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The reinterpretation of dreams: An evolutionary hypothesis of the function of dreaming

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Abstract: Several theories claim that dreaming is a random by-product of REM sleep physiology and that it does not serve any natural function. Phenomenal dream content, however, is not as disorganized as such views imply. The form and content of dreams is not random but organized and selective: during dreaming, the brain constructs a complex model of the world in which certain types of elements, when compared to waking life, are underrepresented whereas others are over represented. Furthermore, dream content is consistently and powerfully modulated by certain types of waking experiences. On the basis of this evidence, I put forward the hypothesis that the biological function of dreaming is to simulate threatening events, and to rehearse threat perception and threat avoidance. To evaluate this hypothesis, we need to consider the original evolutionary context of dreaming and the possible traces it has left in the dream content of the present human population. In the ancestral environment human life was short and full of threats. Any behavioral advantage in dealing with highly dangerous events would have increased the probability of reproductive success. A dream-production mechanism that tends to select threatening waking events and simulate them over and over again in various combinations would have been valuable for the development and maintenance of threat-avoidance skills. Empirical evidence from normative dream content, children's dreams, recurrent dreams, nightmares, post traumatic dreams, and the dreams of hunter-gatherers indicates that our dream-production mechanisms are in fact specialized in the simulation of threatening events, and thus provides support to the threat simulation hypothesis of the function of dreaming.

Keywords: dream content; dream function; evolution of consciousness; evolutionary psychology; fear; implicit learning; nightmares; rehearsal; REM; sleep; threat perception

Introduction

Dreaming is a universal feature of human experience, but there is no convincing explanation as to why we should experience dreams during sleep. Why do we have vivid, intense, and eventful experiences while we are completely unaware of the world that physically surrounds us? Couldn't we just as well pass the night completely nonconscious? The function of dreaming seems to be a persistent mystery, although numerous suggestions have been put forward about the possible functions it might serve. The leading neurocognitive theories, however, seem to have given up the hope of identifying any useful function for dreaming at all. They cannot provide us with an answer to the question "Why do we dream?" Instead, they seem to imply that we dream for no particular reason at all: Dreaming is biologically epiphenomenal. Dream consciousness is viewed as some sort of random noise generated by the sleeping brain as it fulfills various neurophysiological functions during REM (rapid eye movement) sleep.

Although the prospects for discovering useful functions for dreaming look rather bleak, the empirical evidence should be reevaluated once more from a truly multidisciplinary point of view, including dream content analysis, the neurophysiology of dream sleep, and evolutionary psychology. The exploration that I undertake in the present target article leads to the slightly surprising conclusion that dreaming does have a well-defined and clearly manifested biological function after all. In section 1, I clarify the nature of the basic question: What exactly is it that we want to understand when we inquire about the function of dreaming? The answer is that we need a clear idea of both what the phenomenon of dreaming is and of the sense in which we are using the word "function." In section 2, we review the currently dominant views on the function of dreaming in

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the cognitive and neuroscientific literature as well as in the more clinically oriented dream psychology. The most common view in cognitive neuroscience is that dreaming has no function whatsoever. In clinical literature, the function of dreaming has been linked with problem solving and psychological adaptation, but the direct empirical evidence bearing on such functions remains scarce. In section 3 we point out that none of the previous theories have placed dreaming in the appropriate context for evaluating its possible biological functions: the human ancestral environment in which the dreaming brain was evolving for hundreds of thousands of years. If dreaming does have any biologically adaptive functions, they must have been effective in the evolutionary context, if anywhere.

In the rest of the article I argue that switching the context in such a way puts dreaming into an entirely new light, which suggests that the biologically adaptive function of dreaming is to simulate threatening events in order to rehearse threat perception and the appropriate threat-avoidance skills and behavioral programs. I emphasize that to claim threat simulation as the biological function of dreaming is not to claim that every single dream of every single individual should realize this function. It is only to claim that in certain adaptively important situations with certain ecologically valid cues, the system does become fully activated, and this is the principal reason why dreaming was selected for during our evolutionary history.

The threat simulation theory of dreaming is expressed here in the form of six propositions, each of which is empirically testable. The propositions can be summarized as follows:

1. Dream consciousness is an organized and selective simulation of the perceptual world.
2. Dream consciousness is specialized in the simulation of threatening events.
3. Nothing but exposure to real threatening events fully activates the threat-simulation system.
4. The threat simulations produced by the fully activated system are perceptually and behaviorally realistic rehearsals of threatening events.
5. The realistic rehearsal of these skills can lead to enhanced performance regardless of whether or not the training episodes are explicitly remembered.
6. The ancestral environment in which the human brain evolved included frequent dangerous events that constituted extreme threats to human reproductive success. They thus presented serious selection pressures to ancestral human populations and fully activated the threat-simulation mechanisms.

The empirical evidence relevant for the evaluation of each proposition is then reviewed (sect. 3). In the light of the currently available evidence, all of the propositions are judged as likely to be true, which consequently lends support to the threat-simulation theory of dreaming as a whole. In section 4, the dreams of hunter-gatherer populations and animals are considered in the light of the threat simulation theory. In section 5, new predictions are derived from the theory and the empirical testability of the theory is evaluated. Finally, the theory is elaborated upon and summarized in section 6.

After presenting the threat simulation theory, other theories that have taken an evolutionary perspective on dreaming are reviewed. Although some of them are related to the present view, none of them includes the idea that dreaming is a threat-simulation mechanism. In the final section, the theory is compared with neurocognitive theories of dreaming.

Taken together, this target article aims to show that the threat-simulation theory of dreaming integrates a considerable body of data from multiple sources in a theoretically meaningful way. The theory treats the conscious phenomenal experience of dreaming as a natural biological phenomenon best understood from the combined viewpoints of psychology, evolutionary biology, and cognitive neuroscience. This multidisciplinary treatment, I hope, manages to clarify the mystery of why we dream.

1. What is it that we want to understand when we inquire about the function of dreaming?

We should first make clear what it is we are asking when we inquire about the function of dreaming. We must explicate what we mean by dreaming and what we mean by function.

1.1. What is dreaming?

Dreaming refers to the subjective conscious experiences we have during sleep. We may define a dream as a subjective experience during sleep, consisting of complex and organized images that show temporal progression (Farthing 1992). Questions regarding the function of dreaming must be clearly distinguished from those regarding the function of REM sleep. Dreaming is a subjective conscious experience, while REM sleep is a physiologically defined stage of sleep. Furthermore, as is now clear, REM sleep is neither a necessary nor a sufficient physiological condition for dreaming, although it seems to be the typical and perhaps optimal physiological condition in which fully realized dreams are brought about (Pivik 1991). As Foulkes and Cavallero (1993, p. 9) emphasize, dreaming needs a level of explanation independent of the neurophysiological level at which REM sleep is defined, because "there almost certainly is REM sleep without dreaming and . . . there certainly is dreaming without REM sleep. No account of the distinctive physiology of REM sleep could provide either a necessary or a sufficient explanation of dreaming." Thus, the question we will be exploring is: Does it serve any useful function to have, during sleep, the sorts of conscious subjective experiences that dreaming consists of?

In order to make it clear that we distinguish the level of description at which dreaming proper resides from the levels of neurophysiological description, we may say that dreaming is realized at the experiential or *phenomenal* level of organization in the brain (Revonsuo 1997). We want to find out whether the realization of this level of organization during sleep serves any natural function. The specification of the functions that lower-level neurophysiological mechanisms serve during REM sleep does not constitute a specification of the functions that the realization of the phenomenal level serves, for the neurophysiological functions can be fully specified without ever mentioning the fact that subjective experience happens to be realized as well.[1]

1.2. What is it to be "functional"?

We must be clear about what we mean by "function" or "functional." The appropriate sense of "function" in this context is that of a biological, adaptive function. According to

Tooby and Cosmides (1995) the biological standard is the only standard of functionality that is relevant to analyzing why brain and cognition are organized in one fashion rather than another. A cognitive system is functional in the evolutionary sense if and only if it promotes the organism's inclusive fitness. That is, the biologically functional system must solve problems that will increase the probability that the organism possessing the system will produce offspring, or that the organism's kin will produce offspring. Evolutionary biology gives the concept of "function" a very specific content: The function of a system solely refers to how it systematically caused its own propagation in ancestral environments (Tooby & Cosmides 1995). If dreaming has an adaptive function, then dreaming must solve some adaptive problems whose solution tends to enhance survival and promote reproduction, thus causing the persistence of the brain's dream-production mechanisms and their spread in the population.

If dreaming does not have any adaptive function of its own, then it is likely to be coupled to properties that do. In that case, dreaming is a mere by-product, a nonadaptation that was not selected for (or against) during our evolutionary history but was dragged along because the features to which it was coupled were actively selected for. Flanagan (1995) makes an important distinction between "natural" and "invented" functions of dreaming. A similar distinction has been made by other dream theorists between what we do with dreams once we recall them, and what the dream can do itself (Blagrove 1996; Breger 1967). Natural functions are biological, adaptive functions in the sense defined above, whereas invented functions are derivative psychological or cultural functions. We can put our recalled dreams to a variety of personal or cultural uses,[2] but no matter how enlightening and meaningful such uses may be, they are invented by us, not by natural selection. It is doubtful that any truly natural function of dreaming could be based on the conscious recollection or verbal reporting of dream content, for the natural functions of dreaming, if any, must have been effective in such ancestral conditions and species in which self-reflective dream recollection or reporting were not likely to occur – thus, the natural functions of dreaming cannot have been dependent on them.

Now we are in the position to state our question more specifically. The question we are presently interested in is whether dreaming serves any natural functions: Does the realization of the subjective phenomenal level of organization (the experience of dreaming) solve any adaptive problems? That is, does phenomenal dreaming in any way enhance the prospects of the reproduction of the individual (and/or its close relatives); does dreaming increase the inclusive fitness of the individual?

2. Current theories of dream function

2.1. Theories in cognitive neuroscience

In cognitive neuroscience, recent theories and views on dreaming have led to the conclusion that dreaming as a conscious experience does not serve any useful biological function. Only the neurophysiological events associated with dreaming and REM sleep are assumed to be biologically functional, for they may serve important functions in the development of the brain and in periodically restoring the brain's neurochemical balance.

The Activation-Synthesis theory (Hobson 1988b; Hobson & McCarley 1977) emphasizes the randomness of dream imagery. During REM sleep, PGO waves originate in the pons and activate the forebrain. The forebrain attempts to make sense of this random activation and it synthesizes dream images to fit the patterns of internally generated stimulation. The forebrain selects images that isomorphically correspond to the patterns of eye movements and motor commands elicited during REM sleep. The images are loaded from memory, in which day residues are particularly salient. The theory delivers no answer to the question *why* the brain should generate any images at all during REM sleep; it is simply assumed to be an automatic process. The narrative content of dreams remains unexplained as well. More recently, Hobson (1994) has suggested that REM-dreaming might have a function in memory processing, and he specifically regards the rehearsal of motor programs as a possible function of dreaming during REM sleep. In Hobson's theory, however, dreaming *as an experience* with vivid phenomenal content is seen as a kind of random epiphenomenon that merely *reflects* some totally different events going on at other levels of organization where such events may serve useful neurobiological or mnemonic functions. The Activation-Synthesis theory suggests that the experiential dream imagery itself, the content of consciousness, is functionally as aimless as are the noises emitted by a computer when it processes information. The phenomenal level of organization is not regarded as biologically functional.

The theory presented by Crick and Mitchinson (1983; 1995) is related to Hobson's views, but contains some original ideas. In this theory, memory in the brain is compared to simple models of associative nets. When such a net gets overloaded, it easily starts to produce outputs that are combinations of actually stored associations. In order to make storage more efficient and avoid overloading, a process of reverse learning can be used. The net is disconnected from its normal inputs and outputs, and random input is given to it. The associations that this random input produces are consequently weakened, and the process is repeated many times with different kinds of random input. According to Crick and Mitchinson (1983; 1995) this is loosely analogous to what happens in the brain during REM sleep: the brain is disconnected from its usual inputs and outputs, and PGO waves provide it with more or less random input.[3] The theory explains why REM dreams are full of bizarre intrusions, consisting of mixtures of features previously stored in memory: these are the associations arising in an overloaded network and have to be unlearned. The reverse-learning theory does not even try to explain the narrative aspect of REM dreams, and it certainly does not assign any independent function to the phenomenology of dreaming; phenomenal dream images merely reflect the functioning of a memory-cleaning process.

David Foulkes (1985) has put forward a cognitive theory of dreaming. He proposes that dreaming originates in diffuse, more or less random activation of semantic and episodic memory during sleep: "Since it seems that the activation of mnemonic elements during dreaming and their selection for dream processing is random and arbitrary, it's not likely that the *particular content of our dreams* – in and of themselves – serve any adaptive functions" (Foulkes 1985, p. 200).

Foulkes, however, distinguishes dream content from dreaming as a process. Dreaming, unlike specific dream contents, has very predictable features. It involves an interrelated sequence of events occurring within a "world analog" (or a model of the world) composed of integrated multimodal sensory imagery; the dreamer participates in these events actively and personally; the contents and events depicted in the dream are related to the recent or distant past of the dreamer, not as a simple replay of a past experience but rather as a variation of the past as something that really could have happened to the dreamer. Foulkes suggests that, since the content of dreams seems to be random, what is important about the mnemonic activation is that it is in *some* way unique, not the precise way in which it is unique. In Foulkes's theory the phenomenal level of organization is not regarded as functional, apart from the general feature of producing novel and unique mnemonic configurations. Thus, Foulkes's theory is not essentially different from Hobson's as to the functionality of phenomenal dream content.

Solms (1997a) has recently defended the view originally proposed by Freud: the function of dreaming is to protect sleep. According to Solms, the dream process begins when external or endogenous stimuli activate "the curiosity-interest-expectancy circuits." Inhibitory mechanisms prevent the "appetitive interest," aroused by stimulation, from leading to motor activity; therefore the activity proceeds "regressively" in the direction of hallucinations. In anxiety dreams this mechanism of sleep protection fails. It is clear that this view does not attribute any functions to the specific content of dreams: Solms regards dreams simply as bizarre hallucinations that the weakened frontal reflective systems mistake for real perception.

Owen Flanagan (1995) explicitly denies that dreams as conscious experiences have any biological function. Dream experience, or *p*-dreaming (phenomenal dreaming) as Flanagan calls it, is "a likely candidate for being given epiphenomenalist status from an evolutionary point of view. *P*-dreaming is an interesting side effect of what the brain is doing, the function(s) it is performing during sleep. To put it in slightly different terms: *p*-dreams, despite being experiences, have no interesting biological function. I mean in the first instance that p-dreaming was probably not selected for, that *p*-dreaming is neither functional nor dysfunctional in and of itself" (Flanagan 1995, pp. 9–11). Flanagan argues that phenomenal experience during dreaming – dream consciousness – has no adaptive significance, because the functions of REM sleep and PGO waves, in early development of the visual system and in the restoration of neurochemicals for the next waking period, do not in any way require mentation of any sort. Furthermore, dream thoughts associated with such biological functions do not seem to be worth remembering. "The visual, auditory, propositional, and sensory-motor mentation that occurs is mostly noise" (p. 24). Antrobus (1993a) seems to agree with Flanagan's analysis. He says that since in REM sleep no sensory information is processed and no association-motor commands are executed, it makes no difference what the association cortex does. Dreaming has no maladaptive consequences, so it has survived.

In conclusion, theorists in cognitive neuroscience tend to regard the phenomenal content of dreaming as a biological epiphenomenon, although at least some of the (nonconscious) cognitive and/or neural activity during REM sleep are regarded as serving useful functions.

2.2. Theories in dream psychology

In psychological theories of dream function, the emphasis is on the individual person's psychological adaptation to his current waking life. The basic assumption behind this approach seems to be that dreaming is functional for the individual if the dream in some way helps the individual cope with his current waking concerns, solve current problems, and to promote psychological well-being. These views can be traced back to Jung (1933) who argued that dreaming helps to maintain the individual's psychic balance and Adler (1927) who believed that dreaming serves a personal problem-solving function.

These types of theories of the psychological function of dreaming can be divided into two categories. The first holds that dreaming has a problem-solving function in an intellectual or cognitive sense: The function of dreaming is to find solutions to (or to facilitate the solving of) intellectual problems. The second holds that the function of dreaming is related to emotional adjustment, not to intellectual problems. Any real-life event that can be considered an emotional concern for the dreamer can be seen as presenting a problem for psychological adjustment, and dreaming is assumed to contribute to the emotional or behavioral adjustment that is called for in order to solve the emotional problem (e.g., Breger 1967).

2.2.1. Do dreams solve intellectual problems? Some studies have directly addressed the question of whether we can solve intellectual problems in our dreams or with the help of them. Dement (1972) reports a series of experiments in which 500 undergraduate students were given a copy of a problem, and before going to bed the students were to spend exactly 15 min trying to solve the problem. In the morning, they wrote down any dreams they recalled from the previous night and, if the problem had not been solved, spent another 15 min trying to solve it. In 1,148 attempts, the problem was solved in a dream on only seven occasions. This means that less than 1% of the dreams were successful in solving the problem. Montangero (1993) reports a sleep laboratory experiment with six subjects. Four subjects were given a formal problem, while two were trying to solve an intellectual problem relating to their own professional careers. Although elements of the problems appeared in the dreams, none of the 29 reported dreams presented the solution to the problem. However, the subjects did find the solutions to the problems with relative ease during the first hour after awakening in the morning. Unfortunately, it remains unclear whether dreaming causally contributed to this problem-solving success at all. Cartwright (1974a) compared solutions to problems arrived at either after a period of REM sleep or an equivalent amount of waking. She concluded that "There is no evidence from this study that a period of sleep during which dreaming occurs is regularly followed by a better performance on intellectual tasks" (p. 454). In a study by Barrett (1993) the subjects were allowed to choose the problem that they tried to solve in their dreams. The results showed that problems of a personal nature were much more likely to find a solution through dreaming than problems of an academic or intellectual nature. The personal problems, however, lacked definitive criteria for what should count as a solution, raising the suspicion that at least some of the alleged solutions may have been attributed to the dream during retrospective reflection required during the reporting rather than having been arrived at within the dream itself.

Blagrove (1992a) presents a thorough review and critique of the problem-solving paradigm of dream function. The assumption behind this paradigm is that the function of dreaming is to work actively and creatively toward solutions to actual current waking problems, thus going beyond what was known prior to the dream and causally contributing to the solution of a real-life problem. In order to evaluate the evidence for such claims, Blagrove distinguishes three types of problem-solving dreams: (1) Dreams that actually create a new and useful solution to a current problem in waking life; (2) Dreams that contain problem-solving activity that is internal to problems encountered in the dream world, but not relevant to waking problems; (3) Dreams that reflect solutions to waking problems, but for which there is no evidence that such solutions have not already occurred to the waking mind (i.e., the dream does not contribute to the solution, it merely reflects the solution once it has already been found during waking). Blagrove (1992a) argues that there is little evidence for problem-solving dreams of the first type; most of the dreams apparently solving problems either simply reflect solutions already known or solve problems only relevant in the context of the dream. Although a psychological change may be *correlated* with a dreamed solution to a problem, there is little reason to believe that there is a *causal* relationship between them. It is most likely that the actual solution first arises during waking, and the consequent dreaming merely reflects the solution, and thus becomes correlated with whatever the beneficial consequences of the solution were. The conclusion from Blagrove's (1992a) review is that whatever the function of dream experience is, it does not appear to be the finding of new and useful solutions to the problems we face in our waking reality.

2.2.2. Do dreams solve emotional problems? Probably the most popular theory of dream function within psychology is the hypothesis that dreaming solves our emotional problems by helping us to adjust psychologically to, and maintain our mental health in, the real-life situations that trouble us emotionally and psychologically. There is an overwhelming amount of evidence showing that dream content indeed reflects the current emotional problems of the dreamer (Hartmann 1998; Kramer 1993). The question is: Does dreaming have an effect in reducing the negative affect and other negative psychological consequences induced by our real-life troubles and traumas?

Cartwright (1996) argues that the best way to test this hypothesis empirically is to study subjects who are undergoing a life event that creates genuine affect. She studied subjects undergoing marital separation. Seventy subjects were chosen from a group of 214 potential subjects. Forty of them were depressed as a consequence of the divorce. All subjects slept for three nights in the laboratory, and during the third night, REM dream reports were collected. The depressed subjects' dreams were emotionally more negative than those of the nondepressed subjects. Furthermore, the depressed subjects were more likely than the nondepressed to incorporate the about-to-be-former spouse as a character in the dreams. In a one-year follow-up, those depressed subjects who had dreamt about their spouse were better adjusted than those who had not. However, it remains unclear how this correlation should be interpreted; on the basis of this study no causal relationship between dream content and adjustment can be established.

Kramer (1991; 1993) argues that during REM sleep there is a surge of emotion, and that the function of dreaming is to contain or to attempt to contain this surge. If the dream is successful in fulfilling this function, it does not enter awareness or memory, but protects sleep. A successful pattern of dreaming first states and then works on and resolves the problem, which leads to a positive affective outcome and no dream recall. Kramer's (1993) studies show that a successful night's dreaming is associated with having more characters in the dreams and leads to increased happiness during the next waking period. If the problem is simply restated and not solved, as in repetitive nightmares, then the problem remains unsolved, emotions remain negatively toned, and the dream easily enters awareness. Nightmares and bad dreams are therefore seen as unsuccessful attempts at solving our emotional problems. This theory is called the selective mood regulatory theory of dreaming (Kramer 1993).

Hartmann (1995; 1996a; 1998) has recently argued that our dreams deal with our emotions and emotional concerns by making pictorial metaphors of them. Dreaming cross-connects or weaves in new material, which, according to Hartmann (1998), helps us adapt to future trauma, stress, and the problems of life. Thus, dreaming and psychotherapy fulfill somewhat similar functions. A stressful real-life experience can be processed in both cases in a similar way, essentially by "making connections in a safe place" – that is, by associating and integrating traumatic experiences with the rest of life in order to facilitate psychological healing. Dreaming "calms" the emotional "storm" going on in the mind. Hartmann calls the class of psychological adaptation views of dreaming consistent with his theory the "contemporary theory of the functions of dreaming."

Punamäki (1997; 1998) has recently tested the role of dreams and dream recall in protecting psychological well-being in traumatic conditions. She studied the dreams of a group of Palestinian children living in a violent area in Gaza and a control group living in a peaceful area in Galilee. She reports that traumatized children had better dream recall than nontraumatized ones, and the more the children were exposed to trauma, the more negatively emotional and the less bizarre were their dreams. Frequent dream recall was associated with depressive symptoms, whereas infrequent dream recall was associated with somatic and anxiety symptoms. Thus, the pattern of mental health effects associated with dream recall is not straightforward, for both good and bad dream recall were associated with some, although different, psychological symptoms. Furthermore, on the basis of this study it remains unclear whether dream recall was a cause or a consequence of these symptoms, as well as whether frequent or infrequent dream recall in any way serves a positive long-term mental health function in the recovery from trauma.

Thus, the literature on the possible mental health functions of dreaming is inconclusive as to whether dreams truly solve our emotional problems, protect our mental health, or help us to adjust psychologically and to recover from traumatic experiences. The empirical evidence for such psychologically adaptive functions appears to be relatively weak and correlational at best. Furthermore, it is not entirely clear what the predictions of such a theory really are and whether the empirical evidence confirms or disconfirms them. If the idea is that dreaming "protects" our mental health from negative emotional impact by turning the stressful emotional experience into something better and by integrating it with the rest of our lives, it is surprising how often this function deserts us when we need it most. Recurrent dreams during times of stress are accompanied by negative dream content, and are associated with a deficit in psychological well-being (Zadra et al. 1997–1998). When we live under constant emotional stress or have recently experienced trauma, our dream consciousness typically makes us suffer from intensive nightmares that constantly remind us of the trauma by reactivating powerful negative feelings and other elements from the trauma (see sect. 3.5). If the real function of dreaming is psychological healing, shouldn't we in fact expect exactly the opposite: pleasant, comforting, manifestly healing dreams – calming, not amplifying, the traumatic experience? Intuitively, reliving the emotional shocks over and over again in dreams would not seem to be exactly what traumatized people are psychologically in need of.

The usual explanation for this anomaly is that the assumed dream function has simply "failed"; nightmares are treated as "failures" of dream function (Kramer 1991). But if this is so, then dream function fails a little too regularly, and exactly when it would be needed most. In opposition to these psychological adjustment theories of dreaming, I shall argue that nightmarish dreams are not ones that failed to perform their function, but, by contrast, are prime examples of the kind of dreams that fully realize their biological function. The view that dreams solve our emotional problems and increase our happiness and psychological well-being seems to include the biologically misguided assumption that normal life is free of emotional pain and trauma. Biologically adaptive responses to danger, such as pain and fear, are not there in order to increase our happiness but to increase our reproductive success. Natural selection cares only about fitness, not our comfort (Nesse & Williams 1997). If dreams are biological adaptations, they may not care about our comfort either.

3. The biological function of dreaming

The discussion above shows that there is no convincing evidence that dreaming would causally contribute to the solving of either intellectual or emotional problems. We must look elsewhere to discover the biological function of dreaming.

3.1. Background assumptions

The construction of the appropriate context for discovering the biological function of dream consciousness requires clarification of the following two questions: (Q1) What is the level of organization to which we attribute a function when we attribute it to consciousness? (Q2) What was the biological context in which dream consciousness evolved? Here are brief answers to these questions:

(A1) Consciousness can be reconceptualized as the phenomenal level of organization in the brain (Revonsuo 1999a). A function attributed to consciousness concerns the causal powers and behavioral effects of events realized at the phenomenal level of organization. The phenomenal level forms the brain's real-time model of the surrounding world, of the organism's internal state, and of its external position in the environment. Dreaming as a subjective experience is realized at the phenomenal level.

(A2) The primary evolutionary context for considering the possible adaptive function of dream consciousness is the prehistoric Pleistocene environment in which humans and their ancestors lived as hunter-gatherers for hundreds of thousands of years. If dream consciousness is biologically functional, it should have had adaptive value at least in that original environment, under the conditions in which human ancestral populations lived. Whatever the adaptive role of dream consciousness might have been in that long-gone original context, there is no guarantee that the average dreaming brain today, facing a completely different environment than the one in which it evolved, should fulfill any functions that we recognize as adaptive in the present environment.

I will simply take these answers as background assumptions that are reasonably well established; space does not permit a full defense of these views here (but for more on consciousness see Revonsuo 1995; 1997; and for an evolutionary perspective in cognitive neuroscience see Cosmides & Tooby 1995; Tooby & Cosmides 1995).

When put into the proper context in this manner, the question "Does dream consciousness have a function?" becomes: "Did the activation of an off-line model of the world in the ancestral human brain during sleep in some way enhance the probability of reproductive success of the individual living in the natural, original environment?"

My answer is in the affirmative: The off-line model of the world we call "dreaming" is specialized in the simulation of certain types of events that regularly and severely threatened the reproductive success of our ancestors, in order to enhance the probability that corresponding real events be negotiated efficiently and successfully.

3.2. Dream consciousness and threat simulation

We are now ready to formulate an evolutionary hypothesis on the function of dreaming. The hypothesis I am putting forward states that dream consciousness is essentially a mechanism for simulating threat perception and rehearsing threat-avoidance responses and behaviors. The threat simulation hypothesis of dreaming is presented below in the form of several independent empirically testable propositions. If each of these propositions is judged as probably true in the light of empirical evidence, then the threat-simulation hypothesis will receive considerable empirical support; but if most of them are not supported by empirical evidence, then the hypothesis will be falsified. I try to show that there are good reasons to believe that each of these propositions is actually true.

3.3. Proposition 1

> Dream experience is not random or disorganized; instead, it constitutes an organized and selective simulation of the perceptual world.

The demonstration that something is a biological adaptation is always "a probability assessment concerning how likely a situation is to have arisen by chance" (Tooby & Cosmides 1992, p. 62). The content of dreams shows far too much organization to be produced by chance. Empirical dream research has shown that dream consciousness is organized along the same lines as our waking consciousness. All sensory modalities are involved in perceptual dream experience, and approximately with a frequency comparable to that of everyday waking experience (e.g., Foulkes 1985;

Strauch & Meier 1996; Zadra et al. 1998). The visual appearance of dreams is for the most part identical with that of the waking world (Rechtschaffen & Buchignani 1992). The dreaming brain constructs a complex, organized off-line model of the world in which there typically is an active dream self with a body-image much like the one we experience when awake, surrounded by a visuo-spatial world of objects, people, and animals, participating in a multitude of events and social interactions with other dream characters.

This highly predictable and organized form of dreaming presents a challenge to any view claiming that dream experience is merely an incidental by-product of neurobiological processes operating at a different level of organization. It is extremely implausible that a low-level neurochemical restoration process, for example, should produce as some sort of "noise" a complex and organized model of the world at a higher level of organization (cf. Foulkes 1985). If dreams truly were just noise, they should appear much more noisy and disorganized than they actually are. Random noise in the system is not likely to create organized perceptual wholes, nor is it likely to make a good story, or any story at all;[4] it would be expected to generate disorganized sensations and isolated percepts. True noise in the brain is produced in connection with an aura of migraine for example. It does not generate an organized perceptual world of objects and events; rather the contrary, it produces for instance white or colorful phosphenes, geometric forms, and scintillating and negative scotomata (Sacks 1992). The visual hallucinations connected with Charles Bonnet syndrome usually consist of static images of people, animals, buildings, and scenery (Schultz & Melzack 1991). Were our dreams closely to resemble these phenomena it would be easy to believe that dreams consist of nothing but random noise reflecting neurobiological processes at other levels of organization in the system.

It could, however, be argued that even random or disorganized processes might activate organized schemas and scripts and thus produce dreamlike phenomenology. For example, in Penfield's (1975) studies the direct electrical stimulation of temporal cortex produced vivid and realistic perceptual "flashbacks." Still, these experiences were in many ways dissimilar to dreams: they were short (a few seconds) and undramatic excerpts of the patients' previous experiences, like randomly chosen artificially activated memory traces: "The mechanism is capable of bringing back a strip of past experience in complete detail without any of the fanciful elaborations that occur in a man's dreaming" (Penfield 1975, p. 34). Thus, the activation of such traces would not produce dreams as we know them. Consequently, there is no evidence that any kind of essentially random activation could produce the phenomenology and narrative structure of fully developed dreams.

Dream phenomenology, therefore, is likely to be the consequence of an active and organized process rather than a passive by-product of disorganized activation. This process generates an organized world-model. Foulkes (1985) points out that dreams are coherently organized both momentarily and sequentially. The momentary phenomenal content of dream consciousness is comprehensible and conforms to the kinds of multimodal perceptual experiences that we have during waking perception. These momentary phenomenal contents cohere sequentially so as to constitute narrative stories or temporally extended episodes of experience of the same general form as our waking experience. According to Foulkes, dreams are credible multimodal world analogs that are experienced as life: "The simulation of what life is like is so nearly perfect, the real question may be, why *shouldn't* we believe this is real?" (Foulkes 1985, p. 37).

Thus, all of the above shows beyond any reasonable doubt that dreaming is an organized simulation of the perceptual world; a virtual reality (Revonsuo 1995). Even granted this, it could still be the case that the phenomenal content of dreaming is simply a *random or indiscriminate sample* of the phenomenal content of waking consciousness (or the episodic memories thereof). However, this does not seem to be the case. There are certain experiences that are very frequent contents of consciousness during our waking lives but rarely or never enter our dreams. Hartmann (1998) describes two studies in which it was shown that even subjects who spend several hours daily reading, writing, or calculating virtually never dream about these activities. In the first study, two judges examined 129 written dream reports from several studies and found no instances of reading or writing and only one possible instance of calculating. In another study a questionnaire was mailed to 400 subjects who were frequent dreamers and interested in their dreams. They reported spending an average of six hours per day engaged in reading, writing, calculating, or typing, but answered that they dreamed "never" or "almost never" about any of these activities. They furthermore estimated on a seven-point scale how frequent different activities are in dreams compared with waking life. Their ratings showed a remarkable dissociation between waking and dreaming life: the average rating was at the "far more prominent in my waking life than my dream life" end of the scale as to the frequency of writing, reading, and typing.

This shows that dreaming is not only an organized but also a selective simulation of the world. Not every type of event or activity is simulated by the dream-production mechanisms, no matter how prominent they may be in our waking lives. Given that reading, writing, typing, and calculating are excluded from, or at least grossly underrepresented in, dream experience, what kind of phenomenal content is overrepresented in it? Which events is dream experience really specialized in simulating? This question leads us to Proposition 2.

3.4. Proposition 2

> Dream experience is specialized in the simulation of threatening events.

3.4.1. Dream content shows a significant bias toward representing threatening elements in dreams. If dreams are specialized in simulating threatening events, then we ought to find that dream content is biased toward including various negative elements (reflecting threats) rather than positive elements. Several prominent features of dream content suggest that this bias indeed exists.

3.4.1.1. Emotions in dreams. In the normative study by Hall and Van de Castle (1966), 500 home dream reports from female and 500 from male college students, aged 18–25, were content analyzed. Of the more than 700 emotions expressed in the dream reports, about 80% were negative and only 20% positive. The figures remain similar when only the dreamers' own emotions are considered. About half of the negative emotions experienced by the dreamers were classified as "Apprehension," the other half consisted of "sadness," "anger," and "confusion."

In the first normative laboratory study, Snyder (1970) collected 635 REM dream reports from students and found that more than two-thirds of the emotions mentioned in the reports were negative, fear being the most common and anger the next most common. Strauch and Meier (1996) report a sleep laboratory study in which they not only collected REM dream reports from 44 subjects but also asked them how they had felt during the dream. The emotions described in response to this question were analyzed. Specific emotions were mentioned in connection with every other dream. Negative emotions appeared twice as often as positive ones, with anger, fear, and stress being the most frequent types of negative emotions. In contrast to specific emotions, general mood states were found to be more often positively than negatively toned.

Foulkes et al. (1988a) and Revonsuo and Salmivalli (1995) have shown that emotions in dreams are in most cases appropriate to the dreamed situations in which they are experienced; therefore, the high proportion of negative emotions is a sign of frequent unpleasant dream events that should be expected to produce negative emotions if they were real. Emotions are evolved adaptations that increase the ability to respond appropriately in adaptively important situations. Negative emotions such as anxiety, fear, and panic, can be seen as adaptive responses that increase fitness in dangerous situations threatening a loss of reproductive resources (Marks & Nesse 1994). When emotions are experienced or expressed in dreams, they are much more likely to be negative than positive ones, and very likely to be appropriate to the dreamed situation. These findings are consistent with the hypothesis that dream content is biased toward simulating threatening events.

3.4.1.2. Misfortunes in dreams. "Misfortune" names a class of dream event in which a bad outcome happens to a character independent of anything the character has done (Hall & Van de Castle 1966). Misfortunes include, for example, mishaps, dangers, and threats. The opposite is called "Good Fortune." In the Hall and Van de Castle (1966) normative study, there were altogether 411 cases of Misfortune in 1,000 dream reports, and only 58 cases of Good Fortune. Thus, Misfortunes in dreams are seven times more frequent than Good Fortunes. Furthermore, about 70% of the misfortunes happen to the dream-self, and it is accidents, losses of possession, injuries or illnesses, obstacles, and threats from environment that comprise almost 90% of these misfortunes, whereas death and falling are rare types of misfortune (Domhoff 1996; Hall & Van de Castle 1966). Misfortunes, therefore, typically reflect situations in which the physical well-being or the resources and goals of the dream-self are threatened.

3.4.1.3. Aggression in dreams. Aggression is the most frequent type of social interaction found in dreams, the other classes in the Hall and Van de Castle (1966) scale being Friendliness and Sexual Interactions. About 45% of the dreams in the normative sample included at least one aggressive interaction. Dreamers are involved in about 80% of the aggressions in their dreams, and when they are involved they are more often the victim than the aggressor (Domhoff 1996; Hall & Van de Castle 1966).

3.4.1.4. Summary. Negative emotions, misfortunes, and aggression are prominent in dreams. These findings indicate that normative dream content frequently contains various unpleasant and threatening elements, which supports the view that dreams are specialized in simulating threatening events.

3.4.2. Dream content is consistent with the original evolutionary environment of the human species rather than the present one

3.4.2.1. "Enemies" in our dreams. Domhoff (1996) defines "Enemies" as those dream characters with which the proportion of aggressive encounters of all aggressive + friendly encounters is greater than 60%. This calculation on the Hall and Van de Castle (1966) normative sample reveals that animals and male strangers are the enemies in men's as well as women's dreams (Men vs. Animals 82%; Women vs. Animals 77%; Men vs. Male Strangers 72%; Women vs. Male Strangers 63%). Encounters with Female Strangers are not at all so aggressive, but predominantly friendly (Men vs. Female Strangers 40%; Women vs. Female Strangers 43%) (Domhoff 1996). According to Hall and Domhoff (1963), unknown males are responsible for the high proportions of victimization and physical aggressions with male characters.

Hall (1955) content analyzed 106 dreams of being attacked and found that the attacks predominantly represented situations in which the dreamer's life or physical well-being was at stake. The attacker was usually human or a group of humans (70%) but not infrequently an animal (21%). When the sex of the human attacker was identified it was virtually always male. The dreamer usually reacted to the attack by running, escaping, or hiding (unless she woke up). Hall and Domhoff (1963; 1964) analyzed aggressive and friendly interactions in more than 3,000 dream reports. They found that interaction was aggressive with 48% of the animal characters in men's dreams and with 29% of the animals in women's dreams.

Van de Castle (1983) compared college students' dreams (more than 1,000 dream reports altogether) in which humans were the dominating dream characters with those in which animals predominated. He found that dreams with animal figures typically take place in an outdoor setting, have a great deal of activity that is often of a violent nature, and that the dreamer typically experiences fear. If an animal figure initiates an interaction with the dream-self, the nature of the interaction is aggression 96% of the time and friendliness only 4% of the time. Van de Castle writes that "almost without exception, if the animal figure initiates any response to the dreamer, it is some form of threat or hostility" (p. 170).

Why are animals and male strangers our enemies in dreams? Ancestral humans lived in environments in which many animals (e.g., large carnivores, poisonous animals, parasite-carrying animals) presented an ever-present mortal threat for humans. Therefore, behavioral strategies to avoid contact with such animals and to escape or hide if attacked by them obviously were of high survival value. Some deep-rooted human fears and phobias of snakes, spiders, rats, and open spaces are indications that ancient threat avoidance programs still remain with us (Marks & Nesse 1994). Dreaming simulates and rehearses these ancestral threat-avoidance programs in order to maintain their efficiency, because the costs of a single failure to respond appropriately when the danger is real may be fatally high, while the costs of repeated threat simulations during sleep are remarkably low.

Our present-day encounters with unfamiliar males in the waking life are not predominantly aggressive. In the ancestral human environment, however, intergroup aggression and the violent competition over access to valuable resources and territories is likely to have been a common occurrence. Since intergroup warfare and violence was and still is almost exclusively practiced by males (Wrangham & Peterson 1996; see also Campbell 1999), encountering male strangers is likely to have been a potentially threatening situation in the ancestral environment, comparable to the threats presented by dangerous animals. Indications that unfamiliar males often present a mortal threat to offspring come from other primates where infanticide by genetically unrelated males is common (Hrdy 1977). Furthermore, human infants universally develop stranger fear at about six months of age, and even in the modern world are much more likely to be killed or abused by genetically unrelated adults than by close kin (Daly & Wilson 1988). Thus, although an overwhelming majority of our current waking-life encounters with animals and male strangers are not particularly aggressive or threatening, dream content still reflects the ancestral conditions in which such encounters were potentially life-threatening. Dreams are biased toward simulating threats that were common in our ancestral environment.

3.4.2.2. Children's dreams. If dreams are naturally biased toward simulating ancestral threats, then we should expect that the traces of these biases are strongest early in life, when the brain has not yet had the chance to adjust the biases in order to better fit the actual environment. This seems to be the case when it comes to the appearance of animals and aggressions in children's dreams. One of the most prominent differences between child and adult dreams is the much larger number of animal characters in children's dreams. Hall and Domhoff (1963; 1964) analyzed about 500 dream reports from children aged 2–12 years; Hall later increased the sample to 600 dreams and Domhoff (1996) reports the results from this larger sample. Animal characters make up about 25–30% of all characters in the dreams of children 2–6 years of age, and about 15% in 7–12 years of age, whereas the normative finding for adult dreams is about 5% (Domhoff 1996).

Van de Castle (1983) also reports studies of children's dreams. The 741 dream reports (one from each child) were written down by schoolteachers or directly reported by the pupils themselves. The general trend toward a decrease in the frequency of animal dreams as a function of age is clearly manifested. Two-year averages in the percentage of animal dreams for children 4–16 years old were 39.4% for 4–6 years olds, and 35.5, 33.6, 29.8, 21.9, and 13.7% for the next consecutive two-year age groups. In an earlier study on a smaller sample of dreams, Van de Castle (1970) reported closely similar figures (Fig. 1).

Surprisingly, in their dreams children often encountered animals that were seldom or never encountered in the waking world. Wild or frightening animals (e.g., snakes, bears, monsters, lions, spiders, gorillas, tigers, wolves, insects) comprised nearly 40% of all animal characters in children's dreams in this study, but less than 20% in college students' dreams. Dogs, horses, and cats accounted for 28% of animals in children's dreams but 38% in college students' dreams (Van de Castle 1983). Thus, the proportion of domestic animals increases and that of wild animals decreases with age.

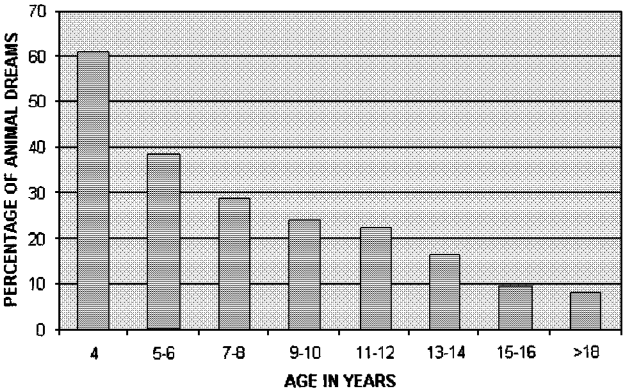

Figure 1. Percentage of animal dreams in relationship to age (modified from Van de Castle 1970).

Due to the methods of collecting the dream reports, the studies mentioned above may have included a somewhat biased sample of dreams.[5] However, also in the laboratory study of Foulkes (1982b), animals were the major characters in the dream reports of children 3–5 and 5–7 years of age, appearing in 30–45% of the reports. Also the decrease in the number of animal characters with increasing age was confirmed. Strauch (1996) reports results from both home and laboratory REM dreams in Swiss children 9–11 years of age. Both types of dreams involved more animals than young adults' dreams, again confirming the decrease of dream animals with increasing age. Home dreams contained animals about twice as often as laboratory dreams, which was explained by dream report length: home dreams were longer and included more characters. Girls' dreams contained more animals than boys' dreams. In the REM dreams, 102 animals were found. In girls' dreams, tame animals and pets prevailed (63%) over wild native or exotic animals (37%), whereas in boys' dreams, wild animals were much more common than tame ones (61 vs. 39%). Taken together, on the average one out of two animals encountered in the children's dream world is an untamed wild animal. For boys around 10 years of age this is the most common type of dream animal.

Hall and Domhoff (1963) showed that children also have a higher rate of aggression in their dreams than adults. The greatest amount of aggression occurs in the dreams of children 2–12 years of age. According to Domhoff (1996), much of this larger amount of aggression is with animals and the child is usually the victim of an attack by the animal. In Strauch's (1996) data of combined REM and home dreams, about 30% of all the animals appearing in 10-year-old children's dreams were in the role of aggressors, compared to 10% in adults' dreams.

Levine (1991) studied the representation of conflicts in the dreams of 77 children who were about 10 years of age and came from three different cultures: Bedouin, Israeli, and Irish. Conflictual dreams accounted for about two-thirds of the reports and were reported about twice as often as nonconflictual dreams in all three cultures. The Bedouin children, who were living in a traditional seminomadic tribe, had dreams that were realistic and concerned with threats to physical survival, usually from the natural world.

Children's dreams thus show strong biases toward simulating a world that contains animals (especially wild animals), aggression, conflicts, animal aggressors, and victimization to a greater degree than does their own waking world or the dream world of adults. These biases decrease with age if the child's real environment is largely devoid of them. It seems unlikely that young children would have had more frequent real waking experiences of such things than teenagers or adults have had; therefore, it is difficult to explain these biases by referring to the waking lives of the children.[6] These biases seem to be another sign of the fact that the dream-production system is prepared to simulate threatening events consistent with and prevailing in the human ancestral environment. The biases decrease with age, as the perceptual world proves to be quite different from what was anticipated by the dream-production mechanisms.

3.4.2.3. Recurrent dreams and nightmares. Robbins and Houshi (1983) asked 123 university students whether they had ever had recurrent dreams, and if so, they were asked to describe them. Sixty percent reported that they had had recurrent dreams, many beginning in childhood. A content analysis revealed that only one type of recurrent dream occurred with any frequency, an anxiety dream in which the dreamer was being threatened or pursued. The threatening agents were wild animals, monsters, burglars, or nature forces such as storms, fires, or floods. The dreamer was watching, hiding, or running away. The authors regarded these descriptions as reasonably close to nightmares (Robbins & Houshi 1983, p. 263). Recurrent dreamers reported more problems in their lives and more physical symptoms than those who did not report recurrent dreams, indicating that recurrent dreams may be related to increased levels of stress. Feldman and Hersen (1967) found that frequent recurring nightmares in adults were related to conscious waking concerns about death and to having experienced the death of a close relative or friend before the age of 10. Zadra et al. (1997–1998) reported that in both late teenagers and older adults recurrent dreams with negative content occur during times of stress.

Nightmares, or long, frightening dreams that wake the dreamer, are the paradigm cases of highly unpleasant dreams. It is estimated that almost everyone has had a nightmare, that children, especially from 3 to 6 years of age, very frequently experience some, and that adults quite commonly have occasional nightmares. In a study of 1,317 subjects, 5% reported having nightmares once per week and an additional 24% once per month (Feldman & Hersen 1967). The themes in the dreams of lifelong nightmare sufferers are remarkably similar to the themes of recurrent dreams, and the most frequent theme is, again, that of being chased or attacked (Domhoff 1996; Hartmann 1984). Such dreams usually begin in childhood and involve being chased by a monster or a wild animal. In adulthood, the chaser was more likely to be a large unfamiliar man, a group of frightening people, or a gang. These dreams can be frequent, seem very vivid and real, but still do not usually reflect any actual events that ever happened to the dreamer (Hartmann 1998).

Recurrent dreams and lifelong nightmares not directly connected with any real-life traumas appear to be very powerful simulations of rather primitive threats. Again, we should note that the origin of these simulations apparently is not in the real life of the dreamer. Where do these recurrent themes come from? In the light of the human ancestral environment, it makes great sense to simulate violent encounters with animals, strangers, and natural forces, and how to escape from such situations.[7] Therefore, these simulations are incorporated as default values in the threat simulation system, and they can be activated in almost anybody, at least occasionally. In lifelong nightmare sufferers the trigger seems to be the fact that, because of their highly sensitive personality ("thin boundaries"; Hartmann 1984), for them even everyday experiences may be highly stressful or traumatic (Domhoff 1996; Hartmann 1998) and, as we will see in later sections, such emotional triggers can have profound effects on subsequent dream content.

3.4.2.4. Absence of reading, writing, typing, and calculating. One explanation for the fact that we do not dream about reading and writing is that they include little if any emotional charge for us. However, Hartmann (1998) found that walking, talking to friends, and sexual activity are represented in dreams about as often as in real life, although these activities differ considerably as to their emotionality. Therefore, the principal reason we do not dream about writing, reading, and doing arthmetic probably is that all these activities are cultural latecomers that have to be effortfully hammered into our evolved cognitive architecture. They were not present in ancestral environments nor are they neurally hardwired in the human brain in the way that other complex cognitive functions, frequently present in dreams, are (e.g., speech comprehension and production). Furthermore, they are highly dependent on abstract symbol systems rather than on the recognition or manipulation of concrete objects. Thus, they are in many ways activities fundamentally different from the ones that the human brain was selected for in its original environment.

3.4.2.5. Brain activation during REM sleep reflects the neural correlates of threat simulation. If the essence of dreaming is threat simulation, then we should find that the brain areas active during REM sleep are ones involved in generating emotional and perceptual experience.

According to Hobson (1999a) PGO waves are believed to be the neural generators of the internal stimulation that results in dream phenomenology. They occur as bursts of waves during REM sleep, activating, in particular, the thalamocortical circuits involved in vision, but also radiating to the limbic lobe and amygdala. In the waking state PGO waves are triggered by strong, novel stimuli and are associated with surprise and fear: "PGO waves prepare us for fight or flight should these prove necessary. The startle reactions provoked in us by real or imaginary intruders are mediated by PGO-like signals" (Hobson 1999a, p. 169). Thus, the function of PGO waves during waking is clearly consistent with internal threat simulation during dreaming.

Research on emotionally charged memories and memory under stress has recently come up with the idea that there is a separable "hot" amygdala-centered emotional system distinct from the "cool" hippocampally centered episodic memory system (for a review, see Metcalfe & Jacobs 1998). The two systems work in cooperation, the "hot" system highlighting those species-specific or learned elements of memory traces that are highly emotional by nature. The "hot" system is believed to have a role in releasing species-specific behaviors such as fear or defensive responses to emotionally charged stimuli. As the stress levels of the organism increase, the "hot" memory system becomes increasingly activated. When a person is in a stressful and dangerous situation, the hippocampal "cool" system may not be optimal for responding to threat. Instead, the "hot" system may very efficiently process the threatening cues and immediately activate threat-avoidance mechanisms. The "hot" system is considered to be more automatic and primitive than the "cool" system, thus allowing the organism to realize rapid protective responses. In accordance with this view, a recent PET study suggests that the human amygdala modulates the strength of conscious episodic memories according to their emotional importance (Hamann et al. 1999).

Recent functional brain-imaging studies of sleep show that brain areas involved in the processing of emotionally charged memories are strongly activated during REM sleep and dreaming. The dream-production mechanisms thus seem to be in close interaction with the primitive "hot" memory system, preferably selecting memory traces with high emotional charge. A study of regional cerebral blood flow distribution showed that during human REM sleep, activation and functional interaction occurs between the amygdaloid complexes and various cortical areas, but the prefrontal cortices are deactivated (Maquet et al. 1996). The authors concluded that these interactions might lead to the reactivation of affective components of memories. A similar pattern was found in another study, concluding that pathways which transfer information between visual cortices and the limbic system are active during REM sleep (Braun et al. 1998).

In sum, neurophysiological studies and functional brain imaging reveal the dream-production mechanisms at work during REM sleep, searching for and processing emotionally charged memory traces in the evolutionarily ancient, "hot" memory system. The dream-production mechanisms, guided by the dominant emotional concerns of the dreamer, create the content of dreams in interaction with other long-term memory systems (Cavallero & Cicogna 1993) and perceptual cortical areas.

3.4.2.6. Summary. Many elements abundant in contemporary life (e.g., reading, writing) are absent from dreaming, whereas many such elements that are not common in waking life, but consistent with simulating primitive threats (e.g., aggressive interactions with animals and male strangers), are universally present in adults' dreams, children's dreams, recurrent dreams, and nightmares. Furthermore, brain activation during REM sleep is consistent with the activation of brain areas required to simulate emotionally charged, threatening events.

3.5. Proposition 3

> Encountering real threats during waking has a powerful effect on subsequent dream content: real threats activate the threat simulation system in a qualitatively unique manner, dissimilar from the effects on dreaming of any other stimuli or experience.

3.5.1. The effect of traumatic experience on dream content. Real experiences of actual dangers or life-threatening events are very likely to be incorporated into dreams (Barrett 1996; Hartmann 1984; 1996a). This is most clearly manifested in cases of post-traumatic nightmares. These nightmares are reported by people who have undergone, for example, wartime battles, natural catastrophies, terrible accidents, or assault, rape, or torture. The frequency of post traumatic nightmares depends, among other things, on the degree of threat perceived to be targeted at self and significant others. It appears that the greater the sense of threat created by the experience, the more likely it is that nightmares will follow (Nader 1996). For example, 100% of 23 children who were kidnapped and buried in a truck trailer; 83% of six children that underwent a life-threatening medical operation; 80% of 10 children witnessing their mothers being raped; 63% of children exposed to sniper fire on their schoolyard, and 40% of children whose suburb was exposed to radioactivity after a major nuclear power plant accident reported nightmares related to the respective incidents (for a review, see Nader 1996). Ninety-six percent of 316 Vietnam combat veterans described a combat nightmare in an interview (Wilmer 1996).

These are very impressive figures, especially in view of the fact that laboratory research has failed to find any strong determinants of dream content. Presleep stimuli, such as films depicting violence, are only marginally if at all incorporated into dreams. The conclusions of Vogel (1993), in a review of stimulus incorporation in dreams, are revealing:

> dream content is remarkably independent of external psychological and physical stimuli both before and during sleep and equally independent of currently measurable physiological processes during sleep. Therefore, the sources of dream content, that is, its themes and its specific elements, remain a mystery. (Vogel 1993, p. 298)

Laboratory research has failed to find the actual determinants of dream content, probably because it is practically and ethically impossible to expose experimental subjects to situations that evoke a deep enough sense of threat. The stimuli that are typically used in laboratory research on stimulus incorporation, such as films, never induce anything like a genuine sense of real threat to one's own life. Therefore, they do not function as ecologically valid cues for the dream-production mechanisms. We must turn to the cruel experiments inadvertently designed by wars, crime, and nature. The sense of severe personal threat probably is the most powerful factor we know of in the modulation of the content of dreams: the experience of a severe trauma can induce nightmares in almost anyone; the majority of people, especially children, involved in traumatic events do report nightmares; and traumatic nightmares can occur in several stages of sleep (Hartmann 1984).

Once the dream-production system encounters the memory of an event combined with a deep sense of threat, how does it handle that? There seems to be a more or less universal pattern involved in the ways in which post-traumatic dreams are constructed (Hartmann 1984;1998). In the first stage, immediately after the traumatic event, the frequency of trauma-related dreams and nightmares increases and the event is being replicated a few times in the dream world, in a form often closely similar but not exactly identical (Brenneis 1994) to the original experience. The first stage normally lasts a few days or weeks, but in severe post-traumatic disorder it may persist for years.[8] In a longitudinal study on children who were exposed to a sniper attack on the school playground, 42% continued to have bad dreams 14 months after the incident (Nader et al.

1990). In another study on a bushfire disaster, 18% of the children continued to have post-traumatic nightmares when studied 26 months after of the actual event (McFarlane 1987).

Gradually, the nightmares change into increasingly modified versions of the event. At this stage, the original experience is associated with and connected to other similar contents in memory. The resulting dreams may be small variations of the original threat, the original threat mixed with previously experienced ones, and with classical nightmare themes such as being chased or escaping powerful natural forces. Eventually, perhaps after a few weeks or months, the content of dreams returns to approximately normal. Even long after the original trauma, events that remind of it or also induce a deep sense of threat may trigger the recurrence of the trauma-related nightmares. In post-traumatic stress disorder, this normal development of the dream sequence does not occur; instead, replications and different variations of the original trauma continue to recur, even for years (Hartmann 1984; 1996a; Stoddard et al. 1996).

Ordinary as well as post-traumatic nightmares are especially frequent in children (Hartmann 1984). Nader (1996, pp. 16–17) mentions the following types of trauma-induced threat simulations in children's dreams. Kuwaiti and Croatian children exposed to war dreamed of being personally endangered by someone trying to kill them with a knife, a gun, or bare hands, and of being captured or tortured. Children from Los Angeles who had witnessed their mothers being raped dreamed of the rapist returning, of being threatened, of being severely physically harmed, of directly confronting the assailant, or of taking revenge. A girl who was chased and groped by an unfamiliar man had recurrent dreams in which people or animals chased her. Children who were in a cafeteria when a tornado knocked the wall down with serious consequences dreamed of the wall falling again, of houses being destroyed by a tornado, of branches falling, of being hit by glass, and of trying to find bandages for dead people. After a hurricane, both parents and children dreamed of being threatened by winds or tornadoes coming directly at them.

In a study of the dreams of Arab and Jewish children 11–13-years of age (Bilu 1989), all the dreams representing the "other side" were extracted and analyzed. In these 212 dreams, aggression appeared in about 90% of the interactions, while friendliness was virtually nonexistent (4%). Jewish children dreamt about Arab terrorist attacks and camouflaged detonating explosives in public places. In these dreams, the dreamer was usually the recipient of an unprovoked assault initiated by an adult adversary who was typically defeated in the end. Arab children living in a refugee camp dreamt about brutal physical aggression, which resulted in death on either side, in 25% of the dreams. The dreamers were typically harassed, expelled, arrested, beaten, injured, or killed. Bilu (1989, pp. 385–86) comments that the conflict between Arabs and Jews seems to have an even stronger presence in these children's dreams than it does in reality (i.e., it is *overrepresented* in dreams): "the intensity and pervasiveness of the conflict as reflected in the dreams cannot be taken for granted even by those well-acquainted with the situation."

Dreams after trauma reflect the dream-production system working at full capacity, producing a regular pattern that proceeds from near-identical replications to increasingly modified variations to gradual fading and possible recurrence. Hartmann (1996a; 1998) suggests that dreams after trauma should be seen as the paradigm case of dream formation. He makes the important observation that:

> One hundred thousand years or so ago, when the human brain was gradually developing to its present form, our lives were considerably more traumatic; the after-effects of trauma may well have been an everyday reality. (Hartmann 1996a, p. 158)

According to Hartmann's (1996a; 1998) view, the content of dreams is greatly modulated by the current dominant emotional concern of the dreamer. Dreaming connects the trauma and the associated feelings and emotions to a wide variety of related images and memories in the dreamer's memory networks. Domhoff (1993) suggests that all dreams could be seen as dealing with traumatic experiences of differing degrees and regards recurrent dreams as "watered-down" versions of traumatic dreams, but otherwise basically within the same category of dreams. Domhoff (1996) treats nightmares, recurrent dreams, and dreams after trauma under the heading of "the repetition dimension" in dreams, and says that no theory of dreaming should be taken seriously if it cannot deal with this dimension. The present hypothesis explains this dimension as the paradigm case of threat simulation in dreams.

3.5.2. Real threats as cues that activate the threat simulation system. The view that emerges can be summarized as follows: Experiences of real threats are the only ecologically valid cues for the threat simulation system. Encountering real threats powerfully activates the threat simulation system: first, they may intensify the neurophysiological events underlying threat simulations; second, they tend to render the threat simulations more realistic; and third, they may even influence the development of the dream-production system.

There is some evidence indicating that real threats may intensify REM sleep. In normal subjects the presence of stressful life events is associated with increased intensity of REM sleep (Williamson et al. 1995). One study (Ross et al. 1994) found that patients with post-traumatic stress disorder and frequent anxiety dreams showed elevated tonic REM sleep measures: they spent a higher percentage of total sleep time in REM sleep and their REM sleep periods were longer than those of control subjects. Furthermore, they had heightened phasic-event generation in REM sleep and manifested increased rapid eye movement activity. However, another study (Hurwitz et al. 1998) did not find any differences in polysomnographic sleep between Vietnam combat veterans and normal controls. Thus, more studies are needed to establish the relationship between stressful or life-threatening events and the intensity of REM sleep.

In a study on Palestinian children living in traumatic conditions it was found that the more the children were exposed to trauma, the more negatively emotional and the less bizarre their dreams were. The children exposed to trauma also had better dream recall than other children (Punamäki 1997). These findings indicate that the dream-production system creates especially vivid and realistic simulations of threatening events encountered in the real world.

Real threats might even trigger the ontogenetic development of dreaming. Foulkes (1999) argues that adult-like "true" dreaming appears relatively late in childhood, at about 7–9 years of age. By contrast, clinical case reports suggest that the earliest nightmares may be experienced as early as during the second year of life (Hartmann 1998). Some traumatized preschool children report fully developed nightmares, unlike those typical of the age (Nader 1996), suggesting that traumatic experiences may actually stimulate the development of the dream-production system, or, conversely, that a lack of real life-threatening events might hold it back, or at least preserve the dream-production system in a resting state although it would already be capable of generating threat simulations if only exposed to the ecologically valid cues (see also N. 5 on children's dreams).

It could be argued against Proposition 3 that both positive and negative real emotions are equally strong in activating the dream-production system. This alternative hypothesis is not supported by evidence. Hartmann (1998, p. 73) observes that "even when people experience a happy event, they are more likely to dream about problems associated with it than the pure happiness of the event itself." Thus, dreams tend to represent even happiness in the light of the possible threats that might endanger it.

According to the present hypothesis, the brain's dream-production system selects traumatic contents not because they represent unsolved emotional problems, but primarily because such experiences mark situations critical for physical survival and reproductive success. What from a psychological point of view is a "traumatic experience" is, from a biological point of view, an instance of threat perception and threat-avoidance behavior. Negative emotions, such as fear and terror, accompanying the perception of serious real-life threats, serve to label such events as critical to one's own survival and future reproductive success. The contents of the threat simulations are selected by the dream-production system from long-term memory, where recent memory traces associated with threatening emotional impact are the most salient ones to enter the dream-production mechanisms. The stronger the negative emotional charge, the more threatening the situation is likely to have been, and the more likely it is that it will be selected by the dream-production system as a recurrent theme for threat simulation. The dream-production system is highly sensitive to situations critical for the physical survival and future success of the individual: violent attacks, being chased by strangers or animals, finding intruders in one's private territory, losing valuable material resources, being socially rejected, encountering untamed natural forces or dangerous animals, being involved in accidents, and misfortunes. Such dream contents involve, from a biological point of view, threat perception, threat avoidance, antipredatory behavior, and coping strategies against threats.

3.6. Proposition 4

The threat simulations are perceptually and behaviorally realistic and therefore efficient rehearsals of threat perception and threat-avoidance responses.

3.6.1. Perceptual realism and lack of insight. So far we have shown that dreaming specializes in the repetitious simulation of threatening events. Next, we need to show that these events constitute realistic rehearsals of threat perception and avoidance, for otherwise they would not be useful simulations. First, dreams and especially nightmares consist of vivid images that seem perfectly real. Second, during dreaming we are in an uncritical, delusional, and isolated state of mind that very efficiently prevents us from realizing it is all just a hallucinatory simulation (Rechtschaffen 1978). The relatively rare exception of lucid dreaming (Gackenbach & LaBerge 1988) notwithstanding, we take the dream world for real while it lasts, totally lacking insight into our true condition. Thus, these two factors, perceptual realism and delusional lack of insight, guarantee that the simulation is taken most seriously. If that were not the case, we might instantly recognize the dream world for what it is and not be motivated to defend ourselves against the simulated threats. Lucidity has in fact been recommended as a possible cure for recurring nightmares (e.g., LaBerge 1985; Zadra & Pihl 1997).

3.6.2. Motor realism. What about the dreamed action: What is its relationship to real motor behavior? It should be neurally realized in the same way as real actions are, otherwise it could not be regarded as an efficient rehearsal of what to do in a comparable real situation. Mental imagery of motor actions uses the same motor representations and central neural mechanisms that are used to generate actual actions (Decety 1996; Jeannerod 1995); moreover, dreamed action is experientially far more realistic than mere imagined action. Therefore we have good reasons to believe that dreamed action is equivalent to real action as far as the underlying brain mechanisms are concerned.

Classical neurophysiological studies in the 1960s (reviewed by Hobson 1988b) showed that the pyramidal-tract cells of the motor cortex increased their firing during REM sleep (compared to nonREM, NREM, sleep), having firing rates as high as those during waking with movement.[9] Thus, motor commands are generated during REM sleep at the cortical level but they are not realized in the periphery because of the operation of an inhibitory system that blocks the activity of motor neurons in the spinal cord, resulting in muscular atonia. According to Hobson (1999a), the *experience* of movement in dreams is created with the help of the efferent copying mechanism, which sends copies of all cortical motor commands to the sensory system. The brain thus receives internally generated information about issued motor commands and computes the expected consequences of those commands. The sensory system is not informed that these commands were not in actual fact carried out by the muscles, and therefore the illusion of movement comes about.

If the inhibitory mechanisms that produce atonia during REM sleep are malfunctioning, the result is a recently described sleep disorder called REM Sleep Behavior Disorder (RBD) (Schenck et al. 1986). These patients manifest violent behaviors during REM sleep, which are the acting out of the motor imagery being dreamt about. Thus, dreamed action corresponds to real action as far as the forebrain is concerned. The difference between dreamed and real motor action depends only on the inhibitory cell groups in the pons. Thus, within the forebrain, dreamed action has the same neural realization and the same causal powers as real action does. Dreamed action is experientially and neurophysiologically real. (For a similar view on all motor imagery, see Jeannerod 1994.)

Some illustrative cases of RBD have been reported in the medical literature. Dyken et al. (1995) describe the case of a 73-year-old man. During an episode of RBD, the patient leaped from his bed, fell, and struck the right side of his face on a corner of a chest, awakening him immediately. This resulted in subdural hemorrhage. He had dreamed of working on a loading dock and saw a man running. Someone yelled "Stop him!" and the patient had tried to do just that when he jumped out of his bed with the unfortunate consequences. In the sleep laboratory during REM sleep, the patient suddenly exhibited explosive running movements, followed by an arousal. The patient's actions again clearly corresponded to what he was dreaming about at the time of the observed behaviors. Boeve et al. (1998, pp. 363–70) describe a patient who, on one occasion, "held his wife's head in a headlock and, while moving his legs as if running, shouted: 'I'm gonna make that touchdown!' He then attempted to throw her head down toward the foot of the bed. When awakened, he recalled a dream in which he was running for a touchdown, and he spiked the football in the end zone." Comella et al. (1998) describe a group of patients with RBD. If these patients were awakened during an episode of abnormal sleep behavior, none of them realized that they had executed violent movements, although all recalled violent dreams at the time of awakening: being pursued by an enemy; trying to protect family members from unknown intruders; or fighting off unidentified assailants. Schenck (1993) describes a patient whose EEG, EMG, and EKG were polysomnographically recorded during an attack of violent behavior. The muscle tone was increased and the arms and legs showed bursts of intense twitching, accompanied by observable behavior. After a spontaneous awakening, the man reported a dream in which he was running and trying to escape skeletons that were awaiting him.

It is noteworthy that most cases of RBD involve intensive threat simulation dreams, and the behaviors manifested are (mostly adequate) responses to these threats. It may be that threat simulations are associated with increased cortical activation, leading to intensive motor imagery that breaks through the malfunctioning inhibitory mechanisms.

There are other sleep disorders that can be interpreted as an inappropriate activation of the threat-simulation system, leading to sleep-related behaviors. Night terrors,[10] sleepwalking (somnambulism), and nocturnal wandering appear to be, at least in some cases, threat simulations that take place during NREM sleep and lead to an altered state of consciousness that is a mixture of wakefulness and NREM sleep (Mahowald & Schenck 1992; Mahowald et al. 1998). In this state, one's subjective consciousness is focused on one internally generated, usually terrifying, image or belief. Appropriate threat-avoidance behavior is often realized automatically, violently, and efficiently in the absence of reflective thought – without an awareness of one's altered state, one's actions, or their actual consequences.[11] One patient described by Schenck and Mahowald (1995) once left the house in pajamas by running through a screen door, then entered his automobile and drove eight kilometers to his parents' home where he awakened them by pounding on their door. This episode of somnambulistic automobile driving was initiated by the subject's belief that someone was in the house and about to attack him. Another subject with nocturnal wandering once threw his wife on the floor, ran to his two children, took them into his arms and ran outside. Afterward he said he had believed that the house was on fire (Guilleminault 1995). When aged ten, one patient had risen from sleep, rushed into the sitting room where his parents were still sitting, and thrown the butter dish out of the window, believing it to be a bomb (Oswald & Evans 1985).

Thus, both RBD and NREM-related sleep disorders show that threat simulation during sleep includes realistic and adequate motor activation in the brain in response to the perceived threats.

3.6.3. Summary. The evidence reviewed above shows that dreaming constitutes a realistic simulation that we tend to believe without questioning and that dreaming about an action is an identical process for cortical motor areas as actually carrying out the same action. In some pathological cases, the actions generated in the dream world are inadvertently performed in the real world. Thus, to dream about threat perception and threat-avoidance behaviors is to realistically rehearse these functions in a safe environment.

3.7. Proposition 5

> Simulation of perceptual and motor skills leads to enhanced performance in corresponding real situations even if the rehearsal episodes were not explicitly remembered.

3.7.1. Mental training. It is a commonplace that training and repetition lead to enhanced performance. However, can actions only performed at the phenomenal level and not overtly executed lead to any kind of learning? Research on the effects of motor imagery and mental training to motor performance show that repeated motor imagery can lead to increased muscular strength (Yue & Cole 1992), improvement in the learning of new motor skills (Hall et al. 1992; Yaguez et al. 1998), and improved performance in sports (e.g., Lejune et al. 1994). These learning effects are thought to arise at the cortical programming levels of the motor system (e.g., through activation of Brodmann area 6 where the premotor and the supplementary motor areas reside), not from neural changes at the execution level (Yue & Cole 1992; Jeannerod 1994; 1995). Because even motor imagery and mental training can have these effects, there is every reason to believe that the intensive and thoroughly realistic motor imagery in our dreams can also lead to similar effects. Thus, repeated simulation of threat-avoidance behaviors should lead to enhanced threat-avoidance skills by increasing the efficiency of the programming and execution of motor activity required in the responses to perceived threats.

3.7.2. Implicit learning and implicit memory. There is one difference, however, between "mental training" and dreaming: We do not explicitly remember the learning and training episodes, nor do we have any idea of what the skills we are training in our dreams really are. Thus, doubts may be cast on whether it is possible to learn something in the absence of an intention to learn and memory of what one has learned. Extensive literature on implicit learning, however, confirms that many skills important for human performance are in fact learned without any conscious access to their nature (for reviews, see Berry 1994; Cleeremans et al. 1998; Lewicki et al. 1997). A person may have no idea that s/he uses certain types of acquired knowledge when performing a certain task. Even amnesic patients can learn motor skills despite their inability to remember having ever done the task before: Their performance becomes faster and more accurate, showing implicit skill learning in the absence of any conscious memory of the learning episode. Furthermore, amnesic patients can have implicit memory also for emotional experiences that they cannot remember explicitly (Glisky & Schacter 1988; 1989; Schacter 1996). Therefore, like any other skills, threat-avoidance skills also may be learned and rehearsed without explicit access to what has been learned.

Implicit learning is very sensitive to correlations and covariations between different features of perceived objects. If two features are associated in our experience a few times, an initial coding rule can be acquired that biases perception to detect both features when only one of them is directly perceived (Lewicki et al. 1997). Dream experience might bias waking perception so that certain perceived features are automatically associated with certain other ones in order to be prepared for possible threats. Furthermore, we are predisposed to learn certain reactions to certain stimuli. Stimuli that reflect ancient threats easily come to be feared (Marks & Nesse 1994).

If the function of dreaming is realized through implicit learning and memory, then we should predict that REM sleep deprivation has a detrimental effect on tasks requiring implicit but not explicit memory. This is what in fact has been found: Smith (1995) reports that memory for explicit tasks is not affected by REM sleep loss, but memory for procedural or implicit tasks is impaired by REM deprivation.

3.7.3. Summary. I conclude that rehearsing threat-avoidance skills in the simulated environment of dreams is likely to lead to improved performance in real threat-avoidance situations in exactly the same way as mental training and implicit learning have been shown to lead to improved performance in a wide variety of tasks. It is not necessary to remember the simulated threats explicitly, for the purpose of the simulations is to rehearse skills, and such rehearsal results in faster and improved skills rather than a set of explicitly accessible memories. Furthermore, REM sleep physiology appears to selectively support implicit, procedural learning.

3.8. Proposition 6

> The original environment in which humans and their ancestors have lived for more than 99% of human evolutionary history included frequent dangerous events that threatened human reproductive success and presented severe selection pressures on ancestral human populations. The ecologically valid threat cues in the human ancestral environment fully activated the threat-simulation system. Recurring, realistic threat simulations led to improved threat perception and avoidance skills and therefore increased the probability of successful reproduction of any given individual. Consequently, the threat-simulation system was selected for during our evolutionary history.

3.8.1. Selection pressures and ancestral threats. So far we have shown that dreams are specialized in threat simulations, effectively triggered by real-life threats and engaging the appropriate cognitive and neural mechanisms in ways that have been shown to lead to improved performance in other learning contexts. In order to complete the argument, we now need to show that the human ancestral environment was the kind of place that contained the relevant ecologically valid cues for constantly activating the threat-simulation system, and that there was likely to be a selectional advantage from improved threat-avoidance skills so that repeated threat simulations were likely to lead to increased reproductive success.

We need to show, first, that there was a high selectional pressure in the ancestral environment. How long did people live in those conditions? Which proportion of the population survived to reach the reproductive age? As far as we know, mean life expectancy was remarkably low compared with that of modern times, only 20–25 years. According to one estimation (Meindl 1992), of those who reached five years of age in ancestral hunter-gatherer populations, about 25% died before entering the reproductive period and about 70% died before completing it. Thus, mortality rates were high, and only a selected few ever got the chance to reproduce successfully.

Second, we need to show that the real threats in the ancestral environment were the kind of events the threat-simulation system is good at simulating. What were the most likely threats to survival in the ancestral environment? How severe were they? Some major causes of death in hunter-gatherer populations were probably exposure to predation by large carnivores, exposure to the elements, infectious disease, poor conditions and risky activities during hunting and gathering, and aggression or violent encounters, especially in defense of personal resources or group territories (Landers 1992; Meindl 1992).

These estimates render it quite obvious that the life of an average ancestral human was constantly at risk in the original environment.[12] The death or serious injury of close relatives and local group members was not an uncommon event. Confrontation with extremely dangerous or even life-threatening situations is likely to have been part of everyday life rather than a rare exception. In order to reproduce successfully under such conditions, an individual must have been quite skilled at perceiving and recognizing various threatening situations (e.g., predators, aggressive strangers, poisonous animals, natural forces, social rejection by own group members), at avoiding unnecessary dangers, and when a threatening situation could not be avoided, must have been able to cope with it by using efficient cognitive and behavioral strategies that promote survival.

3.8.2. Activation of the threat simulation system in ancestral conditions. The key question is: What was the dreaming brain dreaming about in those circumstances? In view of the extremely harsh conditions in which our ancestors lived, it is likely that every individual was continuously rather severely "traumatized," at least by modern standards. Therefore, their threat-simulation systems must have been repeatedly activated by the ecologically valid cues from threatening, real-life situations, resulting in a continuous flow of threat-simulation dreams. In effect, the dream-production system must have been in a more or less constant post-traumatic state. In fact, that probably was the *normal* state of the system then, although we who mostly live free of immediate threats to physical survival have come to regard it as a peculiar pathological state.

As Tooby and Cosmides note (1995, p. 1190), natural selection retained neural structures on the basis of their ability to create adaptively organized relationships between information and behavior; for example, the sight of a predator activates inference procedures that cause the organism to hide or flee. Threat simulation rehearses and improves performance in processing exactly such organized relationships, specifically between information interpretable as a threat to survival and efficient cognitive-behavioral procedures that need to be activated in response to such information. In the light of our present knowledge, it seems very likely that the dream-production system had more than enough threatening experiences to work with in the human ancestral environment. Therefore it was likely to simulate realistic threats thousands of times during an individual's lifetime, which was bound to result in improved threat-avoidance skills. Individuals with improved threat-avoidance skills were more likely to leave offspring. Since the neural basis of the dream-production mechanisms is innate, dreaming came to be selected for during our evolutionary history. Individuals without the threat-simulation system would have been in a disadvantageous position, and would have been selected against in the ancestral environment. Now that most humans live in environments far removed from the ancestral ones, and face threats completely unlike the ancestral ones, it may be that the threat-simulation system is not properly activated or not able to construct useful simulations of most of the present-day threats. But dreaming still is an important part of universal human experience, and its persistence and universality can now be explained by referring to the advantages in threat avoidance it provided our ancestors with.

4. The dreams of hunter-gatherers and animals

4.1. Threat simulation in the dreams of contemporary hunter-gatherers

If, as we have argued, the dreaming brain is a phylogenetically ancient threat-simulation system with default values reflecting ancestral rather than modern conditions, then we should expect to see this mechanism naturally activated in individuals who live in conditions closely resembling the ancestral ones. We should predict high levels of survival themes, threat simulation, and animal characters in the dreams of such individuals. Fortunately there are some studies of dream content in hunter-gatherer populations. Dreams from the Yir Yoront, an aboriginal society in Australia, were collected in the 1930s and later analyzed by Calvin Hall. Some of the results have now been published in Domhoff (1996). Compared to American males, the Yir Yoront males dream significantly more about animals, have a higher proportion of aggression with animals, and a very high percentage of physical aggression. They also often dream about sharing meat from the animals they have killed.

Gregor (1981) reported a content analysis of 385 dreams collected among the Mehinaku Indians in Central Brazil whose life had remained essentially traditional at the time of the study. The Mehinaku are an exceptionally fruitful group of informants for a study on dreams, for they have the habit of carefully recalling and often recounting their dreams in the morning. Gregor found that the dreams of the Mehinaku contain significantly more physical aggression, especially with animals, than dreams from the American normative sample. However, gender differences are similar in Mehinaku and American dreams: there is more aggression in men's than in women's dreams, and women are more likely than men to be the victims of aggression. The most frequent attackers are men and animals. There are many themes in the Mehinaku dreams that could be interpreted in the framework of evolutionary psychology: for example, women often dream about being the targets of sexually violent men, and men dream about having sex with women other than their own spouse, and consequently being attacked by jealous male rivals or angry female lovers.

In his paper, Gregor (1981) provides short summaries of the Mehinaku dream reports. Here are some examples of typical threats in the Mehinaku men's dreams:

> A woman attempted to have sex with him, the jealous husband assaulted him;
>
> Lost his belt and could not find it;
> Desired and approached girl, struck by his jealous wife;
> Attacked by a jaguar;
> Stung by wasps while in woods;
> Stung by ant;
> Chased by snake, he turns and kills it;
> Daughter almost drowned, rescued her;
> Stung by bees;
> Had sexual relations with girl friend, wife saw them and became angry;
> Rescued drowning brother;
> Attacked by a herd of wild pigs;
> Shot at threatening jaguar but missed;
> Killed a threatening snake.

The prediction from the threat-simulation hypothesis is that threatening events are overrepresented among dream events, and that nonthreatening, peaceful activities are underrepresented. In accordance with this prediction, peaceful and realistic nonthreatening and nonaggressive activities (e.g., "Went to river and saw birds"; "Worked in the forest"; Watched as the sun rose"; "Went to the garden"; "Went to the field to get corn") make up only about 20% of the 276 dreams reported by the Mehinaku men. In contrast, about 60% of the dreams have a threatening situation as a theme.[13] Even if their waking lives contained more threats than ours, it is unlikely that 60% of their waking time would consist of overtly threatening episodes; for that they would have to spend almost 10 hours per day in situations involving threats (i.e., 60% of the total estimated waking time of 16 hours). Therefore, the prediction holds in the Mehinaku dreams: Dream-production mechanisms selectively overrepresent threatening events and underrepresent peaceful activities.

Dream samples from contemporary hunter-gatherer groups are probably as close to ancestral dreams as it is possible for us to get, which is not to say that they would be identical. In any case, these studies show that threat simulation is very frequent in the dreams of such individuals, and that the dream-production system tends to generate fairly realistic threat simulations when the world it simulates is not very dissimilar from the ancestral human environment.

4.2. Dreaming among other mammals: Evidence for the rehearsal of survival skills

This reinterpretation of the function of dreaming is consistent with the inferences we can make concerning possible dream contents and the function of dreaming in other mammals. Although we cannot know with absolute certainty that other mammals have subjective experiences during sleep, we do know that they can manifest remarkably complex behaviors during REM sleep. In humans the comparable condition is the acting out of dream experience (REM sleep behavior disorder; see sect. 3.6.2). Therefore, we may assume that to the extent these animals have conscious phenomenal experience when awake, they are likely to have similar experiences, that is, dreams, when in REM sleep.[14]

REM sleep without atonia induces complex species-specific behaviors in the cat; for example, motions typical of orienting toward prey, searching for prey, and attacking (Morrison 1983a). In several species of mammals the hippocampal theta rhythm is associated with behaviors requiring responses to changing environmental information most crucial to survival: for example, predatory behavior in the cat and prey behavior in the rabbit (Winson 1990). The theta rhythm disappears in slow wave sleep but reappears in REM sleep. Winson (1990; 1993) suggests that information important for survival is accessed during REM sleep and integrated with past experience to provide a strategy for future behavior. Thus, there is empirical evidence that in other mammals the dreaming brain also rehearses species-specific survival skills, consistent with the present hypothesis that the human dream-production system is primarily a threat-simulation system.[15]

5. Testability and predictions

We can now summarize the central claims of the threat-simulation theory of dreaming, all of which are supported by the available evidence, and present some testable empirical predictions:

1. Dream consciousness is an organized and selective simulation of the perceptual world. *Predictions:* (1) The neural mechanisms directly underlying dream production and threat simulation function in a selective, orderly, and organized manner rather than randomly. (2) The triggering and construction of threat simulations are not random but, on the contrary, systematically modulated by the negative emotional charge attached to episodic memory traces in the amygdala-centered emotional memory systems.

2. Dream consciousness is specialized in the simulation of threatening events, especially the kind of events that our ancestors were likely to encounter frequently. *Predictions:* (1) If we define a new dream content category that specifically includes all the threatening events in dreams, we should find that such events are, in general, overrepresented in dreams. (2) The threatening events in our dreams should be found to include severe or mortally dangerous threats more often than our waking life typically does. (We are currently testing these two predictions in a content analysis study of threatening events in students' home-based dream reports.) (3) If activated by various kinds of real mortal threats, the threat-simulation system should be found to be capable of simulating ancestral threats (e.g., animal attacks, direct physical aggression, natural forces) more efficiently (i.e., with greater frequency or greater degree of realism) than modern fatal threats highly unlike ancestral ones (e.g., smoking, traffic accidents, explosives).

3. Only real threatening events can fully activate the dream- production system. Elements from such real events are regularly incorporated into the simulations. *Predictions:* (1) No class of nonthreatening, real-life events will be found that would activate the dream-production system in a manner comparable to real-life threats (i.e., propagating frequent dream simulations of the event after a single exposure to it and causing the simulation of such events to be overrepresented in dream life compared to waking life). (2) The activation of the threat-simulation system by real threats will be found to be a universal aspect of dreaming in humans, not dependent on any specific culture. (3) The intensity (i.e., frequency and persistence) of the threat simulations triggered by a real event will be directly related to the degree of personal threat that was experienced when the event took place in reality.

4. The threat simulations produced by the dream-production system are perceptually and behaviorally realistic rehearsals of real threatening events. *Predictions:* (1) When the dream-self is in mortal danger within the dream, the dream-self is more likely than not to display a reasonable and realistic defensive reaction. (We are currently testing this prediction in a content analysis study of threatening events in dreams.) (2) The direct neural correlates of subjective visual awareness in dreams will be found to be identical with the direct neural correlates of subjective visual awareness in waking experience. (3) If muscular atonia during REM sleep is completely removed in a controlled manner, then all the movements performed by the dream-self and realized in phenomenal dream imagery will be externally observed as fully realized by the physical body of the dreamer.

5. Perceptually and behaviorally realistic rehearsal of any skills, in this case threat-avoidance skills, leads to enhanced performance regardless of whether the training episodes are explicitly remembered. *Predictions:* (1) The kinds of threat perception and avoidance behavior that are employed in threat-simulation dreams can be shown to consist of such perceptual, cognitive, and motor skill components that become faster and more efficient through implicit (procedural) learning. (2) If exposed to threat-recognition or threat-avoidance tasks during waking, an amnesic person not able to remember the learning episodes explicitly will nevertheless become faster and more efficient in these tasks through repetitive rehearsals, showing implicit or procedural learning (i.e., implicit learning in amnesic patients during waking could be used as a model of implicit learning in normal subjects during dreaming).

6. The original environment in which humans and their ancestors have lived for more than 99% of human evolutionary history included frequent dangerous events that threatened human reproductive success and presented severe selection pressures on ancestral human populations. The ecologically valid threat cues in the human ancestral environment fully activated the threat-simulation system. Recurring, realistic threat simulations led to improved threat perception and avoidance skills and therefore increased the probability of successful reproduction. Consequently, the threat-simulation system was selected for during our evolutionary history. *Predictions:* (1) Children old enough to implement threat-recognition skills and threat-avoidance behavior during waking will be capable of threat simulation during dreaming if exposed to real ecologically valid threats. (2) Ontogenetically early exposure to experienced real (ancestral) threats will stimulate the threat-simulation system, leading to earlier, more frequent, and more intensive threat simulations, lasting throughout life. Conversely, if there is total isolation from exposure to real threats, the dream-production system will develop more slowly or stay in a resting state and threat simulations will remain less frequent and milder.

All of these predictions are empirically testable in principle, and most tests could be carried out in practice. What would primarily be needed to explore the threat-simulation hypothesis empirically is, first, content analysis methods with which to precisely quantify and describe threatening events in dreams and, second, systematically collected dream and nightmare report databases from various populations and age groups that have been recently exposed to threatening events varying in frequency and degree. Such studies would enable a precise description of the operation of the threat-simulation mechanisms in detail, and help us to conclude when and in whom and to what degree the mechanisms are typically activated.

In order to disconfirm the threat-simulation theory (or some part of it), it must be shown empirically that the above predictions are false. If it can be shown, for example, that dream generation is a truly random physiological process (as stated by several theories), or that even experiences completely different from threat-related ones regularly lead to intensive, recurrent simulations, or that there are cultures in which threatening experiences do not lead to threat simulations and nightmares, then the threat-simulation theory is in serious difficulty.[16]

As an evolutionary hypothesis, the threat-simulation theory of dreaming concerns historical events, and the historical events themselves of course cannot be subjected to observation or experimental manipulation. But it would not be correct to say, for example, that theories on what caused the mass extinction of the dinosaurs 65 million years ago, or why Asia has got the Himalayas, are not empirically testable because the original events cannot be observed or experimented on. Therefore, the threat-simulation hypothesis is open to empirical testing, confirmation, and disconfirmation to the same extent as any other hypotheses regarding the causal mechanisms at work in the past, leading the natural world to be as it is in the present.[17]

6. Threat simulation as a biological defense mechanism

This section summarizes and clarifies how the threat-simulation mechanism is hypothesized to operate in dream production, and in what sense this operation can be regarded as biologically functional.

6.1. Dream production and threat simulation

Dream production is an automatic, hard-wired, regularly activated feature of human brain function. The sources of dreams are selected from long-term memory by reactivating and recombining memory traces that are the most salient for the dream-production system. *Saliency* is a function of at least two factors: The degree of threat-related or negative emotional charge and the recency of the encoding or reactivation (or other priming) of the memory traces. Therefore, the most salient memory traces for dream production consist of the ones encoding the most threatening events most recently encountered (or whose memory traces have been otherwise most recently reactivated). The saliency of a set of memory traces gradually declines over time or may be overcome by that of other traces: memory traces compete for access to dream production through their saliency.

Simulations including elements of the selected threatening memories are then reconstructed by the dream-production mechanisms. In this process the dream-production mechanism tends to use dream settings and stereotyped scripts that are compatible with threats similar to ancestral ones (composing events that involve, e.g., attacks, fights, pursuits, escapes, intrusions, losses of valuable resources, and events during which the dream self or close kin are endangered). Typical threat-simulation dreams, such as nightmares and recurrent dreams, are thus composed of a variable mixture of salient, episodic memory traces and suitable threat-simulation scripts. This mechanism is biologically functional (i.e., it solved adaptive problems for our ancestors) because in the original environment the dream-production system regularly generated simulations of such real events that directly or indirectly threatened the reproductive success of ancestral humans.

Simulating these events rehearses performance at two stages: *threat recognition* and *threat avoidance.* The simulation of threat recognition is supposed to proceed in the following way. Salient emotionally charged memory traces are first selected for dream production. The selected visual dream imagery is subsequently realized by the occipitotemporal ventral visual stream. When potentially threatening content is present in visual awareness, the amygdala is activated in order to evaluate the potential threat. Anatomically, the amygdala receives input from the late stages of visual object recognition in the temporal lobe but projects back to all stages of visual processing and has several connections to long-term memory networks (LeDoux 1998); the amygdala and the cortical regions with which it has strong connections are highly activated during REM sleep (Braun et al. 1998; Hobson 1999a; Maquet et al. 1996). Threat recognition simulation, therefore, primes this amygdalocortical network to perform the emotional evaluation of the content of visual awareness as rapidly as possible, in a wide variety of situations in which there is a visual object or event present that is potentially dangerous. The second stage, threat avoidance, consists of the rapid selection of a behavioral response program appropriate to the dangerous situation in question (e.g., fleeing, hiding, defending, attacking) and the immediate realization of this response. Threat-avoidance simulation primes the connections between specific perceptual-emotional content and specific behavioral responses, and rehearses the efficient release of these behavioral responses through the activation of cortical motor programs. The efficient, rapid functioning of these threat recognition and avoidance networks decreases the latency and increases the sensitivity and efficiency of responding to similar real threats during waking. Therefore, threat simulation during dreaming increases the probability of coping successfully with comparable real threats, leading to increased reproductive success.

6.2. Why do we dream about "current concerns"?

The capability for ancestral threat simulation is the essence of the biologically adaptive function of dreaming. However, the threat-simulation mechanisms automatically select *any* available memory traces with highest relative saliency and use them as a basis for simulation, regardless of the specific content selected; the mechanisms have no "insight" into what they are doing and whether it is biologically functional or not. When the individual's waking environment doesn't include any threat cues, the sources of dreams are quite varied and may be difficult to trace; almost any recently encoded or reactivated memory traces may become selected for dream production. Therefore, the present hypothesis is not in the least similar to Freud's (empirically untestable) thesis that *all* dreams are at bottom wish fulfillments. Not all dreams are threat simulations: the functionally crucial feature of dreaming is its *capability* for regular and efficient threat simulation in environments where the appropriate threat cues are constantly imminent.

The threat-simulation mechanisms operating in present-day humans who are living in safe environments rarely find salient memory traces corresponding to ancestral or mortal threats. Even the most salient traces typically represent only relatively mild threats. In the absence of truly dangerous threats, the threat-simulation system selects any recently encoded or reactivated emotionally charged memories that happen to have higher saliency relative to other traces. The selected traces in such cases are typically about the "current concerns" of the dreamer.

There is evidence that the saliency of current concern-related memory traces can be increased by presenting concern-related verbal stimuli during REM sleep (Hoelscher et al. 1981) or by giving concern-related waking suggestions (Nikles et al. 1998) to subjects. In these studies, concern-related topics led to dream incorporation significantly more often than nonconcern-related topics did; a finding well consistent with the current hypothesis of dream-production mechanisms.

Are there any ways to *separate* the predictions derived from the threat-simulation theory from current-concerns theories? The former, unlike the latter, predicts that threat simulations can sometimes be completely *dissociated* from the current concerns of the dreamer. Recurrent dreams and nightmares are often like this. Few people regularly worry about being chased by animals, monsters, aliens, or strangers, but they may nevertheless frequently dream about such events. The current-concerns theory cannot explain these kinds of dreams, whereas the threat-simulation hypothesis can explain both why we tend to dream about everyday current concerns (e.g., occupational or marital troubles) – they are mild emotionally charged threats that are more salient for dream production than emotionally completely neutral contents – and why we also dream about very severe and rather primitive threats ("ancient concerns") – they reflect the threat-simulation scripts embedded in the dream-production system as default settings, defining the types of threatening events that should be rehearsed most frequently. Consequently, the threat-simulation theory provides us with the most parsimonious explanation of dreaming because different kinds of dreams can be explained by referring to a single mechanism, the operation of the threat-simulation system. Different dream events can be ordered on a single continuum according to the different degrees of threat they contain, and their appearance in dreams can be explained by pointing to the relative saliency of the memory traces and threat scripts that the dreams are composed of.

Still, the simulation of the current concerns of modern humans probably has little if any biologically adaptive value. The threat recognition and avoidance programs, and especially the selection pressures and increases in reproductive success associated with current concerns, are hardly comparable to those associated with ancestral threats in the ancestral environment.

6.3. The mechanisms behind post-traumatic nightmares

Persistent post traumatic nightmares are produced by the threat-simulation mechanisms when a set of memory traces is associated with an overwhelming charge of threatening emotional content. This set of memory traces thus becomes overly salient for the dream-production mechanisms and, in the absence of serious competitors, tends to be selected over and over again. The saliency of the memory trace should normally slowly wear off, but in some cases the threat simulations themselves (as well as waking flashbacks) may reactivate the memory traces so often that they remain highly salient for extended periods of time.

Any procedure that decreases the emotional charge associated with the memory traces should render them less salient for dream production. There is evidence that recording one's nightmares and rehearsing them with a changed ending, or thinking about them in a relaxed state (desensitization) leads to significant decreases in nightmare frequency among chronic nightmare sufferers (Kellner et al. 1992; Krakow et al. 1995; 1996; Neidhart et al. 1992). These techniques probably decrease the negative emotional charge associated with the memory traces involved in nightmare generation, thus directly decreasing their saliency for dream production. In the preceding section we reviewed studies showing that the opposite effect, increasing the saliency of certain memory traces, can be achieved through current-concerns-related suggestions. Taken together, the indirect manipulation of dream content seems to be possible by directly increasing or decreasing the saliency of threat-related memory traces for dream production. Efficient methods for manipulating the saliency of the traces will obviously be clinically useful in the treatment of disturbing threat simulations (i.e., recurrent nightmares).

The threat-simulation hypothesis may seem to imply that, for example, war veterans suffering from PTSD and traumatic nightmares should be better adapted to the battlefield than those without any post traumatic nightmares. This prediction, however, does not flow from the threat-simulation theory. Frontline combat conditions undoubtedly create memory traces with the highest negative emotional charge, leading to post-traumatic nightmares, but the threats encountered in such conditions are hardly comparable to those in the human ancestral environment. There are few such skills among human threat-avoidance programs whose rehearsal would be of much help in an environment where one may at any moment get killed by shrapnel, the invisible sniper's bullet, nerve gas, hidden land mines, missiles shot from fighter planes, and so on. Only the ability to cope with threats that closely resemble ancestral ones should with any likelihood improve through repeated threat simulations. The threat-simulation system was useful in the ancestral environment, but it should not be expected to be useful in an environment where the original human threat-avoidance skills, no matter how well trained, are no guarantee of increased probability to survive and reproduce.

6.4. Threat simulation as a biological defense system

It is illuminating to compare the threat-simulation mechanism with other biological defense mechanisms. The immune system has evolved to protect us from microscopic pathogens, whereas the dream-production system (along with a number of other systems) has evolved to protect us from dangerous macroscopic enemies and events in the environment. When a pathogen has invaded the host, an appropriate immune response is elicited, and when the antigen has been removed from the system, the immune responses switch off, as they are no longer required, and the immune system is restored to a resting state. Certain parts of the immune system, however, "remember" the infectious agent and are now better prepared to fight it off next time. Analogously, when a threatening event is encountered in the real world, a threat-simulation response is elicited by the dream-production system, and when the response is completed after repeated threat simulations, the individual will be better prepared to cope with similar threats in the future. If real threats are completely removed from the individual's environment, the threat-simulation system gradually returns to a "resting state" where the content of dreams becomes more heterogenous and less troubled.

Even when the immune system is in the resting state, large numbers of leucocytes continue to be produced. For example, millions of granulocytes are released from the bone marrow every minute even in the absence of acute inflammation (Roitt et al. 1998). These cells only live for 2–3 days; thus, if the individual is saved from infections for some time, astronomical numbers of granulocytes live and die without ever realizing their biological function at all. One may ask: "But what is the biological function of all *those* granulocytes that never took part in any immune response? They must have some hidden function since they are so numerous and are produced so regularly." This question implies a misunderstanding of the biological functionality of the immune system. Similarly, to insist that all those dreams that do *not* simulate threats must have some hidden function of their own is to misunderstand the biological function of dreaming. Exactly as the evolved biological function of the immune system is to elicit appropriate immune responses when triggered by antigens, the evolved biological function of the dream-production system is to construct appropriate threat simulations when triggered by real threats. If no antigens are encountered and recognized within the organism, the immune system remains in a resting state but it nevertheless continues to produce leucocytes; if no traces of threat-related experiences are encountered during regular dream production, the system nevertheless always ends up producing some kind of dreams.

Furthermore, biological adaptations often have features that appear nonfunctional or even dysfunctional. Immune responses frequently occur in an exaggerated or inappropriate form (Roitt et al. 1998). Type I hypersensitivity – a typical allergic reaction – is an immune response caused by harmless antigens (e.g., pollen). In the worst cases it can lead to a generalized anaphylaxis and even death. Another example of extremely harmful immune responses is autoimmunity, where the immune system attacks the individual's own tissue. A highly efficient immune system may thus be prone to false alarms, but probably also more efficient when it is really needed. As long as the net result is that those of our ancestors equipped with an operational immune system were more likely to reproduce successfully than those without, the system is biologically functional, even if negative side effects sometimes occur.

Therefore, we should not be surprised to learn that efficient threat simulation sometimes may have harmful side effects. Subjects suffering from acute or chronic nightmares typically complain of sleep disturbance: for example, fear of going to sleep, awakening from sleep, restless sleep, insomnia, and daytime fatigue (Inman et al. 1990; Krakow et al. 1995b). However, in a group of Vietnam combat veterans with PTSD and subjective complaints of disturbed sleep, no clinically significant sleep disorder could be found (Hurwitz et al. 1998). It is unclear to what extent ancestral humans might have suffered from sleep disturbances due to intensive threat simulations. If some of them sometimes did, that clearly would have been a negative side effect of threat simulation, but – like an allergic reaction – one whose costs would not typically have been too high compared with the benefits.

Natural selection can only take place if there is variation within the population with regard to the biological adaptation in question and if these differences can be genetically transmitted to offspring. Genetic factors have an important role in allergic hypersensitivity (Roitt et al. 1998), which can be regarded as an indication of the sensitivity of the immune system. The sensitivity of the threat-simulation system seems to show a similar pattern. Evidence from a recent study of 1,298 monozygotic and 2,419 dizygotic twin pairs (Hublin et al. 1999a) reveals that the tendency for children to have nightmares (an indication of the sensitivity of the threat-simulation system) has a substantial genetic basis, accounting for up to 45% of total phenotypic variance.

My conclusion is that the dream-production system can be seen as an ancestral defense mechanism comparable to other biological defense mechanisms whose function is to automatically elicit efficient protective responses when the appropriate cues are encountered.

7. Comparison with previous theories

7.1. Theories on dreaming and evolution

Theories of the evolutionary functions of dreaming are few, since the received view in contemporary cognitive neuroscience appears to be that dreaming has no such function. There are, however, a couple of exceptions. In a paper entitled "Toward an Evolutionary Theory of Dreaming," Frederic Snyder (1966) proposed that when it comes to mammals, sleep could be regarded as an adaptive mode of behavior for creatures that had to spend most of their time in hiding: sleep saves metabolic and energy resources and is conducive to longevity – early mammals used sleep to survive to the next period of activity and possible reproduction with costs as low as possible. Since the animals are highly vulnerable during sleep, a built-in physiological mechanism to bring about periodic awakenings would be called for, in order to scan the environment for possible dangers. According to Snyder (1966), virtually every REM period is followed by such a brief awakening, and this serves a "sentinel" or vigilance function. The REM period preceding the awakening serves a preparatory function, activating the brain in order to prepare it for possible fight or flight. The essence of dreaming as a biological phenomenon is endogenous perceptual activation that takes the form of a hallucinated reality such as the animal might be in danger of encountering at the time of awakening. A related hypothesis was earlier presented by Ullman (1959).

Snyder's theory is substantially different from the present one. He speculates that dream content, if it has any adaptive functions in addition to general activation of the central nervous system, in some way attempts to anticipate the particular situation that the individual might actually encounter immediately after having had the dream. This explanation of dream content is not particularly convincing, for the odds are obviously very much against having the dream-production system "guess" correctly what sort of danger might be approaching the sleeping organism. Furthermore, the idea that dream content should anticipate the immediately following waking experience is rather implausible in light of the fact of "dream isolation": that dream consciousness and the contents of dreaming are by and large isolated from, for example, stimulus input, reflective thought, autonomic activity, organismic state, and motor output (Rechtschaffen 1978). If the content of dreams were anticipatory of immediately following waking events, then one would expect external cues and stimuli to have a much greater effect on current dream content than is actually the case.

Michel Jouvet (1980) proposes that in mammals a periodic endogenous genetic programming of the central nervous system occurs during REM sleep. He argues that because the learning of epigenetic behaviors requires multiple repetitions of external stimulation in order to alter synaptic organization, we might expect that also endogenous behavior-regulating mechanisms need to be reprogrammed through repetitive endogenous stimulation in order to maintain, reestablish, or stabilize synaptic pathways. The programming requires temporary inhibition of perceptual inputs and motor outputs, but we are able to see the on-line results of the programming during REM sleep if postural atonia is removed. This can be done by lesioning the inhibitory mechanisms responsible for postural atonia during REM sleep, which reveals dramatic "oneiric" behaviors; for example, in the cat: "The cat will then raise its head and display 'orienting behaviour' towards some laterally or vertically situated absent stimulus. Afterwards, it may 'follow' some invisible object in its cage and even 'attack' it, or it may display rage behaviour, or fright. . . . Pursuit behaviour has been observed to last up to 3 min." (Jouvet 1980, pp. 339–40). Jouvet's theory is, however, presented purely as a theory of the function of REM sleep, and he does not comment on the content of dreams at all. More recently, Kavanau (1997) has suggested that, in order to maintain synaptic efficacy, repetitive spontaneous activation is needed in neural circuits that are in infrequent use. In REM sleep, patterns of activity including motor components would undergo this kind of "dynamic stabilization": memories involving motor circuitry are reinforced during REM sleep. However, Kavanau regards dreaming as biologically epiphenomenal.

As we mentioned in section 4.2., Winson (1990; 1993) suggests that in animals information important for survival is accessed during REM sleep and integrated with past experience to provide a strategy for future behavior. Although the theta rhythms relevant to his arguments have not as yet been recorded in humans, Winson nevertheless speculates that human dreaming during REM sleep may also reflect the integration of information that reflects the individual's strategy for survival. Thus, Winson's view comes quite close to the present one, and provides support to the hypothesis that the function of dreaming in simulating survival skills is not uniquely human. Still, I would not describe the result of dreaming as the forming of a "strategy" for survival. The essence of human dreaming is repeated threat simulation and the only strategy is to become as proficient as possible in coping with a variety of threatening situations without having to take unnecessary risks. Winson (1993) says that his theory actually encompasses the one emanating from current dream research, "i.e., dreams reflect adaptation in the light of current experience" (p. 245). Thus, Winson sees his theory as closely related to the ones arising from clinically oriented dream psychology, pertaining to the *psychologically* adaptive function of dreaming, which we found not entirely convincing (see sect. 2.2).

All in all, there are previous theories on the evolutionary function of dreaming, but although many of them contain valuable insights and seeds of the present proposal, none of them has considered the human ancestral environment as the proper context of the dreaming brain.[18] Neither have they taken into account, within one unifying theory, the content of normal dreams, recurrent dreams, nightmares, children's dreams, post-traumatic dreams, the dreams of hunter-gatherer populations, and the dreams of nonhuman mammals.

7.2. Dreaming and daydreaming

We should still consider the possibility that it was daydreaming that was selected for in evolution as a safe method of virtual threat perception and avoidance, and that dreaming is only a nonadaptive consequence of this. Like night dreams, daydreams are often vivid and multimodal simulations of real experience and contain dreamlike features (Klinger 1990). Singer (1966; 1988) proposes that daydream and night-dream content are closely related: both typically have their sources in the current concerns of the dreamer. Daydreaming often reflects our attempts at exploring the future through trial actions or through positing a variety of alternatives.

However, there are also important differences between daydreams and dreams: daydreams very often contain interior verbal monologue and they are typically more pleasant than dreams. Findings from college students' daydreams suggest that, on the average, in daydreams we focus on anxiety-provoking or worrisome thoughts only about 3% of the time, and less than 1% of daydreams include violence (Klinger 1990, pp. 84–85). Furthermore, unlike in daydreams in dreams we invariably lose our self-reflectiveness: dream events happen to us without our control (Domhoff 1996). Thus, daydreaming appears to deal with the evaluation and setting of particular future goals, and charting the ways in which we might achieve such goals. Daydreaming is at least partly controlled voluntarily. By contrast, dreaming is a fully developed involuntary simulation of the perceptual world, tuned especially to simulate and rehearse the perception of, and immediate defensive reactions to, possible threatening events.

Both daydreams and night dreams consist of mental imagery, but the former tend to chart the *goals* we would like to achieve *in the future* (and we need to be reminded about), whereas night dreams tend to simulate the *dangers* we (or our ancestors) encountered *in the past* (and we would not particularly like to be reminded about). In light of these differences, it is unlikely that night dreaming should be only a nonadaptive consequence of what daydreaming was selected for. Their functions can rather be seen as complementary to each other.

7.3. Other theories on dreaming

The present hypothesis on the evolutionary function of dreaming is not seriously incompatible with many of the theories reviewed in the introduction (but see N. 16 for their predictions that conflict with the threat-simulation theory). Hobson (1994) suggests that the function of dreaming is memory consolidation and the linking of memory representations with motor programs. This is true, but it is an incomplete description of the real point of the system: Which memories are linked with which motor programs and why? Such questions can only be elucidated once we consider the evolutionary context of dreaming and the role of threatening experiences in the construction of dream content. In his latest book, Hobson (1999a) suggests in a remark made in passing that his current views are more or less consistent with the threat-simulation hypothesis. He writes (p. 170): "Waves of strong emotion – notably fear and anger – urge us to run away or do battle with imaginary predators. Flight or fight is the rule in dreaming consciousness, and it goes on and on, night after night, with all too rare respites in the glorious lull of fictive elation."

Foulkes (1985) regards the *form* of dream experience as the important factor. This is true as well: it is remarkable how closely the world-model created during dreaming corresponds to the one created during waking perception. The reason for such faithful replication (and perhaps also for the fact that we rarely recognize a dream for what it is) is the fact that if you want to simulate something in such a way that the simulation works as good training for the real thing, the simulation ought to be an exceptionally good copy of the real thing. This is true of dreaming: threatening elements in dreams do look and feel like the real thing. And better still, while inside the threat simulator (i.e., while we are dreaming) we take the simulation for the real thing and fight for our lives.

Foulkes (1985) regarded the novel combinations of memory representations as an important feature of dreams. It is indeed unlikely that having once encountered a threat, the same threat should be replicated in real life in *exactly* the way it was first experienced. Thus, in order to be prepared for all kinds of situations somehow reminiscient of the original event, it is reasonable to construct several possible variations on the theme rather than just one stereotyped original version. Blagrove (1992a; 1996) pointed out that dreams do not solve the problems of the waking world, although they might solve the problems internal to the dream world itself. This is a valid point: the dreaming brain is not adapted to solve problems such as finding a job, writing a thesis, or preventing pollution. Such problems did not exist in the ancestral environment; so they are not the kinds of problems that the dream-production system would recognize or know how to handle. By contrast, it does know how to handle problems that were abundant in the original environment but have become obsolete in most Western societies: escaping and fighting aggressors and predators, defending one's family and territory, and escaping natural forces. Furthermore, the activity of the dreaming brain is not appropriately described as "problem-solving." The specific *solutions* may not be as important as is the very *repetition* of the situations critical for survival. Hartmann (1998) and Domhoff (1996) are right in treating post traumatic dreams, recurrent dreams, and nightmares as the paradigm cases of dream functioning, although their interpretation of what this function is differs from the present view.

The present hypothesis is inconsistent with the theories presented by Freud (1900) and Flanagan (1995). Freud thought that wish fulfillment is the basic point of all dreams and he tended to dismiss anxiety dreams and post traumatic dreams as just exceptional. In the present view they are, on the contrary, the paradigm cases of the biological function of dreaming. Dreaming as threat simulation can be thought of as wish fulfillment only in the sense that dreams are expressions of the primeval "wish" to survive. Flanagan (1995) doesn't believe that dream consciousness has any survival value at all. However, his assertions are not based on any kind of review of the vast empirical literature on the phenomenal content of dreams, although that is exactly the empirical body of data relevant for the evaluation of his hypothesis. He furthermore neglects the proper evolutionary context of dreaming, the ancestral environment. Thus it is no wonder he ends up claiming that dream consciousness has no biological function. He has never even considered the relevant evidence seriously.

Conclusion

Previous theories of dream function have not put dreaming into the evolutionary context in which it belongs: the ancestral human environment. If dreams have any biological function, any survival value at all, such functions must have been manifested in that context. The dreaming brain along with the rest of human cognitive architecture has its evolutionary history, and without an understanding of what that history was like, it may be extremely difficult to figure out what the brain is attempting to do when it dreams. The hypothesis advanced in the present paper states that we dream (i.e., the phenomenal level of organization in the brain is realized in its characteristic ways during REM sleep) because in the ancestral environment the constant nocturnal rehearsing of threat perception and threat-avoidance skills increased the probability of successful threat avoidance in real situations, and thus led to increased reproductive success.

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NOTES

1. Owen Flanagan (1995) makes a corresponding distinction between the *p*-aspects (phenomenal) and *b*-aspects (brain) of dreaming. He says that these brain states are essential aspects or constituents of the conscious states. His view (to be discussed below) is that the phenomenal aspects of dreaming are biologically epiphenomenal.

2. An example of an invented function of dreaming is dream interpretation. Such a function may be quite meaningful and serve many useful purposes for those involved. For example, Hill et al. (1993) have shown that interpreting one's own dream led to deeper insight than interpreting another person's dream, indicating that dream reports include personally significant elements that may help in gaining self-understanding. Nevertheless, it is unlikely that this invented function of dreaming should be one that was selected for during human evolution, since the vast majority of dreams are totally forgotten and since our ancestors probably seldom recorded or communicated even the ones they might have recalled.

3. It has not been empirically tested whether or not the assumption that PGO spikes are "random" or that they induce "random" activation of the forebrain is in fact true.

4. This point has been made also by Rechtschaffen (1978, p. 106): "If there is any isomorphism between mental experience and brain activity, then one could hardly infer a disorganized brain from dream content because dream content is not especially disorganized. . . . dreams frequently take the form of definite stories. There is neither the kaleidoscope of unrelated images nor the cacophony of isolated thoughts and words that one might expect in truly disorganized consciousness."

5. There is an ongoing controversy about the nature of children's dreams and whether small children really have any dreams at all (e.g., Foulkes 1999; Resnick et al. 1994). These deep disagreements are due to the different results produced by different dream-collecting methods. Representative sampling of REM sleep in the laboratory suggests that dreaming is either not present at all or only very rudimentary in the preschool period, and only develops into full form from the ages of 5 to 9 (Foulkes 1999). This contradicts the earlier findings on children's home-reported dreams (e.g., Van de Castle 1970). Foulkes (1999) argues that small children's home-based dream reports are not reflections of subjective experiences during sleep at all, but, instead, are personal or social constructs of the waking reality: results from uncontrolled parental suggestion and active confabulation. His opponents have argued that the sleep laboratory situation somehow represses the natural flow of dream experience (e.g., Hunt 1989). My view is that neither database should be completely discredited. Foulkes's (1982b; 1999) data undoubtedly show that the REM periods of small children who are living in a safe modern environment are only rarely associated with conscious experiences that fulfill the criteria of a dream. However, these data do not show that such experiences are not possible, at least occasionally or in specific subgroups of children who are living in less safe environments or who have otherwise been exposed to various threatening events. It seems extremely implausible that the vast samples of children's home-based dream reports (e.g., Van de Castle 1970; 1983) would be nothing but products of suggestion and confabulation. It is hard to believe that parents would suggest to their children the topics that have been found to be prevalent in children's home-based dreams, such as the high proportions of aggression and victimization, since such dream content might easily be perceived by the parents as an indication of psychopathology or psychological disturbance in their children. Children's nightmares obviously are even less likely to be mere social constructions and confabulations: The American Sleep Disorders Association (1990) estimates that 10–50% of children at the age of 3–5 so frequently have nightmares as to alarm their parents. Furthermore, there are common features in the home-based and laboratory databases, such as the declining proportion of animal characters with increasing age, which suggests that both data flow from the same source. Foulkes (1999) advocates a highly contestable theory of consciousness on which his interpretations of the data are based: he takes consciousness to be "reflective consciousness" and argues that small children and animals lack it and therefore not only are unable to experience dreams but are in general like some kind of nonconscious zombies. Instead of accepting this view, the threat-simulation theory predicts that small children should be capable of having threat simulation dreams as soon as their perceptual and motor skills are at a level that enables threat recognition and avoidance in the waking state. However, this capability is only rarely realized if the child is not exposed to real threatening events that would activate the threat-simulation system properly. Children's home-based dream reports may thus largely reflect those relatively infrequent situations in which the threat-simulation system has become active and dreaming proper is experienced and consequently spontaneously remembered. This interpretation seems plausible in light of the fact that in home-based studies only one or a few dream reports at most, per child, were typically reported by a very large number of children (e.g., Van de Castle 1983), whereas in laboratory studies typically several REM-sleep awakenings were performed in a relatively small number of children but only a few reports that would qualify as dreams were obtained. The laboratory studies primarily reveal that, in children, there is a lot of REM sleep without any dreaming. However, the home-based dream reports and clinical and parental observations reveal that, when dreams proper do occur in children, they remarkably often include threatening elements.

6. It could be claimed that children are exposed to fairy tales and cartoons that include animals, and therefore dream about them. However, when listening to fairy tales or watching cartoons, children never directly perceive the actual animals, but only rather poor representations of them. The child is never personally in danger; the threats are directed against some characters in the story. Furthermore, whereas the amount of animals and aggressions in dreams declines with age, exposure to increasingly violent stories, movies, games, and so on increases. Thus, if fiction were the main source of animal and aggressive content in children's dreams, we could expect, first, the simulations to be simulations of storytelling or watching- TV experiences ("I dreamt that father told me a frightening story about an angry bear"; "I dreamt that I was watching a very frightening TV-program about wild animals"), not of personal encounters with the threatening agents, and, second, the frequency of fiction-induced animal and aggression content in dreams to increase with increased exposure to all forms of fiction with age. Neither of these predictions is supported by the data. Furthermore, as Van de Castle (1970, p. 38) observes: "To say that [the high percentage of animal characters in children's dreams] would be attributable to the influence of the many animal characters that appear in children's books would be begging the question because one would then ask why are animals so frequently utilized in children's stories and what accounts for children's fascination with them?"

7. "Long-term, across-generation recurrence of conditions . . . is central to the evolution of adaptations. . . . Anything that is recurrently true . . . across large numbers of generations could potentially come to be exploited by an evolving adaptation to solve a problem or to improve performance" (Tooby & Cosmides 1992, p. 69).

8. Wilmer (1996, p. 88) mentions that 53% of 359 catastrophic dreams from Vietnam veterans suffering from post-traumatic stress disorder were "terrifying nightmares of the actual event as if it were recorded by cinema verité." These dreams portray "a single event in recurrent replays" and, according to Wilmer, "they are the only human dreams that define themselves in a completely predictable manner." Another 21% of the veterans' war nightmares contained plausible war sequences that conceivably *could* have happened but had not actually occurred. However, Brenneis (1994) argues that the relation between dreams and the original traumatic experience is not isomorphic: if trauma texts are paired with dream texts, at least some transformed elements can invariably be observed.

9. According to recent PET studies (e.g., Maquet et al. 1996), neither significant increase nor decrease of regional cerebral blood flow (rCBF) can be observed in the motor cortex (Brodmann area 4) or premotor cortex (Brodmann area 6) during REM sleep. However, such blood flow measurements reflect the actual neural activity only quite indirectly and with coarse spatial and temporal resolution. The increased neural activity during REM sleep in the selected population of pyramidal tract cells, verified by direct single-cell measurements in sleeping animals, evidently does not result in any measurable net change in rCBF in the motor areas (where there are also other types of cells that may behave differently during REM sleep). PET studies do show that there is a significant decrease of rCBF in a large area in the dorsolateral prefrontal cortex (Brodmann areas 10, 46, 9, and 8). These areas are believed to be involved in deliberate, "free-willed" actions and new choices that take place without the dictations of external cues but involve internal planning and voluntary decision-making (Passingham 1993). Thus such reflective planning and decision-making functions should not be supported by REM sleep. However, the performance of habitual, procedural actions in response to external cues is assumed to depend on premotor mechanisms alone (Passingham 1993), which are not suppressed during REM sleep. Threat-avoidance responses typically are externally cued (by the perceived external threat) and fairly "instinctive" actions whose efficiency the threat simulations aim to preserve or increase, and therefore the dorsolateral prefrontal cortex need not be involved in threat simulation.

10. A recent study by Hublin et al. (1999b) confirms that there is a strong correlation between the occurrence of nightmares and night terrors, supporting the present view that both phenomena may in fact reflect an increased level of activation in one underlying system, the threat-simulation mechanism.

11. This behavior is similar to panic, during which "Intense mental activity is focused on planning escape. When the overwhelming urge to flee is translated into action, all effort is concentrated on escape" (Nesse 1997, p. 77). Panic can be viewed as an adaptation that evolved to facilitate flight from life-threatening danger (Nesse 1997).

12. Meindl (1992) presents estimates of mortality based on three different hunter-gatherer cemetery sites in Africa and North America where hundreds of skeletons have been unearthed. The oldest of the communities dates back to circa 10,000 years ago. Mean life expectation in each of the three populations is estimated to have been from 20 to 22 years. As Meindl (pp. 408–10) observes, "the relentless forces of mortality at every age assured that only a small proportion of a hunter-gatherer society was 'elderly' in our sense of the word"; instead, since "fertility must have been high to balance the annual death toll," "the paleodemographic data imply that the villages were rather like modern child day-care centers." Furthermore, the "demands of their economy may have compromised the health and safety of hunter-gatherers," "numerous healed long-bone fractures in the skeletons . . . as well as the higher mortality rates for males . . . suggest the perils of a foraging way of life" (Meindl 1992, pp. 408–10).

13. A content analysis of the 276 Mehinaku men's short dream summaries reported in Gregor (1981) was carried out. Two independent judges classified the dreams using the following mutually exclusive classes: (1) Threatening event (objective threat); (2) Subjective threat; (3) Peaceful activity; (4) None of the above or unclassifiable. The definitional criteria were refined and the use of the scale was practiced by first scoring the 109 Mehinaku women's dream summaries from Gregor (1981). The following definitional criteria were used:

1. Threatening event: Any event in the dream, which, if it were to occur in the waking life, would potentially decrease the probability of future reproductive success of the dream-self and close kin. Such events include the following: (a) Events that probably or potentially lead to immediate loss of life of the dream-self or close kin or local group members (i.e., any member of the local Mehinaku village of about 80 people); (b) Events that probably or potentially lead to physical injury of the dream-self or close kin or local group members; (c) Events that probably or potentially lead to loss or destruction of valuable physical or social resources of the dream-self or close kin. Physical resouces include all valuable possessions of and the territory controlled by the dream-self or close kin; social resources include membership and social status in the local group or society and access to desirable mates.

Examples of possible threatening events for the Mehinaku were outlined: Any local group member (including self and close kin) that is: (1) participating in an aggressive encounter with animal, human, or other malevolent characters (e.g., monsters, spirits) that can cause death, physical injury, or loss of territory or freedom; (2) encountering or perceiving dangerous animals in the vicinity (e.g., snake, wild pig, alligator, stingray, jaguar) even if the animal does not attack or show aggressive behavior; (3) being the victim of sickness or encountering animals or people or objects (e.g., parasite carrying animals, rotting food or corpses, feces) that carry or can otherwise cause disease; (4) victim of circumstances or natural elements (e.g., weather, coldness, heat, fire, rain) that can cause sickness or injury or prevent access to resources (e.g., making hunting, fishing, gathering difficult or impossible); (5) victim of accident or failure or misfortune that can cause death, physical injury, or loss of physical resources (getting lost, losing/breaking or not getting access to valuable possessions such as weapons, tools, prey, food, clothes). Dream-self or close kin is: (1) victim of social rejection or isolation that can cause loss of important social relationships and status in the group and/or loss of help and support from other group members; (2) taking part in risky activities (e.g., stealing, breaking rules/taboos) that can cause social punishment, isolation, shame, or loss of social status in the group.

2. Subjective threat: An event that does not fulfill the criteria of Threatening Event, but during which the dream-self nevertheless interprets the situation as threatening or experiences fear and anxiety.

3. Peaceful, everyday activity: An activity that is likely to be a part of the dreamer's everyday life, is realistic (nonbizarre), and involves no threatening or aggressive content.

4. None of the above: All such dreams that do not clearly fulfill any of the criteria of classes 1–3.

The results of the inter-rater agreement between the judges was 82.2% (i.e., 227 of the 276 dream summaries were scored identically). Disagreements were subsequently resolved through discussion.

The relative proportion of threatening events in Mehinaku men's dreams were as follows: Threatening events (objective threats): 56.2%; subjective threats: 7.6%; peaceful activities: 20.3%; none of the above: 15.9%.

To summarize: some kind of threatening elements are present in 63% of the dreams; events potentially threatening future reproductive success, were they real, ("objective threats"), make up the majority of these, accounting for 56% of all dream themes in the dreams of Mehinaku men.

14. Mammals had to live for at least 100 million years in the shadow of ferocious reptiles. Long periods of sleep allowed them to remain in hiding and save their strength for the brief active periods of finding food. Threat simulation or simulation of survival skills during REM-sleep may have been a valuable adaptation during this era, when mammals had to compete with the much larger and more numerous reptiles for resources. Dreaming may be just one more addition to the biological arms race whereby different species prosper in their different ecological niches. It may also be that other than mammalian brains simply cannot support the sort of multimodality simulations that dreaming consists of.

15. Thus, the hypothesis as applied to all mammals in general is: "Dreaming rehearses species-specific survival skills" – the exact nature of these skills, of course, varies from species to species depending on the niches that the species occupy. The hypothesis as applied to humans specifically is that dreaming rehearses threat perception and threat avoidance, particularly significant types of human ancestral survival skills.

16. We can contrast these predictions with those derived from other theories. All the theories claiming that dream production is based on fundamentally random processes (e.g., Crick & Mitchinson 1983; Foulkes 1985; Hobson & McCarley 1977) are of course inconsistent with predictions 1.1–1.3. All theories claiming that dreaming is specialized on some type of psychological content or effect (e.g., problem solving, emotional calming, mental health) other than threat simulation are in conflict with predictions 3.1. and 3.2. Such theories would need to show that the kinds of dreams they claim to be functional are generated by the dream-production mechanisms as reliably and effectively as threat simulations are and that having such dreams in the ancestral environment was likely to lead to increased reproductive success. Predictions 6.1 and 6.2 are inconsistent with Foulkes's theory of children's dreams (see N. 5). A central claim in Solms's (1997a) theory is that volitional motor activity is not possible during sleep and that the entire motor system is deactivated. These claims are inconsistent with Proposition 4 and the predictions derived from it. Furthermore Solms's theory is inconsistent with the data on high levels of activity in the corticospinal pyramidal tract neurons of the motor system during REM sleep (blocked downstream in the spinal cord to prevent dream enactment) and with the clinically well-documented phenomenon of REM sleep behavior disorder, a parasomnia disconfirming the claim that full motor activity and its execution would be impossible during REM sleep and dreaming (see also sect. 3.6.2 on the motor realism of dreams).

17. The starting point for the hypothesis was my view of dreaming as a natural virtual-reality simulation in the brain (first published in Revonsuo 1995). I subsequently asked: If dreaming is essentially a simulated perceptual world, what kind of simulations might be useful? I speculated that if flight simulators are used in order to train pilots to handle dangerous events that might arise during a real flight, perhaps the brain trains its own survival skills in a fight-or-flight simulator, specialized for extremely dangerous events that might be encountered in nature. The general prediction, that dream content should reflect this fact, was then made and, as the present paper documents, a surprising amount of evidence supporting the hypothesis has been found in the relevant literature. I was unaware of most of these empirical results when I began the project.

18. In his book *Affective Neuroscience* (which I happened to come across when the present paper was nearly finished) Jaak Panksepp makes an intriguing evolutionary suggestion on the origin of dreams: "Indeed, perhaps what is now the REM state was the original form of waking consciousness in early brain evolution, when emotionality was more important than reason in the competition for resources. This ancient form of waking consciousness may have come to be actively suppressed in order for higher brain evolution to proceed efficiently. This is essentially a new theory of dreaming" (Panksepp 1998a, p. 128). The threat simulation theory of dreaming is certainly consistent with Panksepp's proposal. [See also Panksepp "Toward a General Psychological Theory of Emotions" *BBS* 5(3) 1982.]

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Letters "a" and "r" appearing before authors' initials refer to target article and response, respectively.

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