solving.

6 Dream function 4: Preparation and simulation of waking life

Consolidation, integration, regulation, and reevaluation of acquired information during sleep prepare the organism for its waking life. However, such processes do not necessarily need to be purely reactive, depending solely on the experiences of the preceding day: several authors propose that a major function of sleep and dreaming might include primarily preparational mechanisms. Since REM sleep dominates sleep more during early developmental periods in comparison to later in life, some researchers have argued that REM sleep plays a role in early brain maturation (Roffwarg et al. 1966; Marks et al. 1995; Mirmiran 1995); however, also a life-long preparational function of REM sleep has been proposed. One of the first approaches in this direction was offered by Jouvet (1979), who combined the brain maturation hypothesis with a metaphor offered by Dewan (1970), in which he claims that the brain is a computer that is programmed during REM sleep—suggesting that innate behaviors are rehearsed during REM-sleep dreaming in order to prepare the organism for their application in waking life. Jouvet later revised his approach, assuming that REM sleep constitutes an iterative genetic programming that helps to maintain the process of psychological individuation (Jouvet 1998). In a similar vein, Hobson (2009) proposed that REM sleep may constitute a “protoconscious” state, preparing the organism for waking conscious experiences. The development of consciousness during ontogenetic development in this view is a gradual and lifelong process, building on the more primitive innate virtual reality generator, which is phenomenally experienced as dreaming. With the recent integration of Friston’s (2010) predictive coding approach into this theory, the brain is thought to run a virtual world model (see also Revonsuo 1995, 2006; Metzinger 2003) that is continuously updated by processing prediction errors during wakefulness. Freed from external sensory constraints, processing of prediction errors in the dreaming brain actively refines intermediate hierarchy levels of the virtual world model. Dreaming thereby minimizes internal model complexity in order to generate more efficient predictions during subsequent wakefulness (Hobson & Friston 2012; Hobson et al. 2014).

One of the first and today the most widely discussed preparational approach is based on the observation that during dreaming particularly threatening experiences are overrepresented: the Threat Simulation Theory (TST) proposes that one function of sleep is to simulate threatening events, and to rehearse threat perception and threat avoidance (Revonsuo 1995, 2000). Such a mechanism of simulating the threats of waking life over and over again in various combinations would be valuable for the development and maintenance of threat-avoidance skills. Several empirical studies support TST (Revonsuo 2006; Valli & Revonsuo 2009), however some inconstant findings have been reported (Zadra et al. 2006; Malcolm-Smith et al. 2008, 2012). In a variation of TST, Revonsuo et al. (this collection) propose the Social Simulation Theory (SST), according to which the function of dreaming consists in the simulating of “the social skills, bonds, interactions and networks that we engage in during our waking lives”. The SST aims to predict and explain the simulations of social interaction of dream avatars that happen outside threatening events in dreams. Like the TST, predictions of the SST are supported by a number of studies, but face inconsistent data (Revonsuo et al. this collection).

On a neurobiological level, empirical support for simulation theories of dreaming comes from a recent study demonstrating that the ventromedial prefrontal cortex subserves the simulation and evaluation of possible future experiences, integrating arbitrary combinations of knowledge structures to simulate the emergent affective quality that a possible future episode may hold (Benoit et al. 2014). As the ventromedial prefrontal cortex is known to be activated in REM sleep (Nir & Tononi 2010), this mechanism might also underlie episodes of reality simulation during dreaming. Further neurobiological support for the preparational role of sleep comes from recent research demonstrating a neural “preplay” of future learning-related place-cell sequences in the hippocampus (Dragoi & Tonegawa 2011, 2013). In contrast to the intuitive view that such activation patterns are established for the first time during a novel experience, according to these findings the specific temporal firing sequence during learning seems rather to be selected from a larger repertoire of preexisting activation patterns, thus suggesting that sleep plays a role not only in the subsequent consolidation, but also in the preceding preparation for new experiences. It has been demonstrated that sleep preceding the learning experience indeed influences memory acquisition during the following day (van der Werf et al. 2009). Interestingly, support for the hypothesis that sleep mentation constitutes a virtual reality model preparing for waking life comes also from research outside of sleep neuroscience: approaches probing artificial intelligence demonstrate that robots perform better in navigational tasks if they create and update models of their own structure and actions during a state of motoric inactivity (Bongard et al. 2006). Not surprisingly, this process of evaluation and simulation of prior and future actions was interpreted as dream-like (Adami 2006).

In summary, a fourth important function of sleep and dreaming is preparation for waking life. This includes proposals of REM sleep as an iterative genetic programming system, dreaming as a state of protoconsciousness and virtual world model optimization, and dreaming as a simulation of threats (TST) and social interactions (SST).

7 The multifunctionality of dreaming

Numerous suggestions for solving the mystery of sleep and dream function can be found in the literature. In the previous sections I have reviewed four clusters of proposed functions of sleep and dreaming: 1) consolidation of recently acquired memories, including procedural motor skill rehearsal, replay of recently acquired memories, and integration of memory episodes into autobiographical memory schemas; 2) emotion regulation, including both an enhancement of emotionally-tagged information and a decoupling of this information from its associated emotional tone; 3) creativity and problem solving; and (4) preparation and simulation of waking life, including iterative genetic programming, virtual world model optimization, the simulation of threats (TST), and the simulation of social interactions (SST). The question thus remains what the real or primary function of sleep and dreaming is—and what the relationship between the different candidates might be. SST aims to independently cover the social simulations that fall outside the scope of TST, thereby describing an "original evolutionary function of dreams alongside with the threat simulation function of dreaming" (Revonsuo et al. this collection).

The concept of evolutionary function has been one of the main topics in the philosophy of biology (Mahner & Bunge 2000) and philosophy of mind (Millikan 1984; Neander 1991). Several notions of biological functions exist (Wouters 2003); however a general idea is that the biological function of a trait is determined by its contribution to evolutionary fitness (Walsh & Ariew 1996). Darwin (1871) differentiated between selection occurring as a consequence of ecological factors that directly threaten the organism's survival, such as predators or other potentially life-threatening dangers of nature, and interactions with members of the same species in order to compete for mating partners. Both principles, dubbed natural and sexual selection respectively, eventually determine reproductive success as the ultimate decision points for selection. In contemporary accounts, sexual selection was generalized to the concept of social selection, of which the former is considered a subtype (Lyon & Montgomerie 2012; West-Eberhard 2014). The concept of runaway selection, famously illustrated by the evolution of the peacock's tail, was thought to also be applicable to the evolution of social skills in higher animals, eventually leading to the development of theory of mind, language, dance, or artistic creativity in humans (Flinn & Alexander 2007). This process of an arms race of social skills would require increasing cognitive capacity—and in fact, at least in primates, relative brain size has been related to social group size (Dunbar 1992; Dunbar & Shultz 2007).

It is tempting to associate natural and social selection as the main principles of evolution with TST and SST, respectively. This interpretation would strongly support TST and SST, as it would equate the function of dreaming with two main principles of evolution in general. In this broad sense, however, certain attributes like learning capacity or motor skills increase fitness in terms of natural selection, but do not necessarily serve to help us avoid direct threats. Likewise, certain attributes such as emotion regulation or artistic creativity increase fitness in terms of social selection, but are not necessarily themselves social in a strict sense. Ultimately, of course, all these functions serve reproductive success—however, if any skill ultimately helping us to acquire sexual partners is interpreted as social and any possible obstacle to reproduction is interpreted as a threat, then TST and SST would be trivial, as a biological function is by definition one that supports reproductive success. In contrast, if TST and SST are interpreted in a more narrow, non-trivial way, there is ample space in dreams for further functions: consolidation of navigational information acquired during exploration; rehearsal of a recently learned motor sequence; facilitation of a behavior recently rewarded with food; incubated creative insight into the solution of a recent unsuccessful attempt to build a helpful tool; refinement of the discriminative skills regarding recently perceived pattern, etc.—all these potential benefits of sleep and dreaming increase inclusive fitness of the individual, but do not directly refer to the simulation of threats or social interactions.

This problem can further be illustrated by Revonsuo's (1995, 2006) approach, where he considers any phenomenal experience as a virtual world model: what is the function of waking consciousness, threat avoidance, or social interaction? Both threat avoidance and social interaction, of course—and many others. That this rather uninformative answer can also be transferred back to the function of dreaming might be illustrated with another ubiquitous example of simulation: in child's play, simulation of real life and the practice of skills needed therein is considered one of the main functions —play allows children to simulate coping with threats in a safe environment, and to develop the social skills needed later in life (Mellou 1994; Pellegrini & Bjorklund 2004). However, these aspects, while important, are not the only functions of play—it also offers the rehearsal of motor and sensory skills, training in predatory behavior, and general intellectual development. Hence, child's play can be considered multifunctional, as can waking or dreaming consciousness.

Segmentation of reality (including dream reality) is possible along numerous lines. In a sense, TST and SST could be interpreted as expressing two orthogonal dimensions of dream space: a security dimension with the directions threat vs. safety, and a sociality dimension with the directions social vs. individual. Dreamed accidents or natural disasters would be characterized by low security and sociality, dreamed experience of bullying by high sociality and low security, and dreamed bonding by high sociality and security, etc. Threat and social interactions in a narrow sense are important aspects both of waking and dreaming life, however they are not the only aspects. Other segmentations are also possible, e.g., by a dimension of motor activity vs. inactivity, or emotional vs. neutral dream content, or a novelty dimension. In the broad sense of natural and social selection, threat and social interaction would be the two main drivers of evolution, however to the cost that the answer to the question of the function of dreaming becomes a trivial "to support reproductive success". Of note is that also the other discussed functions might be interpreted within a simulation framework: e.g., simulation visuomotor activity after learning a respective task in the memory function, simulating affective experiences in the emotion regulation function, and simulating problem solving attempts in the creativity function. These different functions are neither mutually exclusive nor strictly independent from each other. In particular the emotion-processing function largely overlaps with both TST an SST—all threats and at least the most important social interactions induce strong emotions, and successful coping with these emotions would be of considerable help when facing threats or social situations. Also other functions of dreaming overlap with TST and SST: consolidation of threat-related information or social gossip improves threat avoidance or social skills, as does creative incubation on threat-related or social problems. On a more abstract level, all these simulations serve the integration of recently experienced information into the behavioral repertoire in order to adapt it to the current waking environment (Hobson et al. 2014).

Identifying the original function of a given trait has proven to be a notoriously difficult issue in the philosophy of biology (Wouters 2013). Dreaming might have originally developed as an epiphenomenon of rather basal neurophysiological sleep functions, and this phenomenological level might eventually have acquired additional functions. Such exaptations (Gould & Vrba 1982) might have been further adapted and in turn developed further neurophysiological exaptations without phenomenological correlates, etc. The original function of dreaming might be unimportant today compared to subsequently evolved functions. Instead of singling out one or two functions of dreaming as original, dreaming might be best seen as a multifunctional general reality simulator, including the simulation of motor skills, emotional processing, problem solving attempts, threats, and social interactions. To follow specific research questions, of course certain functions still could be highlighted and followed as research heuristics with a given purpose. All functions of sleep and dreaming serve reproductive success ultimately, even though some might be more important than others from a selection point of view. For all dream functions discussed in this chapter, there are convincing supporting but also inconsistent data. The fact that dreaming is not an unselective simulation of the waking world as, e.g., the continuity hypothesis suggests (Schredl & Hofmann 2003), is a sign that some simulation functions might be more important than others. We should note, however, that quantitative overrepresentation of a specific function does not necessarily prove the primacy of this function: different functions might rely on different processes with different timescales, with a highly important function potentially requiring only seconds to be processed, while an unimportant function might take hours. In times of sufficient sleep, dream content related to the relatively unimportant function might thus be overrepresented. The relative importance of one function over another might be tested in cases of scarcity of sleep, e.g., under sleep deprivation, when different functions would have to compete for restricted simulation time. Also of interest in this regard is a comparative approach: it has been demonstrated that sleep propensity, and particularly REM sleep, negatively correlates with predatory risk across species (Lima et al. 2005), which would rather speak against TST. Concerning SST, the tendency to sleep in groups has been reported to negatively correlate with sleep time, which, however, has been interpreted either in terms of social sleep being more efficient due to reduced predatory risk, or as more social species sacrificing sleep to service social relationships during wakefulness (Capellini et al. 2008). Against this background, sleep and dreaming pose an optimization problem: how much time is best spent asleep, spent in specific sleep stages, and spent engaging in specific dream mentation in order to optimize the interplay between the different functions of sleep and dreaming? Dreaming as a general reality simulator might dynamically change its functional priorities, favoring one over the other of its several functions, depending on the current requirements and constraints of the environment.

8 The oblivious avatar

Even though it is likely that no ‘original’ function of dreaming can be acknowledged, but rather a multiplicity of functions depending on specific research questions and segmentations of the dream space, one aspect of dreaming might distinguish TST and SST from other functions of sleep and dreaming, including other simulation functions: obliviousness of the avatar about being in a dream. Impaired insight into the own state of mind is a hallmark of normal dreaming, (Dresler et al. 2015a). The well-known exception of this symptom of most dreams is the case of lucid dreaming (Dresler et al. 2015), which in turn can be used to test whether state obliviousness is indeed a characterizing feature of TST and SST when compared with other dream functions.

There is no obvious reason why obliviousness about the dream state would be necessary for the memory function of sleep and dreaming. For procedural memory consolidation, lucid dreaming has even been suggested as a state that allows for a hyper-realistic mental training of recently learned motor skills (Erlacher & Chapin 2010). Several studies support this idea: lucidly dreamed training of coin tossing (Erlacher & Schredl 2010) or a finger tapping task (Stumbrys et al. 2015) has been demonstrated to be effective, and a considerable number of professional athletes use lucid dreams to practice sports skills, with most of them having the impression that their performance is thereby improved (Erlacher et al. 2011). For the creativity and insight function of sleep and dreaming, obliviousness regarding the current state of mind is no prerequisite, and lucid dreaming has explicitly been suggested and shown to be used as a tool to increase creative processes (Stumbrys & Daniels 2010; Schädlich & Erlacher 2012; Stumbrys et al. 2014). As with non-lucid dreaming, lucid dreaming is associated with defocussed attention and flat association hierarchies—lucid dreams have been reported to include even more uncommon and bizarre elements than non-lucid dreams (McCarley & Hoffman 1981). At the same time, regained reflective capabilities enable the creative dreamer to evaluate new associations and ideas, a step in the phase model of creativity that for non-lucid dreams is reserved for subsequent wakefulness. This mechanism is illustrated by two interesting case studies: Barrett (2001) describes the case of a painter who in his lucid dreams visited galleries, and then searching for interesting motifs to be painted soon after awakening from the lucid dream. A comparable strategy was used by one of our own study participants (Dresler et al. 2011, 2012), a music composer: when he aimed to compose a new piece of music, he turned on a radio in his lucid dreams and changed radio stations until he heard a composition that he considered interesting. He then woke himself up and wrote the new composition down. In line with these data, questionnaire studies reported that frequent lucid dreamers might be more creative than less-frequent lucid dreamers (Blagrove & Hartnell 2000).

For the emotion regulation function of sleep and dreaming the situation is less clear, however here there is also some evidence indicating that obliviousness is not generally necessary: for the case of positive affects, subjects often report that lucid dreams are associated with particularly positive emotions. And for negative affects, the successful use of lucid dreaming as a therapeutic tool in affective disorders indicates that dream lucidity does not interfere with the emotion regulation function of dreaming (Holzinger 2014).

In contrast, for those cases where a general emotion regulation function of dreaming overlaps with the TST, the necessity of staying ignorant about the true state of consciousness becomes obvious: to successfully serve as an authentic simulation of a threat, the dreamer has to take the threat as real and thus be oblivious towards his true state of mind. The cognitive insight that everything encountered consists only of hallucinated dream imagery and thus cannot harm the dreamer in reality immediately takes the sting out of the threatening experience. This mechanism has been successfully utilized for recurrent nightmares, where lucid dreaming has been demonstrated to be of therapeutic value (Spoormaker et al. 2003, 2006; Dresler et al. 2015; Rak et al. in press). Thus, for the threat simulation function of dreaming, obliviousness regarding the current state of mind is essential.

For SST, several lines of evidence indicate that obliviousness regarding the current state of mind is a prerequisite for social simulation to be effective. During normal dreams, non-self dream characters are attributed with feelings and thoughts just like in waking life (Kahn & Hobson 2005). Being oblivious about the true nature of these dream characters might ensure that non-perfect social simulations are also taken as autonomous agents instead of mere puppets controlled by the dreamer: dream characters are often implausible compared to their real-life waking counterparts (Kahn & Hobson 2003) , however, are nevertheless recognized and identified without major puzzlement (Kahn et al. 2000, 2002b). During a lucid dream, implausible dream characters might be treated less seriously by the dreamer, rendering the social simulation much less effective. This is illustrated by a recent study demonstrating that being tickled by an intentionally-controlled non-self dream character during a lucid dream was comparably ineffective as self-tickling during wakefulness, whereas being unexpectedly tickled by another dream character felt more ticklish (Windt et al. 2014). Non-self dream characters lead to different predictions depending on their perceived autonomy, and their respective simulation thus serves different functions. Lucid dreaming frequency correlates with the amount of control over the dream (Wolpin et al. 1992; Stumbrys et al. 2014), implying that frequent lucid dreamers would conceive dream characters as less autonomous than less frequent lucid dreamers. Thus, although non-self dream characters appear to have quasi-independent mental lives during lucid dreams (Tholey 1989), convincing training of social skills would require the dreamer to be oblivious to the fact that dream characters are not real, but hallucinated.

In summary, in contrast to other functions of sleep and dreaming, TST and SST essentially depend on state obliviousness of the dreamer. State obliviousness in dreaming might therefore be seen as a prime example of an epistemic constraint of phenomenal experience that leads to new and beneficial functional properties (Metzinger 2003). While both TST and SST (and other functions of sleep) might be applicable to humans and other social animals alike, state obliviousness might be a function that specifically developed in humans: it is unlikely that animals without sophistic language skills possess the ability to reflect on their current state of mind and compare it to alternative mind-states. In turn, such animals do not need a differential mechanism switching state reflectiveness on and off depending on the current vigilance state. Of note, neural correlates of state reflectiveness, i.e. lucid dreaming, strikingly mirror brain differences seen in humans vs. non-human primates (Dresler et al. 2013).

9 Conclusion

Sleep and dreaming do not serve a single biological function, but are multifunctional states. Their functions include memory consolidation and integration, emotion regulation, creativity and problem solving, and preparation for waking life. One promising description level is that of dreaming as a general reality simulator. TST and SST describe two important purposes of simulation, namely successful coping with threats and social interactions. The merit of TST and SST is not so much that they conclusively explain the function of dreaming—although they represent the two classical principles of evolution, natural and social selection, there are also several other sleep and dream functions. TST and SST might be the only candidates among the multiple functions of sleep and dreaming that explain a particularly striking feature of dream phenomenology: dreaming is a remarkably realistic simulation of waking life, with the exception of a complete failure to successfully reflect on the current state of consciousness. Veridical insight into the dream state is biologically possible, as the phenomenon of lucid dreaming demonstrates. The fact that state reflectiveness is nevertheless generally absent in dreaming—dream lucidity is a rare phenomenon (Schredl & Erlacher 2011), and even during lucid dreams, lucidity lapses are common (Barrett 1992)—, suggests that state obliviousness during dreaming has an important function. As demonstrated here, among the different candidates for explaining the function of dreaming, TST and SST are the only ones that are capable of elucidating this specific function: state obliviousness is necessary for the effective simulation of threats and social interactions.

Even though recent neurobiological research has begun to reveal the neural correlates of state reflectiveness and, by contrast, of state obliviousness (Voss et al. 2009, 2014; Dresler et al. 2012), the specific neural mechanisms preventing the dreaming brain from realizing its full repertoire of cognitive capabilities are still largely unclear. Further research into these mechanisms might enable exciting opportunities for sleep and dream research by revealing simple methods of dream-lucidity induction. However, if such ways to induce a simulated reality under full control of its user become available too easily and broadly, this might also lead to unforeseen problems, as at least two important functions of dreaming—simulation of threats and social interactions—probably cannot be processed without state obliviousness. This proposed necessity generates a testable hypothesis: individuals with very frequent lucid dreams can be expected to differ from the majority of infrequent lucid dreamers in their threat-avoidance and social skills.

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