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THREAT SIMULATION
THE FUNCTION OF DREAMING?

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"Do Androids Dream of Electric Sheep?"
Philip K. Dick (1968)

KATJA VALLI: Threat Simulation. The Function of Dreaming?

ABSTRACT

Dreaming is a pure form of phenomenality, created by the brain untouched by external stimulation or behavioral activity, yet including a full range of phenomenal contents. Thus, it has been suggested that the dreaming brain could be used as a model system in a biological research program on consciousness (Revonsuo, 2006). In the present thesis, the philosophical view of biological realism is accepted, and thus, dreaming is considered as a natural biological phenomenon, explainable in naturalistic terms.

The major theoretical contribution of the present thesis is that it explores dreaming from a multidisciplinary perspective, integrating information from various fields of science, such as dream research, consciousness research, evolutionary psychology, and cognitive neuroscience. Further, it places dreaming into a multilevel framework, and investigates the constitutive, etiological, and contextual explanations for dreaming. Currently, the only theory offering a full multilevel explanation for dreaming, that is, a theory including constitutive, etiological, and contextual level explanations, is the Threat Simulation Theory (TST) (Revonsuo, 2000a; 2000b). The empirical significance of the present thesis lies in the tests conducted to test this specific theory put forth to explain the form, content, and biological function of dreaming.

The first step in the empirical testing of the TST was to define exact criteria for what is a 'threatening event' in dreams, and then to develop a detailed and reliable content analysis scale with which it is possible to empirically explore and quantify threatening events in dreams. The second step was to seek answers to the following questions derived from the TST: How frequent threatening events are in dreams? What kind of qualities these events have? How threatening events in dreams relate to the most recently encoded or the most salient memory traces of threatening events experienced in waking life? What are the effects of exposure to severe waking life threat on dreams?

The results reveal that threatening events are relatively frequent in dreams, and that the simulated threats are realistic. The most common threats include aggression, are targeted mainly against the dream self, and include simulations of relevant and appropriate defensive actions. Further, real threat experiences activate the threat simulation system in a unique manner, and dream content is modulated by the activation of long term episodic memory traces with highest negative saliency. To sum up, most of the predictions of the TST tested in this thesis received considerable support.

The TST presents a strong argument that explains the specific design of dreams as threat simulations. The TST also offers a plausible explanation for why dreaming would have been selected for: because dreaming interacted with the environment in such a way that enhanced fitness of ancestral humans. By referring to a single threat simulation mechanism it furthermore manages to explain a wide variety of dream content data that already exists in the literature, and to predict the overall statistical patterns of threat content in different samples of dreams.

The TST and the empirical tests conducted to test the theory are a prime example of what a multidisciplinary approach to mental phenomena can accomplish. Thus far, dreaming seems to have always resided in the periphery of science, never regarded worth to be studied by the mainstream. Nevertheless, when brought to the spotlight, the study of dreaming can greatly benefit from ideas in diverse branches of science. Vice versa, knowledge learned from the study of dreaming can be applied in various disciplines. The main contribution of the present thesis lies in putting dreaming back where it belongs, that is, into the spotlight in the cross-road of various disciplines.

Keywords: Dream Content, the Function of Dreaming, the Threat Simulation Theory, Evolutionary Psychology, the Multilevel Framework, Biological Realism

Contents

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In Turku, 17th of October, 2008

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LIST OF ORIGINAL PUBLICATIONS

I. Revonsuo, A., & Valli, K. (2000). Dreaming and consciousness: Testing the Threat Simulation Theory of the function of dreaming. Psyche, 6. http://psyche.cs.monash.edu.au/v6/psyche-6-08-revonsuo.html[a]

II. Valli, K., Lenasdotter, S., MacGregor, O., & Revonsuo, A. (2007). A Test of The Threat Simulation Theory – Replication of results in an independent sample. *Sleep and Hypnosis*, 9(1), 30-46. [b]

III. Valli, K., Strandholm, T., Sillanmäki, L., & Revonsuo, A. (2008). Dreams are more negative than real life – Implications for the function of dreaming. *Cognition and Emotion,* 22(5), 833-861.[c]

IV. Valli, K., Revonsuo, A., Pälkäs, O., Ismail, K. H., Ali, K. J., & Punamäki, R-L. (2005). The Threat Simulation Theory of the evolutionary function of dreaming: Evidence from dreams of traumatized children. *Consciousness and Cognition*, 14, 188-218.[d]

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VI. Valli, K., & Revonsuo, A. (in press). The Threat Simulation Theory in the Light of Recent Empirical Evidence – A Review. *American Journal of Psychology.*[f]

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ABBREVIATIONS

CH	Continuity Hypothesis
CST	Costly Signalling Theory
DLPFC	Dorsolateral prefrontal cortex
DTS	Dream Threat Scale
EEA	Environment of Evolutionary Adaptedness
EEG	Electroencephalography
EP	Evolutionary Psychology
ERD	Earliest remembered dream
fMRI	Functional magnetic resonance imaging
LSCL-33	Limbic System Checklist
MEG	Magnetoencephalography
MRD	Most recent dream
NREM	Non-rapid eye movement sleep
PET	Positron emission tomography
PGO	Ponto-Geniculo-Occipital wave
PTSD	Posttraumatic stress disorder
RAT	Random activation theory
RBD	REM sleep behavior disorder
REM	Rapid eye movement sleep
SWS	Slow wave sleep
TRC	Total recall count
TST	Threat Simulation Theory

1. INTRODUCTION

Sleep and dreaming are the most often naturally occurring altered states of consciousness, involving dramatic changes in overt behaviour, physiological responses and subjective experiences. The ability to have subjective experiences during sleep is one of the most puzzling features of human nature. Dreams are experienced by most individuals, and in all cultures. Thus, the brain's capability to produce subjective hallucinatory experiences during sleep seems to be part of our biological machinery, a trait genetically passed on in successive generations. Nevertheless, despite rigorous empirical research and theorizing, it is still far from clear whether dreaming serves any function, and if it does, the specific function of dreaming has not been satisfactorily explained.

This thesis explores dreaming from a multidisciplinary perspective, by drawing together contributions from various fields of science. These fields include philosophy, consciousness research, dream research, evolutionary psychology, and cognitive neuroscience. In the following, I will first explain how different ideas from these fields are integrated in this thesis, that is, by using an explanatory model adopted from biological sciences: the Multilevel Framework. I then move on to reviewing how various theories put forth to explain the form, content or function of dreaming fit into the framework. I will focus especially on the Threat Simulation Theory (Revonsuo, 2000a) because of all the suggested dream theories it fits most elegantly to the multilevel framework.

The empirical part of this thesis focuses on testing the Threat Simulation Theory, an evolutionary psychological theory of the function of dreaming. I will explain the content of the main method developed for the empirical testing of the TST, the Dream Threat Scale, and its theoretical background assumptions. Then, I summarize the results we have acquired by using the scale in the samples of Finnish and Swedish university students' dreams, and traumatized and nontraumatized Palestinian and Kurdish children's dreams. A reinterpretation of the results is also offered.

The discussion is devoted to evaluating the TST in the light of the results of the present thesis and of other research relevant in the context of the TST. I aim also to point out the strengths and the weaknesses of the TST, and propose future guidelines for the empirical testing of the theory. Finally, I will return to the multilevel framework, and summarize how the TST manages to explain dreaming within this model, and why a multidisciplinary approach is needed for a full explanation of such a complex phenomenon as dreaming.

2. THE MULTIDISCIPLINARY APPROACH TO DREAMING

The biggest one of the main contributions of the present thesis lies in the integration of various fields of science, that is, philosophy, consciousness research, dream research, evolutionary psychology, and cognitive neuroscience. Thus far, dreaming has been either independently explored within these sciences or ignored altogether. I argue that without merging the most valuable contributions from each field, we will never be able to satisfactorily explain such a complex phenomenon as dreaming. Next, I will elucidate what are the most insightful contributions that these fields can offer to the explanation of dreaming, and how the views merge in the present thesis.

2.1. Consciousness research and Biological realism

The roots of the present thesis lie in the philosophical assumption that subjective consciousness is a real natural biological phenomenon in the brain. This approach is called 'biological realism' (Revonsuo, 2001; 2006). Biological realism is only one approach to explaining consciousness, and there are a number of other contemporary approaches, with varying philosophical commitments. An approach very close to biological realism is biological naturalism, proposed by Searle (1992), and in this approach, consciousness is also considered as a biological phenomenon. Regardless, in philosophy biological views to consciousness are in the minority, and the mainstream approaches differ significantly.

First, there are views that deny the existence of phenomenal consciousness altogether (Dennett, 1976; 1991), or deny that experiences have qualitative properties (O'Regan & Noë, 2001). Thus, these views also deny dreaming as a form of phenomenal consciousness, or deny that dreaming has qualitative features. Second, some views accept phenomenal consciousness, but locate it outside the brain (Dretske, 1995; Noë & Thompson, 2004a; 2004b; Thompson & Varela, 2001; Tye, 1995). These externalist views face problems in explaining how dreaming as a form of phenomenal consciousness can occur in the absence of external referents. Panpsychism (Chalmers, 1996; 2000; Lehar, 2003) goes even further than externalist views by claiming that consciousness can be everywhere as it is a fundamental feature of the physical universe. Everything is more or less conscious, and the real question concerns only the degree of consciousness. Thus, in these latter views dreaming is considered a real phenomenon, but we should not say that it is located in the brain or that it can be fully explained by brain activity.

By contrast, biological realism treats subjective consciousness as a biological phenomenon embedded in the brain. Consequently, it follows that subjective consciousness requires a fully naturalistic explanation, similar to the explanation of other biological phenomena. As dreaming resides at a particular level of biological organization in the brain, dreaming could and should be explained with naturalistic terms.

Biological realism ties the explanation of consciousness into biological sciences, where the underlying explanatory strategy is 'multilevel explanation' (Bechtel, 1994; Bechtel & Richardson, 1992; 1993; Craver, 2001; Craver & Darden, 2001). In multilevel explanation, the phenomenon or system under investigation is first identified and described at one level of organization, and the next step involves trying to figure out what the components of the system are. With various research instruments, the system or the phenomenon is broken down into subsystems or microcomponents that help in building an idealized multilevel model of the system (Revonsuo, 2006).

Biological realism interprets consciousness as a phenomenal level in the brain, and places the overall explanation of consciousness into the multilevel framework (Revonsuo, 2006). In the framework, the explanation of mental phenomena can be broken down into several smaller explanatory tasks; constitutive (the downward-looking), contextual (the upward-looking), and etiological (the backward-looking) explanations (see Figure 1.). Constitutive explanations involve looking at smaller-scale phenomena or a spatio-temporally lower level of organization, that is, they aim at decomposing the phenomenon under investigation to its constituent parts, and describing the lower level mechanisms that causally contribute to the emergence of the phenomenon. Etiological explanations focus on the causal history of the phenomenon, that is, aim to trace back in time the causal chains that lead to an occurrence of the phenomenon. The etiological or causal explanations can be divided into 1) the immediate or proximate causes of the phenomenon, 2) the ontogenetic developmental causes of the phenomenon, or 3) the ultimate or evolutionary causes of the phenomenon. Contextual explanations, in contrast, aim to describe the role of the phenomenon at higher level of organization where it is just one element or subsystem in a complex mechanism. Each line of explanation, forming now a subproblem in the overall explanation of explaining consciousness, can then be separately investigated by a dedicated science or with a particular method.

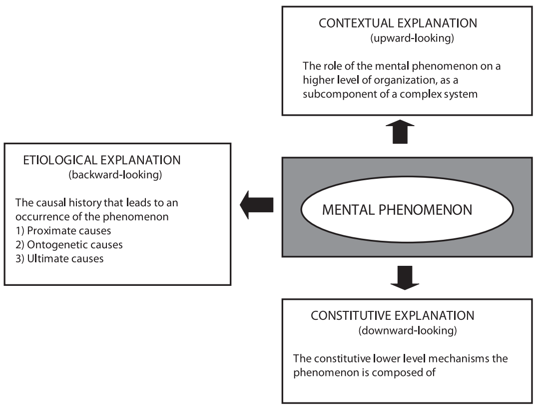

Fig. 1. The multilevel framework for the investigation of mental phenomena. Modified from Revonsuo (2006).

2.2. Dreaming in multilevel framework

Revonsuo (2006) suggests that dreaming provides consciousness research with a unique model system which could yield valuable information on how the brain produces phenomenological reality. During dreaming, the brain creates a rich phenomenological reality completely independent of the external world. Phenomenal consciousness during dreaming includes a full range of subjective contents, with similar overall form as phenomenal consciousness during wakefulness. As dreaming occurs in isolation from external stimuli, in the absence of sensory input and motor output, it can be regarded as a special and pure form of consciousness (Revonsuo, 2001; 2006). Yet, in consciousness research dreaming has been mostly ignored as a model system for the explanation of consciousness.

By placing dreaming into a multilevel framework, it is possible to divide the research problems we face in explaining the phenomenon into smaller sub-problems. Once identified and described, each component can then be studied independently, by the relevant field of science. When we have sufficient answers to our research problems from all or most levels of the framework, we can begin to build an idealized multilevel model of the system. In the end, if we have managed to find the right answers and build a multilevel model of dreaming, even if an idealized one, we have also managed to explain the phenomenon under study, at least to some degree.

2.2.1. Dreaming as the phenomenon under investigation

Dreaming as a phenomenological form of consciousness can be inserted into the multilevel framework as described in Figure 2. First, the phenomenon itself, dreaming, needs to be identified and described in detail. The accomplishment of this task is the goal in dream research, and thus the contribution of dream research into the explanation of the phenomenon under investigation lies in identifying or defining dreaming, and in describing dreaming with systematic, normative, statistical studies of dream phenomenology and content. Consequently, dream research is in a central role in this thesis. After fully explaining the multilevel model of dreaming, I will present the answers and the main contributions that dream research has provided to the identification and description of dream phenomena.

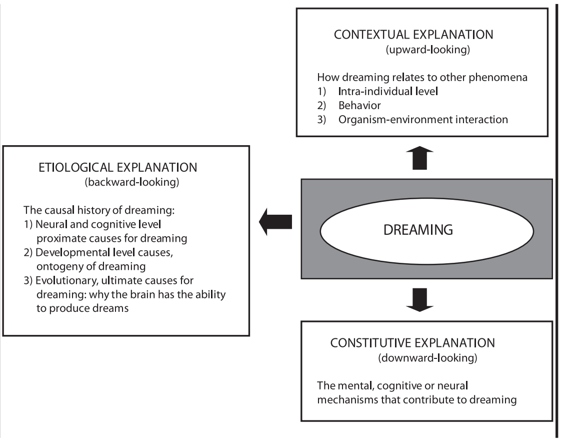

Fig. 2. The multilevel model of dreaming.

2.2.2. Constitutive explanations for dreaming

The constitutive explanation of dreaming aims at decomposing it into its constituent parts, and describing the lower level mechanisms dreaming is composed of or whose activity together produces the phenomenon. In the context of dreaming, the problem arises whether dreaming resides only on the phenomenal level, or whether nonconscious mental or cognitive processes are involved as well. The question that follows from this problem is whether the underlying levels of the phenomenal level are only neural or also cognitive level processes. For example, binding sensations and perceptions into a unified whole can be explained in terms of cognitive level informational processes or in terms of underlying neural level processes. Thus, in the context of dreaming, the downward-looking explanation involves finding out what are the mental, cognitive, and neural nonconscious mechanisms that contribute to dreaming. These tasks belong to the scope of psychology, cognitive science, and cognitive neuroscience.

Cognitive neuroscience has been described as the empirical science developed to close the explanatory gap between biological processes and processes of the mind (Gazzaniga, 1995), seeking global theoretical integration between the biological and the mental, the latter primarily understood as ‘cognition’. Nowadays, however, also consciousness is included into the scope of cognitive neuroscience. Thus, the aim in cognitive neuroscience is to explain the neural mechanisms underlying cognitive and conscious phenomena. Only a minority of neuroscientists have devoted their efforts to revealing the neural basis of consciousness, not to mention dreaming.

Nevertheless, cognitive neuroscience can greatly contribute to the investigation of constitutive explanations for dreaming. When the phenomenon is first described in detail (as is the aim in dream research), cognitive neuroscientists can then explore the neural mechanisms behind, that is, correlates or constituents of, specific types of subjective experiences. Most of the theories in dream research aim to explain the form and content of dreaming, and would thus predict specific brain activation patterns responsible for the form or content of dreaming (although these predictions are seldom clearly outlined). This is also called a top-down approach: dream research provides data that lead to predictions of which brain areas should be activated during dreaming and which should not. Cognitive neuroscience, in contrast, adopts a bottom-up approach to dreaming. It provides empirical data of which brain areas have been observed to be activated or deactivated during dreaming. These top-down and bottom-up approaches should be compatible and predict findings from the opposite approach. Consequently, as results from cognitive neuroscience can be combined with empirical findings in dream content studies, cognitive neuroscience can contribute to theoretical models of dreaming as well as be used to empirically test predictions of various theories and models on dreaming. At the moment, the main research problem posed by dreaming to cognitive neuroscience is to find out the dream generator mechanisms in the brain.

2.2.3. Etiological explanations for dreaming

An etiological explanation aims to explain the causal history of the phenomenon, that is, to trace back in time the causal chains that lead to an occurrence of the phenomenon. The causal explanations can be divided into 1) the immediate or proximate causes of the phenomenon, 2) the ontogenetic or developmental causes of the phenomenon, or 3) the ultimate or evolutionary causes of the phenomenon. In the context of dreaming, these explanations involve both neural level and psychological level causes.

The proximate causes of dreaming in the neural level should describe how the preceding stimuli, such as internal brain activation during sleep, cause dreaming to occur. These proximate explanations again belong mostly to the scope of cognitive neuroscience. Psychological level proximate explanations should describe how cognitive level preceding causes, such as the activation of memory sources (both long term memory activation and day residues), emotional state and activity, hyperassociativity, memory consolidation, attention, stimulus incorporation, and self-awareness, participate in producing dream phenomena. These psychological level causal explanations are investigated mainly in psychology and cognitive science. For example, Foulkes (1999) has formulated a cognitive theory of dreaming, addressing psychological level proximate explanations to dream formation (see section 2.4.3). However, as each psychological level phenomenon has its unique constitutive level in the brain, cognitive neuroscience is also involved.

The ontogenetic or developmental explanations in the context of dreaming aim to clarify how, during individual development, the brain became wired up so that the dream generator systems of the brain mature and how the mind develops cognitively and psychologically so as to gradually produce adult-like dream experiences. This task is enormously complex, and requires united efforts from fields such as developmental and cognitive psychology, biology, and even genetics. Nonetheless, one developmental explanation for dreaming has been suggested by Foulkes (1982; 1985; 1999). His theory offers an interpretation of how psychological processes are involved in dream production, and will be reviewed later in section 2.4.3.

The ultimate or evolutionary explanations look even further back in time, and aim to elucidate how, at some point in the evolutionary history, the brain evolved the ability to produce dreaming. Evolutionary explanations try to figure out how the first dream generators appeared in some distant ancestors of ours, perhaps in the first humans, perhaps in the first mammals. Did dream generators first appear as a nonfunctional epiphenomenon of other sleep-related mechanisms (a so-called spandrel; Gould & Lewontin, 1979), but as they later proved to be functional in the biological sense of the word, were thenceforth selected for their survival-enhancing properties? Evolutionary explanations try to find out whether the dream generator has any or had any survival-enhancing consequences or not. Did dreaming promote the reproductive success of those who were able to dream in the evolutionary environment? Thus, the ultimate explanations are researched in evolutionary biology and evolutionary psychology.

During the last fifteen years or so, evolutionary psychology (EP) has evolved into a popular approach to understanding psychological phenomena. Evolutionary psychology attempts to explain psychological traits as adaptations, that is, as the functional products of natural or sexual selection. Adaptationist thinking about biological mechanisms, such as the immune system, is common in evolutionary biology, and basically, evolutionary psychology applies the same thinking to psychology. Evolutionary psychologists see much of human psychology and behavior as having foundations in psychological adaptations that evolved to solve recurrent problems in human ancestral environments.

Tooby and Cosmides (1992; 1995) define adaptations as mechanisms crafted by natural selection to solve the specific problems posed by the environments encountered by ancestral populations during the course of the species' evolution. One of the main criteria for an adaptation is that it shows clear design for a function, that is, it seems to be specifically engineered to solving a specific adaptive problem. Thus, an evolutionary analysis of a psychological mechanism includes an analysis of the adaptive problems that existed in the human evolutionary environment and an explanation of how the psychological mechanism helped ancestral humans to solve some of those problems.

Some dream researchers have applied the EP metatheoretical framework to the explanation of the function of dreaming. When evolutionary psychological reasoning is extended to dreaming, the following questions immediately emerge: Is it conceivable that the process of dreaming or dreaming about particular contents was functional in the biological sense in the ancestral world - that somehow our ancestors had better chances of surviving or reproducing because they regularly dreamed during the night, and especially because they regularly dreamed about particular things? Could dreaming have given any kind of selective advantage for our ancestors and if yes, what kind of advantage? Does dreaming fulfil the main criterion for an adaptation, in other words, does dreaming show a clear design for a specific function, and does it seem to be specifically engineered to solving a specific adaptive problem. All the evolutionary psychological theories seek answers to these ultimate questions about dreaming. In that way, the EP approach has made a significant contribution to modern dream theories.

2.2.4. Contextual explanations for dreaming

The contextual explanation describes the role of the phenomenon at a higher level of description. How does dreaming relate to or affect other psychological or conscious phenomena? What consequences does the dream generator system have for learning, memory, emotion regulation, perception, and ultimately, overt behavior? If dreaming has a function, it must have some useful effects at the contextual level, that is, it must modify waking consciousness or behaviour in some way.

The approaches to dreaming on the contextual level can vary greatly depending on the perspective. For example, in neuropsychology we can ask questions such as whether dreaming as a neurobiological process, or dream content as subjective experience, affects long term memory consolidation, or modifies subsequent waking behavior. In clinical and personality psychology research we could seek answers to how dreams are interpreted by people, or what kind of personal meanings dreams carry. We could investigate dreaming in social psychology by looking at how and under what circumstances people engage in dream sharing, or explore the role of dreams in cultural contexts with methods available in sociology. Contextual explanations tie dreaming to other subjective and psychological phenomena on a more general level, which are intra- or interindividual level, overt behavior, and organism-environment interaction. In the contextual level, mental phenomenon is one of the etiological explanations for observable behavior.

2.3. Dreaming as the phenomenon under investigation: Identification and description of dream phenomena

Dream research is the field of science aiming to identify, describe and explain, at least partially, the phenomenon of dreaming. *Identification* of the phenomenon includes providing clear definitions for what does or does not account as dreaming, and gives the empirical criteria for the presence and absence of dreaming. The systematic *description* of dreaming involves elucidating the phenomenology of dreams, and this is accomplished with systematic collection of large samples of dreaming data and detailed content analysis studies on dream content. The explanations for dreaming (that is, for the statistical patterns found in the data on dream content and its correlations to other phenomena) involve various theories and hypotheses of the constitutive or etiological pathways underlying dreaming, or contextual descriptions of the effects of dreaming.

In this section, only the definition of dreaming, a summary of methods for describing dream content, and description of dream phenomena are presented. Similarly, the relationship between sleep and dreaming is briefly reviewed. The constitutive, etiological, and contextual explanations for dreaming are brought up later in section 2.4.

2.3.1. Definition of dreaming

Even though the scientific and empirical study of dreams began in the 19th century, thus far the mere identification of the phenomenon has proved to be problematic. At the moment, researchers do not even concur on how exactly to define dreaming. This, in turn, affects how the phenomenon is described.

Currently, researchers seem to agree that all conscious mental events that occur during sleep can be categorized as 'sleep mentation'. However, not all sleep mentation comprises as dreaming. In the 1970's, Snyder stated that dreaming refers to the subjective conscious experiences during sleep, and it consists of complex and organized mental images that show temporal progression or change. He thus excluded static, simple, and unimodal imagery, such as static visual images, thinking, reflecting, bodily feelings and fragmentary impressions, from the definition of dreaming. To Snyder, dreams were like stories or at least like scenes from a story (Snyder, 1970). While Snyder's (1970) definition does not state anything about the actual content of dreams, Hobson (1988), and Hobson, Pace-Schott, and Stickgold (2000) emphasize the qualitative features of dream content in their definition of dreaming. They list the following set of features most often present in dreams as definitional features of dreaming: hallucinatory perceptions, delusions, narrative structure, hyperemotionality and bizarreness. Furthermore, according to Hobson (1988) and Hobson et al. (2000), dreams usually lack self-reflection, stability, and volitional control.

Revonsuo (2006) recently suggested that instead of strict definitions and categorisations, we should consider dream phenomena as a continuum. At the one end of the continuum resides full-blown dreaming, defined as complex, organized, temporally progressing, multimodal contents of consciousness during sleep that amount to a simulation of the perceptual world, and at the other end there is sleep mentation, that is, simple contents of consciousness during sleep that show a low degree of complexity and organization. Even though in this definition dream phenomena is considered as a continuum, it might be difficult to draw the line between what types of dream contents amount to world simulation and what do not. Thus, the two main categories, dreaming and sleep mentation, still exist.

2.3.2. Methods for acquiring descriptions of dreaming

Early dream research in the 19th century was characterized by the use of introspective reports and explorations on dream phenomenology (Schwartz, 2000). Despite advances in research and data collection methods, introspective reports are still the main tool in the investigation of dreams.

2.3.2.1. Data collection methods

Reports of dreaming can be collected and analyzed in various ways. The most cost-effective method is to use questionnaires, as they allow quick data collection from large samples (Farthing, 1992), but questionnaires offer a very limited access to the richness of dream phenomena. In addition, forgetting and memory bias interferes with acquiring accurate and detailed information (Farthing, 1992).

A more laborious method is to collect systematic and detailed descriptions of dream content immediately after awakening, either in the home or laboratory setting. These methods share some common features. First, the subjects or participants are aware that their task is to recall dreams, as opposed to unexpected retrospective inquiry in questionnaire methods. Second, the participants are usually given detailed instructions on how to report the dreams. Systematic recording of remembered dream content decreases memory bias, but is slow and demanding for the subject. Thus, the participants are often strongly motivated to recall and report their dreams. Both home and laboratory setting dream report collection methods also involve a practice-effect: the more the participants pay attention to their dreams, and to recalling and reporting dreams, the better the dream recall (Beaulieu-Prévost & Zadra, 2005; Schredl, Wittmann, Ciric & Götz, 2003), and likely, the more detailed the dream descriptions.

In home dream diaries, the participants can recall and report the dreams in the privacy of their own homes. In addition, home dream diaries allow the anonymity of the participant, thus minimizing censorship (Farthing, 1992). Analysis of dream journals kept for different reasons reveal that dream content has great consistency over time (Domhoff, 1996; 2003). Thus, home dream reports form a representative sample of the phenomenon. Nevertheless, in home dream diaries only dreams recalled upon awakening are recorded, and the experimenter cannot control for the physiological sleep stage the dream report originates from. Technical advances, however, offer a solution to these problems. The 'Nightcap' is a portable device that can detect small eye movements, and thus distinguish between non-rapid eye movement (NREM) and rapid eye movement (REM) sleep. The data from sleep stages can be stored to a personal computer, and the computer can also be programmed to conduct awakenings at predetermined times with high levels of accuracy (Aijole, Stickgold, Rittenhouse & Hobson, 1995; Mamelak & Hobson, 1989; Pace-Schott, Kaji, Stickgold, & Hobson, 1994).

While home dream diaries are relatively cheap, collecting dreams in a sleep laboratory setting is expensive because of equipment and resource demands. Also the anonymity of the participant is compromised, and may affect the willingness to report embarrassing dream content. However, immediate dream reporting after controlled awakenings minimizes memory bias, and sleep stages can be controlled for. Further, it is possible to elicit experimental stimuli to study its effects on dream content, or to conduct awakenings at predetermined occasions for all subjects (homogenous data sample). The laboratory setting can, nevertheless, have negative impacts on the quality of data collected. First, laboratory subjects often report incorporation of elements from the experimental setting into dream content (Domhoff, 1996; Schredl, 2008). Second, frequent awakenings are taxing for participants, and can lead to resisting full awakenings and dream reporting (Domhoff, 2003). Third, partial sleep deprivation and sleep inertia due to frequent awakenings may itself affect dreaming.

2.3.2.2. Data analysis methods

The most widely used scientific method in describing and analyzing dream content is content analysis. The earliest content analysis scales reported date back to the 19th century (Calkins, 1893; Weed, Hallam & Phinney, 1896), but in the 1950's and 60's, content analysis gained a steady foothold in dream research. The goal of content analysis is to transform selected aspects of qualitative data (verbal reports) into a quantitative form so that statistics can be conducted (Hall & Van de Castle, 1966). In content analysis, selected elements present in dream reports are separated and classified into categories. The greater the detail with which a category is constructed and defined, the less room there is for the judges to impose their own beliefs or interpretations on scoring of elements (Antrobus, Fein, Jordan, Ellman & Arkin, 1991). After the scoring process is finished, specific proportions, frequencies, and percentages of different elements can be calculated and statistically analyzed. The originally qualitative data can then also be contrasted against various other variables, such as age, sex or cultural background of participants, length of dream reports as measured by word count, order effects (the first vs. later reports in home journals or laboratory awakenings), the effects of sleep stages, or personality measures (Antrobus et al., 1991).

The categories in a content analysis system of classification may be either descriptive or theoretical. Descriptive categories are created by reading numerous dream reports and devising, by trial-and-error, a scale that accurately reflects the content of dreams (Domhoff, 1996; Hall & Van de castle, 1966). In published dream research on the content analysis of dreams, mainly descriptive content scales have been utilized, such as the famous Hall and Van de Castle (1966) system. In contrast, theoretical scales are formulated to measure a specific construct derived from a theory. The earliest theoretical scale, based on psychoanalytic theory, was devised by Alexander and Wilson (1935), soon followed by others (for review, see Hall & Van de castle, 1966). Also Hall and Van de Castle (1966) constructed some categories based on psychoanalytic theory, but later it was found that results on these scales were inconsistent (Domhoff, 1996), and furthermore in contradiction with the predictions derived from psychoanalytic theory (Nathan, 1981).

The formulation of theoretically based content analysis system requires careful planning. First, the investigators must be aware of the details of the theory they wish to test, and second, even the advocates of the theory may disagree as to which dream elements reflect the propositions of the theory (Domhoff, 1996). Nevertheless, theoretical scales are valuable tools not only in testing theoretical claims, but in increasing knowledge of the phenomenal features of dreams, just as descriptive scales. In fact, all theoretical categories are simultaneously also descriptive. Similarly, we could say that all descriptive categories are also theoretical, but they are only based on implicit theories or folk-psychological beliefs of the most obvious or natural categories in human perception and experience.

2.3.2.3. The effect of data collection methods on dream content

Domhoff (2003) provides an excellent review of findings on representativeness of dream collection methods. In a meta-analysis carried out by Domhoff and Schneider (1999), dreams reported at home and in the laboratory were found to be to a large extent similar. The significant difference that emerged in the meta-analysis involved aggression. Home dream diaries were observed to contain a higher percentage of dreams including at least one incidence of aggression, a higher rate of aggression per character, and higher percentage of physical aggression (defined as physical aggression towards characters or personal property). However, the effect sizes were found to be small, except for physical aggression. Thus, Domhoff (2003) concludes that everyday dream recall provides, in general, a good sample of dream life. I would, however, based on the findings of Domhoff and Schneider (1999), suggest caution in interpreting the results concerning physical aggression in home dream journals, as there seems to be a bias towards reporting more aggressive dreams in home versus laboratory setting.

2.3.3. The description of dreaming: form and content

The first task when beginning to assess a phenomenon from a multilevel framework is to identify and describe the phenomenon. Although different types of definitions of dreaming have been used in dream studies, and this has most likely affected data collection methods, data analysis methods, and therefore also results, in this section the available descriptions for dreaming are summarized. The aim is to illustrate the quality of the phenomenon to the extent possible at the moment. Numerous content analysis studies conducted on dreams provide a large body of systematic empirical data on the phenomenology of dreams. Furthermore, most of the data provides convergent evidence on the major statistically reliably occurring features of dreams.

2.3.3.1. Sensory modalities and qualities in dreams

According to many studies, all sensory modalities are present in our dreams, and approximately to the same extent as in our waking reality (Calkins, 1893; Weed et al., 1896; Snyder, 1970; Strauch & Meier, 1996; Zadra, Nielsen & Donderi, 1998). All or most dreams include visual experience, and auditory components are also frequent. Bodily sensations, such as kinaesthesia and touch, are less frequently reported, and smell, taste, and pain experiences are rare but possible. These sensory experiences are less frequent in our daily lives as well, compared to the prevalence of visual and auditory sensations.

The visual qualities of dream experiences were explored in an ingenious experiment in the early 1990's (Rechtschaffen & Buchignani, 1992). The experimenters had a selection of more than 100 photographs in which the visual features (for example, chromaticity, saturation, illumination) had been altered. Immediately after awakening the subjects in a laboratory, the participants selected a photograph that most accurately matched the visual quality of their dream. The most often picked photograph was the one that had not been altered in any way, and the next ones chosen presented only slight variations from normal. Furthermore, Rechtschaffen and Buchignani (1992) noticed that most, but not all, dreams are perceived in color. Approximately 20% of dreams lack color, and are perceived achromatically, in black and white. An explanation for this might be that visual perception in low levels of illumination during wakefulness is achromatic; we only detect shades of grey, not chromatic colors. In sum, the visual qualities of dreams closely resemble the way we perceive the world while we are awake.

The quality of sensations in dreams is also remarkably realistic. What we see, hear, taste, smell and touch, feels so realistic that we cannot usually distinguish between a dream sensation and a comparable sensation in the waking state. For example, although pain sensations as such are quite infrequent in dreams (for example, Strach & Meier, 1996), in a study by Zadra et al. (1998) in the 0.5% of dreams in which pain was described, it was reported to be realistic. The pain was localized in a specific area of the body, and often followed from an injury when engaged in violent encounter with other dream characters. In sum, the idea that dreams are perceptually realistic has received considerable empirical support.

2.3.3.2. The dream self

An element present in almost every dream is the dream self (Snyder, 1970; Strauch & Meier, 1996). Usually, we experience our dreams from the embodied first person perspective, in a similar fashion that we experience our waking reality (Foulkes & Kerr, 1994). The dream self most often possesses a body-image much like the one we have while awake, and we are positioned in the centre of the dream world, actively part-taking the dream events. In this respect, the dream self is not all that different from the waking self. Sometimes, however, we can have a camera-like perspective on dream events, and observe the dream and even ourselves from a third person's point-of-view (Snyder, 1970; Strauch & Meier, 1996).

What is different between the waking self and the dream self are memory lapses, confabulation, and lack of insight into one's own deficient cognition (Revonsuo, 2005). The dream self often has a limited access to his or her autobiographical memory, suffers from transient amnesia, and is disoriented to time and place. Although the dream self in most dreams appears much the same as during wakefulness, there are a small proportion of dreams in which the self appears in an altered form (Revonsuo & Salmivalli, 1995). The milder variations include cases in which the dreamer is the same person, but appears in strange clothing or is of a different age. In a more distorted form, the dreamer can appear as a completely different person, sometimes of the opposite sex or different race, or even an animal. While the dreamer may remember some facts concerning his or her life correctly when dreaming, often the dreamer loses the ability to contemplate whether the events, persons, places, or objects in the dreams are possible. The dream self can also create false memories, such as friends or relatives that do not exist in the waking reality. In fact, the dream self is often totally unable to reflect upon the credibility of his or her beliefs within the dream.

2.3.3.3. Emotions

Dreams include a full range of emotional experiences, but negative emotions seem to be more frequently experienced in dreams than positive emotions. In the classic Hall and Van de Castle (1966) study of home-reported dreams, of the over

700 emotions explicitly mentioned in the one thousand dream reports of college students, 80% were negative and only 20% positive. This was the case for the dream self as well as for the other dream characters. Schredl and Doll (1998) replicated the results in home dream diaries, although the ratio was more balanced. However, they calculated the ratios for the total number of dream reports, not for the total number of emotions as Hall and Van de Castle (1966). Schredl and Doll (1998) report that 56.4% of dream reports included predominantly negative, and 21.1% predominantly positive emotions when rated by external judges. Snyder (1970), and Strauch and Meier (1996) have studied REM dreams collected in laboratory, and their results indicate that two thirds of emotions in dreams are negative. They also found that the most commonly reported negative emotions are fear and anger.

Some discrepancies in the results remain, however, concerning dream emotions. For example, Schredl and Doll (1998) found that self-ratings of dream emotions were more positive than ratings by external judges, and that external judges tended to underestimate the occurrence of positive emotions. Fosse, Stickgold and Hobson (2001) and Strauch and Meier (1996) reported that the single most frequently reported emotion in dreams is joy or elation, although the frequency of one positive emotion is concealed by the combined overall ratio of positive vs. negative emotions. Regardless, dream emotions have been found to be almost always appropriate to the dreamed situations (Foulkes, Sullivan, Kerr & Brown, 1988; Revonsuo & Salmivalli, 1995).

2.3.3.4. Other dream characters and social interactions

The dream self is not alone or passive in the dream world, but surrounded by other dream characters, actively taking part in events and social interactions (Strauch & Meier, 1996). On average, in addition to dream self dreams contain three other animate characters, which are usually human, but sometimes animals or fantastic or fictional characters (Domhoff, 1996). Approximately half of the humans in dreams are persons known to us, and the other half consists of strangers, undetermined people, occupational or fictional characters (Revonsuo & Tarkko, 2001; Strauch & Meier, 1996)

The dream self is also an active participant in approximately four out of five dreams, and an uninvolved observer only occasionally (Strauch & Meier, 1996). The dream self interacts with other dream characters, and various social interactions take place in dreams. Interactions with other characters are more often aggressive than friendly. Almost half of the dreams include an aggressive component, and the dreamer is personally involved in most of these, more often being the victim than the aggressor (Domhoff, 1996). Males dream more often of direct physical aggression than females, and females of friendly interactions. Sometimes the positive interactions take on an erotic tone, although more often in male's than in female's dreams (Domhoff, 1996).

2.3.3.5. Dream themes and events

The themes people around the world dream about share many commonalities, independent of the culture the people come from. *Typical dream themes* are dreams that contain the same general form over and over again across large numbers of people, even though the details of the dream may vary considerably. In questionnaire studies, people have been presented with a list of various dream themes, and asked: "Have you ever dreamed of..?". These surveys reveal that by far the most typical dream theme around the world is that of the dream self being chased or attacked (Domhoff, 1996; Garfield, 2001; Griffith, Miyagi & Tago, 1958; Hartmann, 1984; Nielsen, Zadra & Fukuda, 1999; Nielsen, Zadra, Germain & Montplaisir, 1998; 1999; Nielsen, Zadra, Simard, Saucier, Stenstrom, Smith, et al., 2003; Robbins & Houshi, 1983; Schredl, Ciric, Götz & Wittmann, 2004; Zadra & Nielsen, 1997; 1999).

Other most typical universal dream themes are also mainly composed of negatively toned events, such as falling or being on the verge of falling, drowning, being lost or trapped, being naked or inappropriately dressed in public, being accidentally injured, ill or dying, being in a man-made or natural disaster, having trouble taking a test or other poor performance, and having trouble with car or other transport (Garfield, 2001; Nielsen et al., 2003). Sexual experiences or being naked in public are another well remembered, although less frequently reported dream content, and many recall dreams about being late, or of school, teachers or studying (Garfield, 2001; Nielsen et al., 2003). Flying dreams or dreams with the dream self soaring through the air are also universally reported, and in contrast to the previously mentioned themes, these kinds of dreams are usually positive (Garfield, 2001).

Detailed content analysis studies have also shown that dreams often contain negative events. Events in which a bad outcome occurs to a dream character independent of anything the character does are called misfortunes (Domhoff, 1996; Hall & Van de Castle, 1966). These are, by definition, negative events consisting of mishaps, dangers, accidents, loss of possession, injuries and illnesses, falling and death. Misfortunes are seven times more frequent in dreams than the opposite type of events, good fortunes (Domhoff, 1996; Hall & Van de Castle, 1966). Moreover, the dreamer is personally involved in almost three quarters of misfortunes (Domhoff, 1996; Hall & Van de Castle, 1966).

2.3.3.6. Reflection

Reflective consciousness involves the ability to focus on some particular aspect of the content of consciousness and pass a judgement over it (Revonsuo, 2006). The traditional view has it that dreams are devoid of reflective consciousness and self-awareness (for example, Snyder, 1970). This traditional view may now be changing. During dreaming our ability to critically reflect upon the events we witness is diminished, but it is not completely wiped out. Already in the early 1980's McCarley and Hoffman (1981) found that in 16% of 104 REM dreams the dreamer explicitly noticed some bizarre feature of the dream. That is, reflective thinking of something not being quite right was present, at least for a fleeting moment. Later, more detailed analyses of reflection in drams have been carried out, for instance, by Kahan (1994), Kahan and LaBerge (1994), Kahan, LaBerge, Levitan and Zimbardo (1997), and Purcell, Moffit, and Hoffmann (1993). It seems that self-reflection is not a dichotomous variable, that is, either present or absent in dreams, but can be activated to various degrees during dreaming (Purcell et al., 1993). Self-reflection occurs naturally and substantially in dreams, and it seems to be normally distributed. In fact, in a majority of spontaneous dreams, the dreamer is moderately self-reflective (Purcell et al., 1993).

More recently, Kahn and Hobson (2005) divided reflective thinking in dreams into two distinct components. The first component, reflecting on the dream event itself, that is, thinking about the event, is fundamentally deficient, and very different from waking state thinking (Kahn & Hobson, 2005). The dream event is taken for granted, and the dream self does not question whether the event is likely or even possible in the waking realm. The second cognitive component, however, thinking and reflecting within the event, within the dream scenario, is similar to thinking while awake (Kahn & Hobson, 2005). Even though the confabulatory dream event itself is taken as real, the dream self can think, pass judgments, make decisions and guide his or her behavior the way he or she would do while awake. For instance, the dreamer can protect her baby in the dream from dangers in appropriate and reasonable ways, but fail to realize that she does not have a child in waking reality.

2.3.3.7. Bizarreness

Our sleeping brain combines dream elements in a novel, creative, odd, sometimes absurd way that is impossible or highly improbable in the waking realm. These dream oddities are referred to as bizarreness. Hobson, Hoffman, Helfand and Kostner (1987) categorized dream bizarreness into three distinct forms: incongruity, discontinuity and vagueness. Incongruities are inappropriate syntheses of mismatching elements. In other words, incongruity refers to mismatching dream features appearing together, for example, meeting the president of the United States of America in your kitchen.

Discontinuities are interruptions in orientational stability, and comprise the sudden appearance, disappearance or transformation of dream elements. Vagueness or uncertainty are confusions of distinct conceptions and refer to ambiguity of a dream element, for instance, recognizing the dream character as a familiar person but not being able to specify who exactly the person is.

Bizarreness is an essential feature that any theory or explanation of dreaming has to account for. Therefore, a detailed and accurate description of how bizarre dreams really are, which dream features are most vulnerable to bizarreness, and what type of bizarre phenomena dreams include, is called for. The descriptions available thus far, however, seem to be mixed.

A few content analysis studies on bizarreness have been conducted (for example, Revonsuo & Salmivalli, 1995; Revonsuo & Tarkko, 2001; Snyder, 1970; Strauch & Meier, 1996). While Strauch and Meier (1996) report that three quarters of REM dreams include bizarre elements, Snyder (1970) states that most dreams are lacking bizarre qualities. These ambiguities may well follow from conceptual and definitional differences that affect measurements. For instance, how to draw a line between what is bizarre and what is not? What is an adequate baseline for what is considered to be bizarre?

In a detailed content analysis study by Revosuo and Salmivalli (1995), they used as a baseline for what is bizarre in dreams the subject's personal waking reality, and calculated the proportion of bizarreness in relation to the amount of comparable nonbizarre dream elements. They found that most dream elements are non-bizarre, not distorted in any manner. The results also showed that bizarreness is not randomly distributed across different dream contents. For example, the dream self was extremely rarely bizarre whereas dream language and cognition were more often distorted. Distinct types of bizarreness showed a similar pattern of distribution. Incongruity was found to be the most common form of bizarreness, and vagueness the least frequent.

In another content analysis study on bizarreness, Revonsuo and Tarkko (2002) investigated the representation of human dream characters in dreams, excluding the dream self. Of human characters in dreams, approximately half were found to be bizarre. Revonsuo and Tarkko (2002) also coded whether the characters are contextually or internally bizarre, and found that contextual bizarreness is more common than internal bizarreness. They interpreted the results in the context of the binding problem and cognitive neuroscience: the greater the number of modules that need to be engaged in creating a unified phenomenal experience, the more likely bizarreness is because when the number of independent dream elements increases, also the probability of incorrect combinations of the elements increases.

As a person appearing in the correct context requires more modules to be involved than producing a mere internally consistent representation of the person, contextual bizarreness is likely to be more frequent than internal bizarreness.

Bizarreness is, in fact, an intriguing phenomenon from the perspective of consciousness research, as it reveals how the unity of consciousness is disrupted in dreams (Revonsuo, 1999; 2006). If we were to figure out what are the underlying mechanisms in how the brain fails to bind together information during dreaming, we might learn about how the unity of consciousness is created by the waking brain (Revonsuo, 1999; 2006; Revonsuo & Tarkko, 2002). The binding problem is one of the most fundamental problems in consciousness research as well as in cognitive neuroscience, and on this respect, using the dreaming brain as a model system, bizarre dream phenomena might help in revealing the neural constituents of successful binding (Revonsuo, 1999; 2006).

2.3.3.8. Absent dream content

Self-awareness and the ability to reflect on the nature of dream events are flawed during dreaming to varying degrees. Apart from lucid dreams, we usually lack insight, that is, we take for granted the reality of dreams and fail to understand its hallucinatory characteristic. This may be explained by the specific pattern of brain activation during REM sleep: the dorsolateral prefrontal cortex (DLPFC) where neurocognitive mechanisms crucial for reflective consciousness and self-awareness are believed to reside is very active during wakefulness, but deactivated in REM sleep (Braun, Balkin, Wesensten, Carson, Varga, Baldwin, et al., 1997; Maquet, 2000; Maquet, Peters, Aerts, Delfiore, Degueldre, Luxen, et al., 1996; Maquet, Ruby, Schwartz, Laureys, Albouy, Dang-Vu, et al., 2004; Nofzinger, Mintun, Wiseman, Kupfer & Moore, 1997).

There are also some specific dream contents that are almost non-existent or at least very rare. These include such activities as reading, writing, calculating, and using a computer (Hartmann, 2000; Schredl, 2000; Schredl & Hofmann, 2003). The absence of these dream contents seem striking, as they are activities that we engage in daily, sometimes several hours a day.

Thus far, there is no all-exclusive explanation as to why elements so frequent in our waking lives do not enter our dreams. Some theories accept constitutive neural level explanations for the absence or lack of certain elements. The random activation theories (for example, Hobson & McCarley, 1977; Hobson et al., 2000) (to be reviewed in more detail in section 2.4.1.), for instance, seem to accept that as the DLPFC is deactivated in REM sleep, it automatically follows that the tasks normally executed by DLPFC are also absent in dreams. Thus, the absence of higher level cognitive functions such as self-awareness, or reading and writing, is explained by underlying neural activation patterns. However, the constitutive explanation is not a full explanation, because it does not tell us why the DLPFC is deactivated; to account for that we may need an etiological or a contextual explanation. Also psychological function theories (for example, Hartmann, 1996; 1998; reviewed in section 2.4.5.) may accept constitutive level explanations for the absence of specific dream elements.

In contrast, the Threat Simulation Theory (see section 2.4.6.6.) offers an etiological explanation: dreaming is an evolutionarily ancient form of consciousness, and thus, the world simulations in dreams do not reflect, or are not capable of simulating, novel cognitive accomplishments, such as reading and writing. Disabling self-awareness and enhancing emotionality may reflect an ancient form of waking consciousness, and disabling motor activity and reflective consciousness may be necessary in order to run a realistic simulation at all without immediate motor or cognitive interruptions.

2.3.4. The relationship between sleep and dreaming

The currently available functional imaging methods in cognitive neuroscience, for example, single cell recordings, electroencephalography (EEG), magnetoencephalography (MEG), positron emission tomography (PET) and functional magnetic resonance imaging (fMRI), are producing increasingly detailed functional maps of the brain. Nevertheless, these maps seem only to illustrate which parts of the brain are active or inactive during a conscious experience. Thus, even though these methods have revealed which specific areas are somehow involved in particular task involving phenomenal consciousness, they have not explicated how these areas accomplish the task of creating phenomenal consciousness or what these activated areas are, in fact, doing that relates to the specific task.

The neural correlates of sleep, including REM sleep, have been relatively well established, but the neural correlates of dreaming (or the mechanisms of the neural 'dream generator' independent of sleep stages) are less clear. In the very first EEG studies on dreaming in the 1950's, dreaming was identified with REM stage of sleep (Aserinsky & Kleitman, 1953; 1955; Dement, 1955; Dement & Kleitman, 1957). Quite soon, however, the dissociation between sleep stages and dreaming was reliably established (Foulkes, 1962; for a review, see Nielsen, 2000). After that, all attempts to identify the neural correlates of dreaming seem to have failed, although in recent studies (for example, Esposito, Nielsen & Paquette, 2004; Takeuchi, Ogilvie, Murphy & Ferrelli, 2003) appropriate experimental paradigms and new EEG analysis methods have been used. Regardless, no systematic, replicable EEG correlates for dreaming per se (activity of the dream generator) have yet been reliably established.

More recently, fMRI and PET have been used to study brain activation during REM and different stages of NREM sleep. In different subjects and across several studies, a constant pattern of activated or deactivated brain areas during NREM and REM sleep have been observed, and these patterns differ significantly between NREM and REM sleep (Braun et al., 1997; Dang-Vu, Desseilles, Albouy, Darsaud, Gais, Rauchs, et al., 2005; Hamann, Ely, Grafton & Kilts, 1999; Maquet, 2000; Maquet et al., 1996; 2004; Nofzinger et al., 1997). In only one of these studies, however, dreaming was controlled for (Maquet et al., 1996). Based on that, the functions performed by the activated/deactivated brain areas during wakefulness have been suggested to correlate with the major dream content features (Schwartz, Dang-Vu, Ponz, Duhoux & Maquet, 2005; Schwartz & Maquet, 2002). Although the explanation seems intuitively appealing, and the matches between brain maps of REM sleep and dreaming are promising, these correlations may actually tell us very little about the neural constitutive mechanisms of dreaming. Quite the contrary, they may make the puzzle even more demanding to solve, as highlighted in the following.

Even though dreaming is tightly coupled to REM stage of sleep, as the contents of dream consciousness are most vivid and clear in REM sleep dreams, REM sleep should not be confused with dreaming. Dreaming may occur independent of REM sleep, and REM sleep independent of dreaming (for example, Nielsen, 2000). Solms (2000) has established that specific brain lesions can even selectively obliterate dreaming but preserve REM sleep (lesions to parieto-temporo-occipital junction and to ventro-mesial quadrant of frontal lobe), or preserve dreaming but obliterate REM sleep (brainstem lesions).Therefore, the neural mechanisms of the dream generator cannot be identical to the neural mechanisms of REM sleep, and thus brain maps corresponding to REM sleep may not correspond with brain maps of dreaming. Moreover, as dreaming can be present also in NREM sleep, and brain activation as measured by EEG, fMRI, and PET differs significantly between REM and NREM sleep, how can different types of brain activation patterns lead to similar phenomenal contents of consciousness?

Another question is whether dreaming is quantitatively and qualitatively similar in REM and NREM sleep. Dream recall in NREM awakenings is less frequent than in REM awakenings (Nielsen, 2000). Further, NREM dreams are usually significantly shorter than REM dreams, have less continuity between dream elements and are composed of fewer elements (Hobson et al., 2000; Strauch & Meier, 1996). NREM dreams are also more thought-like, while REM dreams include more hallucinatory characteristics (Fosse, Stickgold & Hobson, 2001;

Hobson et al., 2000). Nielsen (2000) suggests that in many studies addressing dreaming in NREM sleep, also simple and static sleep mentation reports have been interpreted as dreaming. He estimates that possibly only one tenth of NREM reports fulfil the criteria for dreaming.

Nevertheless, when dream report length is controlled for, differences in the content of REM and NREM dreams largely disappear (Cavallero & Cicogna, 1993; Cavallero, Foulkes, Hollifield & Terry, 1990; Foulkes & Schmidt, 1983). Similarly, Fosse, Stickgold, and Hobson (2004) found that in successive NREM periods the hallucinatory characteristics of dreams increase while thought-likeness decreases, and on these characteristics the late night NREM dreams bear close resemblance to early night REM dreams. Thus, the debate whether or not REM and NREM dreams are qualitatively different, and thus produced by two separate dream generator mechanisms working independently in REM and NREM sleep, is still ongoing. This issue is, however, too extensive to be reviewed here. (For thorough reviews, see Hobson et al., 2000; Nielsen, 2000).

2.3.5. Summary

Dream research has, at least partially, accomplished the task of identifying and describing the statistically reliably occurring dream contents. In the present thesis, the definition of dreaming as formulated by Snyder (1970) and Revonsuo (2006) has been adopted. Dreaming is defined as multimodal, temporally progressing, complex, and organized contents of phenomenal consciousness during sleep that amount to a world simulation. This definition has been used in Studies I – VI, and thus, simple, static, and unimodal sleep mentation reports have not been investigated.

Although each dream experience is unique, dreams do generally share similar elements and themes. The author of the present thesis accepts that the form of dream experience is organized along the same lines as perceptual waking consciousness (Foulkes, 1985; Foulkes & Cavallero, 1993; Rechtschaffen & Buchignani, 1992; Strauch & Meier, 1996; Zadra et al., 1998), and the coherent dream world functions as a ‘credible multimodal world analog’ (Foulkes, 1985), or ‘a realistic facsimile’ (Snyder, 1970). Thus, I adopt the view that dreams are usually experienced, during dreaming, as real life (Revonsuo, 2000a; 2006). I have also described the relationship between sleep and dreaming to some extent, mainly to illustrate that constitutive level explanations (sleep physiology) cannot alone account as an explanation for dreaming. Etiological level and contextual level explanations need to be involved as well.

2.4. Dreaming as the phenomenon under investigation: explanations for dream phenomena

There are many competing explanations for dreaming in cognitive neuroscience and psychology, such as the random activation theories, the continuity hypothesis, and the psychological, cognitive and neurocognitive theories. In addition, recent interest in evolutionary psychology has given rise to several explanations in the evolutionary context, such as the psychological problem solving and creativity function, costly signaling function, dreaming as play, and the various social simulation hypotheses. Some explanations focus on a single explanatory level, such as on the neural correlates or constituents of dreaming, while others focus on the etiological or the contextual levels. In this section, I will present the strengths and weaknesses of these alternative explanations for dreaming in the light of empirical evidence.

2.4.1. Random activation theories

In random activation theories (RATs)[1], dreaming is seen as a mere side-effect of the neurophysiological processes going on during REM sleep, having no independent function on its own (for example, Antrobus, 2000; Crick & Mitchison, 1983; 1995; Flanagan, 1995; 2000; Hobson, 1988; Hobson & McCarley, 1977; Hobson et al., 2000). These theories include the following central claims; first, the neurophysiological processes operating during REM sleep are seen as functional; second, dreaming is an epiphenomenon, brought about by the random neurophysiological activity in REM sleep; and third, thus dreaming in itself serves no function. Dreaming, as a biological process, is seen as a selectively neutral side effect of "what the brain is doing, the function(s) it is performing during sleep" (Flanagan, 1995, p. 10). The phenomenal dream experience does not have adaptive significance and therefore it was not selected for, but as it has no maladaptive consequences either, it has survived (Antrobus, 1993; Flanagan, 1995).

The RAT's explain the process of dreaming as a result of the random activation of emotional and memory networks. The mechanisms that actively generate the sleep state are located in the brainstem, and the sleep related activation (for example, the activation of REM- on and REM-off cells, ponto-geniculo-occipital (PGO) -waves) leaks over to the emotional and memory networks, resulting in the random activation of these systems. This random activation is then bound into dream narratives by the forebrain, as it is trying to interpret the brain activation as it normally does while awake.

The narrative and meaningful nature of dream experience follows from the forebrain's attempt to make sense of the random activation (Hobson, 1988; Hobson & McCarley, 1977; Hobson et al., 2000), and thus it is argued that random activation

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[1] The term random activation theory is adopted from Revonsuo (2000b).

can lead to organized phenomenal experience. First, as the most recent memory traces encoded into the long term memory are high in saliency, and thus primed in the network, the random activation of the networks leads to the activation of most recent memories. Therefore, day residues and recent events are more often represented in dreams than events long past. Second, the random activation explains high levels of bizarreness in dreams. As memories are randomly activated, the forebrain has difficulties in making sense of the mixed material and weaving together a coherent narrative. In addition, as the dorsolateral prefrontal cortex is deactivated during REM sleep, the forebrain runs into difficulties in binding the randomly activated memories together (Hobson, 1988; Hobson & McCarley, 1977; Hobson et al., 2000). Third, most of the basic human emotions are negative, and as the emotional networks are randomly activated, the stimulation is more likely to lead to the activation of negative than positive memory traces (Flanagan, 2000). Consequently, dream content is emotionally negatively toned.

The random activation theories cannot, however, explain the most prominent features of dreaming. Dream content has a predictable and well-organized form that consists of a realistic visuo-spatial world full of objects, persons and events that interact with each other and the dream self. The production of such an organized conscious experience requires coordinated interaction between several cognitive modules in the brain that are in charge of orientation to three dimensional visuo-spatial environment, emotion processing, motor coordination, as well as perception of, for example, objects, faces, places, and motion. The brain activation studies (Braun et al., 1997; Dang-Vu et al., 2005; Maquet, 1999; 2000; Maquet et al., 1996; 2004; Nofzinger et al., 1997) confirm that multiple brain areas involved in such functions are active during REM sleep.

As Revonsuo (2000b) has pointed out, other forms of random brain activation, for instance, epileptic seizures (Johanson, Revonsuo, Chaplin & Wedlund, 2003; Johanson, Valli, Revonsuo & Wedlund, 2008; Johanson, Valli, Revonsuo, Chaplin & Wedlund, 2008), migraine (Morrison, 1990), and random artificial brain stimulation (Gloor, 1990) do not cause complexly structured, organized and narratively coherent subjective experiences, but result in reports of random phenomenology. Truly random brain activation seems to elicit most of the time no experiences at all, or only a mixture of static images or quickly passing affective states. Why would the brain make sense of random activation patterns during sleep by constructing complex multimodal dream experiences, but not manage to do this during wakefulness? More plausibly, in the case of dreams the brain activation is not random to begin with, but organized, and therefore results in well-structured and organized phenomenology.

The random activation theorists also seem to overemphasize the bizarre nature of dreams, and regard bizarreness as evidence that dreams are disorganized. The high level of bizarreness and disorganization in dreams is, however, taken for granted, and the assumption is not based on empirical evidence acquired through detailed quantitative studies assessing the frequency and nature of bizarre elements. Most dream elements seem to be, in fact, in harmony with comparable waking perceptions, whereas only 20% deviate from or contradict with waking perception (Revonsuo & Salmivalli, 1995). Thus, even though bizarreness is a regular and striking feature of dreams, it is a mild deviation from otherwise well-organized experience. Consequently, RAT's can explain the bizarre nature of dreams as a consequence of random activation, but fail to explain the well-organized and coherent nature of dreaming.

In sum, the random activation theories offer an explanation for how dreams are generated, and how dream content is constructed, that is, an explanation belonging to the constitutive level, and proximate etiological level. However, dreaming and its qualitative features are considered to be spandrels, haphazard by-products of brain activation during REM sleep. Thus, there is no need to evoke any developmental or ultimate level etiological explanations or contextual level explanations regarding why dreams are generated and why dreams have the qualitative features they have.

2.4.2. Continuity hypothesis

The continuity hypothesis (CH) (Domhoff, 2003; Schredl, 2000; Schredl & Hofmann, 2003) states that there is a continuum between waking experiences and experiences within dreams in a way that dreaming reflects waking life experiences, but no specific function for dreaming is assigned. Several studies actually demonstrate that waking events are reflected in dream content. Up to 65% of dream elements can be linked to waking experiences, and isolated spatial or temporal features of memories have been found to occur in approximately one third of dream reports (Fosse, Fosse, Hobson & Stickgold, 2003). However, exact episodic memory replays are present only in about 1% of dream reports. It has also been demonstrated that episodic memories are depicted in dreams most likely on the subsequent night, and again about a week later (the so-called dream lag effect) (Nielsen, Kuiken, Alain, Stenstrom & Powell, 2004; Nielsen & Powell, 1989; Nielsen & Stenstrom, 2005; Powell, Cheung, Nielsen & Cervenka, 1995).

The most general form of CH seems to predict that the frequency and nature of any real events will be correlated with the frequency and nature of similar dream events in subsequent dream content. As CH assumes a direct relationship between waking and dreaming experiences, it runs into difficulties in failing to explain why certain elements frequently present in waking life are mainly absent from dreams, such as reading, writing and using a computer (Hartmann, 2000; Schredl, 2000; Schredl & Hofmann, 2003). The CH cannot explain the negativity bias of dream emotions, either. Negative emotions are more frequent than positive emotions in dreams, but the ratio of positive and negative affect in waking life has been reported to be exactly the opposite (for a review, see Diener & Diener, 1996). Similarly, the continuity hypothesis cannot account for why incorporation of infrequent life events, such as trauma, occurs repetitively (for example, Barrett, 1996; Hartmann, 1984; 1996; Nader, Pynoos, Fairbanks & Frederick, 1990; Pynoos & Nader, 1988; Pynoos et al., 1987; Terr, 1979; 1983; 1990; Wilmer, 1996).

In fact, the specific predictions and hypotheses of CH have not been described in a clear manner. Furthermore, CH does not claim anything about the possible function of the continuity between dreaming and waking, but, as it has been demonstrated that some waking life experiences are incorporated into dream content, rather states the obvious. What is lacking here is the specification for why some autobiographical memory elements are more likely to be incorporated into dream content than others.

To summarize, the continuity hypothesis does not explicate any constitutive level or contextual level explanations for dreaming, but offers a proximate level etiological explanation. Waking experiences are stored into long term memory, and then activated semi-randomly during sleep. By semi-randomly I refer to the fact that CH assumes that the ratio of specific dream experiences is equal to the ratio of comparable waking experiences, although the emotional concerns of the dreamer may to some degree affect the activation of memory traces. This semi-random activation, nevertheless, leads to an organized and coherent dream experience which is not plagued by inherent bizarreness. The CH does not imply that dreaming has any effects on or interacts with other mental or cognitive phenomena (such as memory) or overt behaviour. Thus, the CH cannot be considered including a contextual level explanation for dreaming, as contextual level explanations require a causal relationship between dreaming and other mental or cognitive phenomena so that the organism somehow benefits from this causal interaction.

2.4.3. The cognitive theory of dreaming

Foulkes's (1985; 1999) cognitive theory on dreaming states that dreaming is instigated by random and diffuse memory activation. First, a variety of different memory elements are activated from long term memory in a random or semi-random manner. Second, a specific dream production system organizes the activated memory elements into a comprehensible, coherent dream narrative. The dream production system is composed of subsystems. One system utilizes our knowledge of narratives or scripts, that is, information of typical sequences of events, and arranges memory elements accordingly. Another system, the visuo-spatial component, is in charge of constructing recognizable kinematic mental images.

Foulkes (1985; 1999) acknowledges that during sleep internal brain activation is the primary source of memory activation. Thus, Foulkes's (1985; 1999) model is compatible with the RATs in the sense that dream content is constructed from randomly activated memories. The cognitive theory is also in accordance with the CH in that waking life events (typical sequences of events) are reflected in dreams. Similarly, Foulkes (1985; 1999) does not assign any meaningful function for dream content, although acknowledges that dreams may be meaningful for the person having the dreams. Regardless, dreaming did not evolve to serve any adaptive function, but is rather a reflection of the activation of normal memory and thought processes during sleep.

The cognitive theory of dreaming (Foulkes, 1982; 1985; 1999) implies that children's dreaming is different from adults' dreaming, because it is dependent on memory and thought processes which develop with age. In fact, Foulkes conducted numerous laboratory studies with child participants of varying ages, awakening them from both NREM and REM sleep stages. The conclusions of Foulkes (1982; 1985; 1999) indicate developmental trends in dreaming. First, the younger the children were, the less dreams they could recall and the shorter the dream reports were. Second, as the children matured, the more complex the dreams became. Self-involvement, activity and emotional content became more frequent. At the same time, measures on visuo-spatial performance correlated with dream reporting, and Foulkes suggested (1982) that visuo- spatial skills are utilized in dream construction, and correlate with complexity of dream content. Thus, memory, thought and language processes affect how organized and frequent dream experiences are.

The cognitive theory of dreaming utilizes constitutive level, proximate and developmental etiological level, and contextual level explanations. Although it provides no analysis of the constitutive level mechanisms, it seems to accept the mechanisms proposed in random activation theories. The activation of memory sources leads to cognitive processing, binding the activated memory information together in the sleeping brain. Thus, proximate level etiological explanations are included in the cognitive theory. The cognitive theory also addresses questions such as how dreaming develops during ontogeny, and how dreaming relates to other mental phenomena, offering developmental level etiological explanations and contextual level explanations for dreaming. The only level of explanation missing in Foulkes's (1985; 1999) theory is the ultimate etiological level, that is, the evolutionary causal explanation for why the brain produces dreams. Foulkes (1985; 1999), in fact, claims that such an explanation does not apply to dreaming.

The cognitive theory of dreaming is partially subject to the same criticism as random activation theories. If memory elements are activated in a random or semi-random manner, how does a coherent dream narrative follow? In addition, why are some autobiographical memory elements, such as misfortunes, more frequently selected from long term memory than other types of events? The cognitive theory does not, however, need to be greatly modified to account for selective dream content. A postulation that the memory activation process is not random would suffice.

2.4.4. The neurocognitive model of dreaming

The neurocognitive model presented by Domhoff (2003) is built on the previously reviewed theories on dreaming. The model takes for granted that constitutive level mechanisms, both neural and cognitive, explain how dreaming is constructed. It states that dreaming occurs when specific neural networks, mainly limbic, paralimbic and associative area of the forebrain, are activated in the absence of external stimuli. Apparently this activation is not regarded as random, as Domhoff (2003) accepts that dream content is coherent.

Dream content is constructed from the same memory systems as waking thoughts, and dream elements are continuous with waking experiences (Domhoff, 2003). The neurocognitive model also acknowledges that dreaming is a cognitive achievement that is gradually attained during ontogeny. What the neurocognitive model does not accept is that dreams have any purpose or function beyond being possibly psychologically meaningful to the person having the dreams. Rather, dreaming is seen as a spandrel of two evolutionary adaptations, sleep and consciousness.

The neurocognitive model integrates previous theories, and aims to explain dreaming on constitutive, proximate and developmental etiological, and contextual levels. The neurocognitive model seems to avoid many pitfalls present in previous theories, as it is, in fact, a novel combination of the theories presented by other theorists. What is valuable in the neurocognitive approach is that Domhoff (2003) emphasizes that a theory of dreaming should take into account the detailed information provided by content analysis studies on dreams. Many previous theories have ignored the nature of the phenomenon to be explained.

The downside of the neurocognitive theory, as presented by Domhoff (2003), is that no new, complete theory is actually formulated. Consequently, no specific predictions are outlined, and no new experiments are described to test them. The neurocognitive model is rather a description of where dream research stands at the moment, a demonstration of the shortcomings of previous theories, and a suggestion how a neurocognitive perspective should be incorporated into future theories.

2.4.5. Psychological function theories

2.4.5.1. Dreams as protectors of sleep

Freud's (1900/1965) theory of dreams has been one of the most influential dream theories in psychology, affecting subsequent theory formation and clinical practice. Freud (1900/1965) suggested that dreams relieve the psychological tension that builds up during the preceding day. The function of dreams is to protect sleep by disguising unconscious wishes, often of infantile sexual or aggressive nature, that undisguised would provoke anxiety and awaken the dreamer. Dreams, by offering an outlet for undesired wishes in a veiled form, thus function as a psychological tension release mechanism, and allow the dreamer to continue sleep in the shadow of manifest dream content.

Dreams also function as wish-fulfilment, but the wishes, the latent dream content, need to be disguised for their anxiety provoking effects. This is accomplished by dream work that transforms the undesired wishes to manifest dream content using dream symbols. The latent dream content can then only be accessed by interpreting the symbols of the manifest content, and thereof revealing the true meaning of dreams. Freud (1900/1965) acknowledged that dreams need to be interpreted case by case, but assumed also that perhaps there are universal symbols that remain the same from dream to dream and dreamer to dreamer.

Freud's dream theory has proven to be problematic. First, it includes numerous methodological problems and is empirically untestable. Second, many of the assumptions of his theory have proven to be false, in contradiction with accumulated empirical evidence (for a review, see Domhoff, 2003). Nevertheless, Freud has not been forgotten. Not only is dream interpretation still widely used in the psychoanalytic paradigm, but recently Solms (1997; 2000; 2003), the founder of neuro-psychoanalysis, has defended Freud's theoretical claims.

Solms (1997; 2003) advocates Freud's idea that dreams are protectors of sleep. He presents convincing evidence that dreaming is controlled by dopaminergic forebrain mechanisms (1997; 2000). As the dopaminergic forebrain system is seen as the basis for the appetitive system, involved in goal-seeking behavior and pleasure (for example, as a site of action of stimulants such as amphetamine and cocaine), Solms draws the conclusion that Freud's psychological concept 'libido' corresponds neurobiologically to the brain's seeking system. Because dreaming is controlled by the appetitive 'curiosity-interest-expectancy' system, the activation of this system, inhibited during sleep from leading to motor behavior, can be compared to Freud's idea of wish-fulfilment dreams that protect sleep (Solms, 1997; 2003). There is, however, very little evidence that nondreamers sleep worse than dreamers; that dreams have wish-fulfilment content; or that dreams disguise anything (Domhoff, 2003). Thus, Freud's and Solms' views do not seem to be sound explanations for dreaming.

2.4.5.2. Psychotherapeutic function of dreams

In dream psychology the most popular suggestion at the moment is that dreaming serves a psychotherapeutic function and maintains our psychological well-being by helping us adjust to current life stress and recover after traumatic experiences (Cartwright, 1996; Hartmann, 1995; 1996; 1998). In the psychological theories of the function of dreaming the emphasis is on the individual's psychological adaptation to his current waking life. Dreaming is seen as psychologically functional if it somehow enhances the individual's coping capabilities to his current waking concerns, solves current waking life problems and promotes psychological well-being, even helps to recover from traumatic experiences (for example, Adler, 1927; Hartmann, 1995, 1996, 1998; Jung, 1933; Kramer, 1991; 1993). Thus, an emotional problem-solving function is attributed to dreams. Empirical evidence does indeed show that dream content reflects the current emotional problems of the dreamer (Hartmann, 1998; Kramer, 1993), and the incorporation of waking stressors, in a form of posttraumatic nightmares, is especially strong after exposure to a life-threatening event (for example, Barrett, 1996; Hartmann, 1984; 1996; Nader et al., 1990; Pynoos & Nader, 1988; Pynoos et al., 1987; Terr, 1979; 1983; 1990; Wilmer, 1996).

In psychological theories the findings that we dream of stressful and traumatic real life events have been taken as evidence that dreams fulfil psychological healing functions. The logic behind psychological theories on dream function seems to be the following: Continuity exists between dream content and waking thoughts (for example, Foulkes, 1985; Domhoff, 1996; 2003; Hartmann, 1995; 1996; 1998). Dream production mechanism automatically selects memory traces form long term memory and these memories are then depicted in dream content. The memory traces most recently encoded or activated and the ones with highest emotional saliency are primed in memory networks and become selected for dream production. Consequently, stressful and emotionally occupying memory traces are repeated in dreams. During dreaming, these memory traces are integrated with other material in the memory networks ("making connections in a safe place"; Hartmann, 1995) to make the dreamer better adapted to the experience, and to diminish the saliency of the memory trace. Dreaming thus works as an internal psychotherapist, helping to adjust to current stressors and promoting well-being.

The continuity principle and the repetition dimension (Domhoff, 2003) of dreams are especially evident after exposure to traumatic event (Hartmann, 1995; 1996; 1998). First, the traumatic event is depicted in dreams in a similar fashion as it occurred in reality, as those memory traces are of highest saliency for the dream production system. Gradually the traumatic experience is integrated with other material in the memory networks, and the saliency of the memory trace diminishes. As a consequence of successful integration of traumatic memories, posttraumatic dreams decrease and dream content gradually normalizes. Therefore, dreaming about the trauma aids the recovery process, and is functional. If dreams fail to make any useful or new connections in the memory networks and the integration process is not successful, the saliency of the traumatic memory does not diminish and the healing process does not proceed. Repetitive posttraumatic nightmares may follow. As posttraumatic nightmares disrupt sleep and cause psychological distress in themselves, especially if they continue for a long time after the original trauma (as in Post-Traumatic Stress Disorder, PTSD), posttraumatic nightmares have been interpreted as a failure in dream function (Kramer, 1993).

The psychological healing function theories try to explain dreaming on constitutive, etiological, and contextual levels. The theories assume that dream content is not randomly constructed, but is based on specific activation patterns of most salient memory traces. Although the theories do not explicate how exactly memory activation occurs on a constitutive level, they must assume neural level processes behind dream phenomena, and that specifically the emotional concerns of the dreamer guide memory activation. Similarly, the theories do not explicitly describe how proximate and developmental level etiological processes contribute to dreaming, but trust that the reason why the specific activation patterns have developed lies in the usefulness of dream imagery for the psychological well-being of the individual. Contextual level explanations are included in the psychological benefit theories, as dreaming is tied to psychological well-being and other mental phenomena. What is missing in psychological healing theories is the ultimate level explanation (except for Hartmann, 1996; 1998; see section 2.4.6.2.), and also, more detailed descriptions of constitutive, proximate and developmental causes.

The central logic of psychological healing function theories seems to be misguided, however. This misconception follows from the assumption that dreaming somehow *causes* recovery. In contrast, equally conceivable explanation is that dreaming about the traumatic event only reflects the recovery process and therefore correlates with dreaming content. Second, psychological theories face a dilemma in stating that dreaming about stressful and traumatic events is important in order to cope with them, but that the emotional problem solving function of dreams may fail if the integration process is not successful, leading to recurrent posttraumatic nightmares. To begin with, where can we draw the line between functional and dysfunctional dreaming? Moreover, does not the healing function of dreams fail too often, as any severe enough trauma probably will lead to persisting posttraumatic nightmares in almost any person? Furthermore, even after successful recovery from trauma, posttraumatic nightmares, that is, dysfunctional dreaming may be re-triggered by any stimulus reminding the person about the traumatic event. If the true function of dreams is to promote psychological well-being, why the process has to be labeled dysfunctional so regularly?

In addition, psychological theories face problems in defining testable empirical predictions. The exact predictions derived from these theories have not been put forward in sufficient detail, and consequently empirical scientists are in trouble when trying to prove the psychological theories either true or false. Without precise predictions and hypotheses, one does not know what kind of evidence would be needed to confirm or falsify these theories.

A related problem is that these theories do not differentiate whether it is the process of dreaming (the ability to hallucinate during sleep), or the dream content (what is being hallucinated), that is functional. Thus far, most studies based on the assumption about the emotional problem solving function of dreaming have concentrated on testing whether dream content, that is, dreaming about certain types of occurrences enhances psychological well-being. Consequently, testable hypotheses should be formulated about what kind of dream content is functional and aids adjustment to current life stressors. Nonetheless, studies on dream content can only tell us about the functionality of dream content, not about the functionality of the capacity to dream. The functionality of the capacity to dream can only be established in studies comparing people who are unable to dream or at least very poor recallers (indicating low frequency of dreaming) vs. frequent dreamers to test whether frequent dreamers are better adjusted to comparable life situations, regardless of their dream content.

Regardless of the theoretical problems discussed above, some studies have been conducted on the emotional problem solving capacity of dreams. Thus far, the results on the possible mental health functions of dreaming are unclear about whether frequent dreaming or dreaming about certain types of occurrences reduces the negative psychological consequences induced by real life concerns and traumas. Cartwright (1996) studied the dreams of depressed and nondepressed women undergoing a divorce, and found that the depressed women's dream content was emotionally more negative, and that the depressed group was more likely to incorporate their spouse as a character in dreams. In a follow-up study a year later, those depressed women who had dreamt about their spouse were better adjusted to the divorce situation than those whose dreams did not incorporate the spouse (Cartwright, 1996). This study does not, however, offer a causal explanation for the possible mental health effect of dreaming about the spouse, only a correlation.

Punamäki (1997) has studied the role of dreaming in protecting mental health in a sample of Palestinian children. The sample was the same as in Study V of the present thesis. Generally, traumatized children recalled more dreams than nontraumatized children, and their dreams were less bizarre and included more emotionally negative themes. Both frequent and infrequent dream recall was associated with psychological symptoms: high recall was related to depressive symptoms while low recall to somatic and anxiety symptoms (Punamäki, 1997). Furthermore, exposure to traumatic events was more important factor in predicting psychological symptoms than dream recall frequency. In sum, the study did not allow any conclusion about whether frequent dreaming (as measured by dream recall) would serve a positive mental health function in the recovery from trauma. It did, however, reveal that trauma leads to increased dream recall, and to more realistic and negatively toned dream content.

In a more recent study, Punamäki, Ali, Ismail and Nuutinen (2005) explored the mental health function of dreaming in a sample of severely traumatized and less traumatized Kurdish children (the same sample as in Study IV of the present thesis). The less traumatized children had more pleasant dreams, and these appeared to have a possible protective mental health function, as less severe psychopathology was associated with pleasant atmosphere, complete narrative and happy endings in dreams. In contrast, the severely traumatized children's dreams were characterized by unpleasant atmosphere, lack of bizarreness, low narrative quality and vividness. These children also reported more nightmares. Poorer mental health adjustment to the traumatic events was associated with dreams including mundane death themes, realistic horror scenes, active participation by the dreamer and unhappy endings (Punamäki et al., 2005). Consequently, dreaming after traumatic experience (mostly consisting of negative and unpleasant themes) did not seem to improve the psychological well-being of the children, quite the contrary.

Altogether, the suggestion that working through traumatic material in dreams is beneficial for mental health seems to be misleading. Rather, after acute trauma pleasant and consoling dreams would be needed to diminish psychological distress. As posttraumatic dreams rarely offer such pleasant themes, while displaying repetitive and realistic simulations of the original life threatening and terrifying events, the theories about of the protective mental heath function of dreams appear unsupported by empirical evidence derived from systematic dream content studies.

Furthermore, the view that dreams help us adapt to real-life problems and traumas seems to include the misguided biological assumption that life should be free of pain and psychological suffering. Quite the contrary, these responses (for instance, fear, anxiety, distress, posttraumatic nightmares) can be seen as biologically adaptive responses to dangerous events in the environment that guide us to avoid such events in the future. Any theory attributing a function for dreaming should thus be able to account for all forms of dreaming, including posttraumatic nightmares.

2.4.6. The evolutionary function of dreams

The theories put forth to explain the form, content, and function of dreaming from an evolutionary biological or psychological perspective all involve an ultimate etiological or backward-looking dimension of explanation for dreaming. Different evolutionary theories include constitutive and contextual level explanations, as well as proximate and developmental level explanations, to varying degrees. This section deals exclusively with the various evolutionary theories that have been suggested for the function of dreaming. Majority of these theories have also been reviewed in Valli and Revonsuo (2007).

2.4.6.1. The sentinel function

Perhaps the first theory to explicitly present an evolutionary biological approach to sleep and dreaming was presented already in the 1960's (Snyder, 1966). Snyder (1966) had noticed that REM sleep is unique only for mammals, and suggested that REM sleep provided early mammals with a selective advantage over the reptiles that dominated the planet when mammals evolved. While long periods of sleep allowed early mammals to minimize metabolic requirements, it also rendered them vulnerable to predators. The selective advantage of REM sleep was to guard the safety of the sleeping animal.

Snyder's (1966) theory is based on the findings that the REM stage of sleep is energetically costly, and that natural selection does not retain costly characteristics unless they provide advantages. REM sleep increases the activity level of the brain and prepares the animal for a brief awakening that takes place after each REM period. If during the awakening danger is detected, the activity level of the brain is already high, and the animal is prepared for immediate fight or flight. Snyder (1966) called this the sentinel function of REM sleep.

The sentinel theory as such does not state anything about dreaming, but Snyder (1966) also proposed that non-human mammals dream during REM sleep. The nature of their dream imagery is modulated by the latest estimate of expected danger at the time of waking up. If the available evidence from the environment predicts approaching danger, the dream will prepare the animal for fight or flight. If no dangers are in sight, then the dreams will preserve continuity of sleep with pleasant dreams. Thus, the evolutionary function of dream content is to be predictive of and preparatory for the situation where the animal finds itself immediately after the currently ongoing REM dream.

The sentinel function theory includes constitutive, proximate and ultimate etiological, and contextual level explanations, but not developmental level etiological explanations. REM sleep physiology is seen as the neural correlate or constituent of dreaming, which is affected by the environmental cues surrounding the sleeping animal. The sentinel theory also places dreaming in the context of fight-or-flight –behavior, that is, explains how constitutive level neural mechanisms affect behavior (contextual level) through phenomenal consciousness. Finally, the sentinel theory assigns an adaptive function for dreaming, an explanation of why dreaming was beneficial for early mammals.

Just because Snyder's (1966) sentinel function theory places the function of dreaming to the context of REM sleep evolution, it makes the theory difficult to test, as we know nothing of what ancient mammals dreamed about, not even whether they dreamed at all. This, of course, applies to modern mammalian species as well. What we do know from human studies is that external stimuli, such as sounds, smells, or tactile experiences are detected by the sleeping brain as activity in specific sensory cortices increases when stimuli are presented. However, these stimuli are not easily incorporated into dream content (Farthing, 1992). Thus, if incorporation is infrequent, how would the animal brain be able to predict approaching danger from external environmental cues?

2.4.6.2. The psychological problem solving and creativity function

Hartmann, who has suggested a psychological healing function for dreams, has also proposed that the capacity of dreaming to form new connections within the neural networks of the brain might have served two functions useful for our ancestors (1996; 1998). Hartmann's first evolutionary argument concerns the idea that dreaming, as a process making new connections, has a kind of psychotherapeutic function, especially in handling traumatic experiences:

> *"....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 and the resolving of trauma a constant necessity...."* *(Hartmann, 1996, p. 158)*

Hartmann's second evolutionary proposal is that the making of broader and wider associations during dreaming might have helped in bringing material together in new ways and this would have been beneficial to our ancestors in their waking lives (1998). Dreams might have provided new innovations in exploiting resources and solving problems related to everyday life. This particular argument emphasizes the creative and problem solving nature of dreams.

> *"….the functions of dreaming… may have been especially important for us at earlier times in our species' development…Only our dreams gave us a chance to do this – to make broader and wider connections…. and also to bring material together in new ways that occasionally might have been useful to us in our waking lives."*
>
> *(Hartmann, 1998, p. 209)*

In sum, Hartmann suggests, at least indirectly, that the evolutionary origin of the function(s) of dreaming is in the ancestral environment where life was dangerous, trauma resolution was required on a daily basis, and creative new ideas could have provided valuable selective advantage. Individuals who were able to regain emotional balance and well-being after trauma were better off than those who did not, and therefore the psychotherapeutic function of dreaming was selected for and became a universal feature of the human mind. Similarly, individuals with creative problem solving dreams were better adapted to their environment and consequently left more offspring than individuals not having extra help from their dreams.

The psychological adaptation and creativity function assigned for dreaming carries all the same strengths as psychological function theories presented in section 2.4.5. Moreover, the ultimate level etiological explanations offered by Hartmann (1996; 1998) give an account, in fact two accounts, for why dreaming might have evolved and been selected for. In traditional psychology, the term *adaptive* is used in a sense referring to the capability of the individual to psychologically adjust to current life situations. In contrast, in evolutionary psychology the term adaptive refers to whether the design enhances fitness in interaction with current environment, and the term adaptation to whether the design was adaptive in the ancestral environment and thus selected for. Hartmann (1996, 1998) seems to be thus far the only advocate of psychological dream function theories who implies, although indirectly, that the emotional problem solving function of dreams might have also fulfilled biological functions in the ancestral environment, and would therefore be an adaptation.

Nevertheless, the same problems that plague psychological dream function theories apply also to psychological adaptation theory. Dreaming does not seem to be adaptive in the sense that it would maintain psychological well-being, or aid in recovery after experiencing traumatic events. Neither does dreaming seem to be equipped to provide us new insightful solutions to everyday problems (Blagrove, 1992).

2.4.6.3. Costly signaling theory

McNamara (2004) has put forth a distinct evolutionary hypothesis about the function of dreaming, the costly signaling theory (CST). The CST builds on the concept of costly signaling which first emerged in the context of sexual selection theory presented by Trivers (1972). Sexual selection theory suggests that some traits have evolved because they signal the fitness of the bearer to members of the opposite sex. The more resources the organism has to allocate for the production of a particular trait, that is, the higher the costs of producing that trait, the more honest is the advertisement of "having good genes". When members of the opposite sex can enhance their own fitness by selecting mates who possess good genes, they will favor individuals displaying costly, and thus honest and hard to fake -signals.

McNamara's (2004) hypothesis of the function of REM sleep and dreaming is grounded on the fact that REM sleep involves high metabolic costs for the organism. The costs result from such physiological changes taking place during REM as high levels of brain activation (especially in limbic and amygdaloid areas involved in emotional information processing), increases in cardiac and respiratory rates, paralysis of skeletal muscles, rapid eye movements and limb twitches, thermoregulatory lapses, changes in growth hormone release and penile erections. Furthermore, during REM sleep, the most vivid and emotionally salient, often unpleasant dreams, are experienced. McNamara argues that these features are not just side-effects of other REM functions, but REM sleep was particularly selected for these properties as they are costly traits and offer fitness benefits that justify the costs.

According to McNamara (2004), REM features influence dream content and affect the mood states and emotional displays of the individual during following wake periods, regardless of whether specific dream content is remembered or not. The individual is, in fact, emotionally "handicapped" by his dreams the subsequent day, especially when dream content has been negative or unpleasant. The emotional burden is the greatest after having a highly memorable negative dream that has already placed the dreamer into an emotionally awkward position, such as finding one self naked in public or being chased or attacked.

As dream content affects subsequent emotional tone and thereof behavioral displays, the emotional signals emitted by the individual during wakefulness are honest and hard to fake. The emotional signals, in turn, affect how the individual engages in communicative interchanges and social interactions. If the individual is able to display appropriate and functional behavior despite of the emotional burden that is carried into waking realm, that is, exhibit behaviors that act as fitness cues, he or she is more likely to be favored by other group members, for example, selected as a mate or preferred over others in cooperative alliances.

In sum, McNamara (2004) suggests that costly REM features affect dream content, and, through producing hard to fake emotional signals, increase fitness by facilitating cooperative social interactions or courtship displays. Thus, if REM sleep and dreams are the primary source for the production of costly emotional signals that are difficult to fake, then REM sleep and dreaming are essential for all human communication and social behavior. The costly signaling theory therefore offers constitutive level (REM sleep), etiological level (fitness benefit), and contextual level (behaviour) explanations for dreaming, although it does not explicate any developmental level explanation.

The problem is that the CST does not specify how exactly behavior is affected by REM sleep and dreaming. What is needed here is the definition of what the external behavioral cues are, supposedly modulated by preceding REM sleep and dreaming, that the other group members can monitor and evaluate. Unlike typical costly features that play a role in mate selection (for example, the peacock's tail), the costly features of REM sleep and dreaming might not be as such directly observable. Nevertheless, some directly observable characteristics must be highly and reliably correlated with REM sleep and dreaming so that by preferring the observable features, the costly features of REM sleep and dreaming would consequently be selected for, albeit indirectly. Furthermore, we should be able to verify that other group members actually find these behavioral cues desirable and that the cues affect favorably the selection of the individual as a mate or cooperative party.

2.4.6.4. Dreaming as play

A common theme in most of the evolutionary psychological theories is that dreaming is regarded as an off-line simulation of the sensory-perceptual, motor, and social space that we experience during wakefulness. Dreams have been regarded similar to play behavior (Bulkeley, 2004; Cheyne, 2000; Humphrey, 2000; Peterson & DeYoung, 2000), and there are indeed several similarities between dreams and play, but also a number of dissimilarities (for a review, see McNamara, 2004). Both are limited (in their clearest forms) to mammals only. Both can simulate reality and rehearse real situations and interactions in a safe context. Both may exaggerate, transform, and display an enormous variation of behaviors that are originally related to other contexts outside play. Both are energetically costly, biologically programmed behaviors that should therefore be in some way useful. In sum, the view that dreaming equals to play rehearsal include ultimate etiological, as well as contextual, level explanations, but do not address constitutive or proximate or developmental level explanations.

Although there are several similarities between dreams and play, (Bulkeley, 2004; Cheyne, 2000; Humphrey, 2000; Peterson & DeYoung, 2000), the problem arises that the adaptive functions of play are not entirely clear (Spinka, Newberry & Bekoff, 2001). Thus, it is not possible to explain the functions of dreaming by saying that they are similar to the functions of play behavior. Most likely play may have multiple functions, such as rehearsal of hunting behavior, aggressive encounters or predator avoidance. Thus, playing and dreaming might have complementary functions in the rehearsal of behaviors: dreaming is perceptually more realistic than play, whereas play is motorically more realistic, involving actual execution of motor programs, muscular movements, and physical exhaustion.

2.4.6.5. Dreaming as social simulation

A recent popular evolutionary psychological view is that dreaming simulates human social interactions with other people and rehearses social perception and social skills. Recently, several slightly different versions of the 'Social simulation hypothesis' have been proposed. Brereton's (2000) 'Social mapping hypothesis' suggests that dreaming allows simulation of self, location, and awareness of others, including awareness of their internal mental states. Dreaming is thus suggested to have rehearsed the perceptual and emotional features required by successful social mapping in human evolutionary history, eventually leading to the emergence of self-awareness. This view offers an ultimate etiological level and contextual level explanations for dreaming, but dismisses questions regarding constitutive, and proximate and developmental level etiological questions.

Humphrey (2000), and Nielsen and Germain (2000) have proposed that as many of the selection pressures faced by ancestral humans were posed by complex human social life, modeling human relationships and interpersonal bonds (for instance, family politics, attachment, love affairs, status battles) might have had adaptive value. Strong family and group cohesion would have enabled organized defences against predators and other enemies and enhanced survival and health of group members. Also McNamara (2004) acknowledges that interacting with other members of the group was an important selection pressure in the ancestral environment, and that simulation of skills such as how to find a mate, build coalitions, and avoid conflict would have been useful. Franklin and Zyphur's (2005) argument is organized along the same lines; they see that via dreaming it is possible to practice dealing with complex social situations, because those most adept in their social environment were likely to have the best access to resources in their social group, such as mates. These social simulation views include, as the social mapping hypothesis, ultimate etiological level and contextual level explanations for dreaming, but lack constitutive, and proximate and developmental level etiological questions.

David Kahn and Allan Hobson (2005) emphasize that awareness of what others are thinking and feeling is a robust aspect of human consciousness, and this aspect is maintained during dreaming despite the changes in chemistry and activation patterns of the brain during sleep. Thus, even though they do not explicitly express it, they imply that awareness of the minds of others ("Theory of Mind") during dreaming might have contributed to the ability to anticipate the intentions of others while awake. Kahn and Hobson (2005) thus offer ultimate etiological and contextual level explanations, as well as account for constitutive explanations (REM physiology as explicated in random activation theories). However, they do not discuss any proximate and developmental level explanations.

Although several slightly different versions of the 'Social simulation hypothesis' have been proposed, none of them has been subjected to detailed evolutionary psychological cost-benefit analysis. The social simulation hypothesis is, however, to some extent compatible with what we know about the form and content of dreams. About half of the human characters in our dreams are persons familiar to us, and appearance, behavior exhibited by the character, and feelings evoked by the character in the dreamer are regularly used in the identification of the person (Kahn, Stickgold, Pace-Schott & Hobson, 2000). More than 80% of known dream characters evoke some kind of emotional response in the dreamer, most often affection or joy (Kahn, Pace-Schott & Hobson, 2002). A significant amount of time in dreams is spent wondering what other dream characters are thinking or planning (Kahn & Hobson, 2005). Thus, our dreams often represent human characters and give plenty of space for opportunities to practice social interactions.

Even though the social simulation hypothesis is consistent with the fact that other people and multiple social interactions are frequently present in our dreams, the hypothesis has some problems as an evolutionary psychological account of the function of dreaming. First, we get a lot of practice in (non-threatening) social interactions during our waking lives, and this practice during waking hours does not yield high costs to us. Thus, it remains unclear why it would be advantageous to practice or simulate something like that further in our dreams. Furthermore, there is a lack of studies on the detailed nature of the social interactions in dreams, and the ones conducted reveal the often aggressive nature of social encounters (Domhoff, 1996; Hall & Van de Castle, 1966). Aggression is a more common type of social interaction than friendliness, while sexual interactions are relatively rare in dreams. Thus, we get less practice in forming positive social bonds, such as making friends and allies, than in dealing with negatively toned social interactions. Even less time in dreams is devoted to mate selection and practicing how to form romantic relationships. Do we, in fact, interact with other dream characters in reasonable ways that might be considered useful simulations of or rehearsals for real life social interactions? To back up an evolutionary hypothesis, a detailed description of the type of dream content and the conditions under which it occurs is required, as well as a cost-benefit analysis that should show why the dream simulation is likely to be useful for us (or was likely to be useful for our ancestors). It remains open whether the social simulation hypothesis will receive support from the more detailed analyses of dream interactions and cost-benefit considerations.

2.4.6.6. Dreaming as threat simulation

The Threat Simulation Theory presents yet another evolutionary function for dreaming (TST) (Revonsuo, 2000a). As the TST is specifically tested in the present thesis, it is reviewed more thoroughly than the theories summarized previously. The main predictions derived from the TST are also outlined.

The TST suggest that dream consciousness evolved as an off-line model of the world that is specialized in the simulation of various threatening events encountered in the human ancestral environment. In human EEA (Environment of Evolutionary Adaptedness; Tooby & Cosmides, 1992), a threat simulation system that selected memory traces representing life threatening experiences from long term memory, and constructed frequent threat simulations based on them, could have provided our ancestors with a selective advantage in practising threat recognition and avoidance skills. During dreaming, threat coping skills could have been maintained and rehearsed without the risks of hazardous consequences that accompany threats in real situations. This kind of a mechanism would have provided our ancestors an additional survival and reproductive advantage. Due to its beneficial effects in enhancing survival and reproductive success, the threat simulation mechanism was selected for, thus propagating its own existence in the ancestral environment.

The TST was originally presented in a form of six propositions, each of them leading to several empirically testable predictions (Revonsuo, 2000a). Consequently, the central claims of the theory are open for supportive or falsifying evidence. Most of the TST's predictions can be tested with the currently available methods in dream research, while some belong more to the scope of cognitive neuroscience and neurophysiology. Next, the six original propositions of the theory as well as its main predictions will be briefly presented.

The first proposition of the TST is that dream consciousness is an organized and selective simulation of the perceptual world (Revonsuo, 2000a). To begin with, the TST accepts, based on current empirical evidence, that the form of dream experience is organized along the same lines as perceptual waking consciousness that is experienced, during dreaming, as real life (Revonsuo, 2000a; 2006). Consequently, the TST claims that the well-organized dream experience is functionally constructed to resemble waking experiences, and therefore shows clear design features for a world simulation function.

Second, the TST claims that dream consciousness is specialized in the simulation of threatening events (Revonsuo, 2000a). Thus, the TST directly predicts that, in order for nocturnal threat rehearsal to be efficient, threatening events should occur in dreams more frequently than in waking life, and that the content of dream threats should reflect the original function of dream consciousness as a threat simulator. Therefore, threatening events in dreams should focus on simulating dangerous events critical for the future survival of the individual, and the threats should mainly endanger the well-being of the dream self and persons significant for the self (close kin and allies). The threats should be relatively realistic portrayals of real threatening events, not based on fantasy, fiction or folk-lore. The dream self should be able to participate in the course of the threatening events, and defend itself with appropriate and reasonable actions that would be relevant in a comparable waking situation.

Third, the TST states that only real threatening events can fully activate the threat simulation system (Revonsuo, 2000a). Encounters with real threats in the environment are stored into “hot” emotional memory, and when asleep, the dream production system automatically selects those memory traces with the highest saliency for dream construction. Consequently, memory representations encoding for fearful and threatening events, containing the highest negative emotional charge, should be selected over and over again for simulation. Thus, real life threat experiences trigger on the threat simulation system by offering raw materials to it. Moreover, the activation of the threat simulation system after exposure to life-threatening trauma should be a universal phenomenon, not dependent on any specific culture, and the intensity of the simulations (frequency and persistence) should be directly related to the degree of personal threat experienced when the event was encountered in reality.

The fourth proposition of the TST states that threat simulations are perceptually and behaviorally realistic rehearsals of real threatening events (Revonsuo, 2000a). While dreaming, the off-line world simulation seems perfectly real to us, and we are unaware that what we currently experience is nothing but a hallucination (except very rarely in so-called lucid dreams). The TST assumes that, in general, covert actions are actual actions relying on the same brain regions, except for the fact that they are not executed. In other words, the sleeping brain is capable of simulating the planning and execution of motor commands, but muscular atonia during REM sleep prevents us from carrying out the planned behaviors. If the muscular atonia during REM sleep is removed, we should observe that the body of the dreamer carries out isomorphic behaviors at the same time when they happen in the dream.

Fifth, the TST claims that perceptually and behaviorally realistic simulation and rehearsal of any skills (in this case threat recognition, avoidance, and coping skills) should lead to enhanced performance, regardless of whether the training episodes are explicitly remembered (Revonsuo, 2000a). This assumption is based on evidence that simulation training and mental training have been shown to lead to enhanced performance, that is, implicit procedural learning occurs when behaviors are repeatedly practiced in non-real situations. Furthermore, learning occurs also in amnesics, showing that performance enhancement can be attained without conscious access to memory of training episodes (Glisky, 1992; Glisky & Schacter, 1988; 1989; Glisky, Schacter & Tulving, 1986; Schacter, 1996).

Finally, the sixth proposition of the TST states that the original human evolutionary environment included frequent dangerous events which imposed severe selection pressures upon ancestral populations, and that the ecologically valid threat cues in the environment fully activated the threat simulation system (Revonsuo, 2000a). Thus, we can predict that children old enough to implement threat recognition and avoidance skills during wakefulness should be capable of simulating threatening events in their dreams, especially when exposed to real valid threat cues. Moreover, ontogenetically early exposure to real threat cues should lead to earlier, more frequent and more intensive threat simulation dreams whereas lack of exposure should lead to slower development of the dream production system and less frequent and milder threat simulation dreams.

3. THE PRESENT THESIS

According to Revonsuo (2000b), to study the biological function of dreams we are required to make a systematic, detailed analysis of the content of dreams across a wide range of large data samples. This includes the "normal" population, cross-cultural samples, and various special populations, especially hunter-gatherers, children, frequent nightmare sufferers, and traumatized people. If in this analysis some dream content characteristics tend to pop out here and there, again and again, those features probably are traces of the original biological function of dreams. Thus, the present thesis included many different participant populations.

In order to test any evolutionary psychological theory in any dream sample, the first requirement is the specification of predictions that are explicated in or implied by the theory. Therefore, the predictions of the TST were explicated in the previous section. The second requisition is a clear definition of the phenomenon under investigation, for example, what types of descriptions in dream reports constitute a social interaction or a threatening event. Then, a theoretically motivated content analysis scale that reliably captures and partitions the specific phenomenon under study needs to be devised. In order to test the TST, a detailed content analysis scale for identifying and classifying threatening events was constructed for the studies included in the present thesis.

3.1. The aims of the present thesis

The main aims of the present thesis were to study the biological function of dreaming as outlined in the Threat simulation theory (Revonsuo, 2000a), with the guidelines listed above. If TST's predictions hold in this type of systematic analysis, the theory receives support, whereas contradictory evidence will weaken or even falsify the theory. Thus, the specific goals were the following:

1) To define exact criteria for what is a 'threatening event' in dreams

2) To develop a detailed and reliable content analysis scale and theoretical categories with which it is possible to empirically explore and quantify threatening events in dreams

3) To empirically test some of the predictions derived from TST, using systematic, detailed analysis of the content of dreams in varying participant samples. The specific questions and hypotheses investigated were:

a. How frequent are threatening events in dreams: The TST predicts that threatening events should be more frequent in dreams than in the waking life

b. What kind of qualities do threatening events in dreams have: The TST predicts that the threatening events should be severe, realistic, targeted against the dream self and significant others, and include simulations of relevant and appropriate defensive actions

c. How do threatening events present in dreams relate to the most recently encoded or the most salient memory traces of threatening events experienced in waking life: The TST predicts that dream content is modulated by the activation of long term memory traces with highest negative saliency, that is, dream simulations are based on memories of events representing the most severe threats ever encountered

d. What are the effects of severe waking life threatening events, trauma, on dream threats: The TST predicts that real threat experiences uniquely activate the threat simulation system, leading to more frequent and more severe threat simulation dreams

4. METHODS

4.1. Participants

For Studies I-III, altogether 141 healthy young Finnish and Swedish university students were recruited (Table 1). In Study IV, the participants were 117 severely or less traumatized Kurdish children, and 70 nontraumatized Finnish children (Table 1.). The participants in Study V were 356 traumatized or nontraumatized Palestinian children (Table 1).

Table 1. Description of Studies I-V

	University student samples			Traumatized and nontraumatized children	
Study	Study I Revonsuo & Valli (2000)	Study II Valli, Lenasdotter, et al. (2007)	Study III Valli, Strandholm, et al. (2008)	Study IV Valli et al. (2005) T/C/F *	Study V Valli et al. (2006) T/C *
Data collection method	Dream diary (4 wks)	Dream diary (2-4 wks)	Dream diary (2 wks)	Dream diary (7 days)	Dream diary (7 days)
Participants	Finnish university students	Swedish university students	Finnish university students	Severely/less traumatized Kurdish & nontraumatized Finnish children	Traumatized & nontraumatized Palestinian children
Number of subjects	52	50	39	187 (64/53/70)	356 (235/121)
Mean age of subjects (yrs)	23.3	26.8	24.1	12.9/12.8/9.5	10.8/11.3
Number of dream reports	592	248	419	763 (331/216/216)	1348 (986/362)
Mean number of dream reports per subject	11.4	5.0	10.7	5.2/4.1/3.1	4.2/3.0
Mean number of dream reports per subject/ week	2.9	2.5	5.3	5.2/4.1/3.1	4.2/3.0
Mean length of dream reports (words)	141.5	261.6	144.5	54.5/29.2/24.7	41.5/31.6

* T = Trauma group; C = Control group; F = Finnish children

4.2. Procedure and data analysis

All participants wrote home-based dream diaries for one week (children) or two to four weeks (adults), according to detailed instructions. In Study III, the participants also kept logs of daily events during the diary period, and were later interviewed about specific threatening life-events. The dream diaries, and in Study III also daily logs and interview transcripts, were then typed, and in the case of Kurdish and Palestinian children, translated into English.

4.2.1. The Dream Threat Scale

For data analysis, a definition of a 'threatening event' was first developed, and then, a detailed content analysis scale that can be reliably used to distinguish threatening events in dreams from other events, and to classify the threatening events according to their specific qualities, was devised. The definition of a threatening event and the categories in the classification system were thoroughly tested in several pilot studies, and modified until they seemed to grasp all relevant threatening events and allow the coding of all the relevant aspects of the threatening events. As a reliability criterion, the interrater agreement levels for identification and classification of threats were constantly monitored in various pilot studies. Those items, that is, parts or categories of the scale, that showed low interrater agreement levels were either omitted from the classification system or revised until sufficient agreement levels were reached. The final version of the scale was named the Dream Threat Scale (DTS), and is presented in Table 2.

The threat criteria adopted in the DTS distinguishes between objective and subjective threats. Objective threats are events in a dream where the physical or mental well-being of any person would be endangered or where any person's physical resources or territory would be jeopardized. Subjective threats, on the other hand, were defined as events experienced or emotionally interpreted by the dreamer to be threatening in the absence of an objective threat. Originally, the aim in distinguishing between objective and subjective was the quantification and comparison of their frequency and quality. It could be argued that subjective threats may be rehearsal for a state of heightened threat detection and vigilance in an environment where there are subtle threat cues but no direct evidence of an upcoming threat. For example, walking alone in a dark alley and being scared of possible attackers or pursuers would be scored as a subjective threat.

All types of harmful events were included into DTS (see category I, Table 2.), also failures and minor mishaps, for important theoretical reasons. In the light of the TST, the overall quantity and quality of threatening content in dreams directly reflects the activation level of the threat simulation mechanism, and

Table 2. The Dream Threat Scale

Threat identification criteria
Objective threat: An event in a dream where, if the event was real, the physical or mental well-being of any person would be endangered or where any person's physical resources or territory would be jeopardized (i.e., any event that would be considered threatening if it should really occur in the waking life). Such an event may be directly witnessed by the dreamer reporting the event or only indirectly heard about in the dream.
Subjective threat: An event in a dream that is interpreted or emotionally experienced by the dreamer (i.e., the dream self) to be somehow dangerous. Any event in which the subject reports the feeling of danger or threat even if no objective threat (as defined above) is reported to accompany this feeling.

Name of the category	I The Nature of the Threatening Event	II The Target of the Threat	III The Severity of the Threatening Event for the Self	IV Participation of the Self in the Threatening Event	V Reaction of the Self to the Threatening Event	VI Resolution of the Threatening Event	VII Consequences of the Threatening Event to Self	VIII The Source of the Threatening Event
Aim of the category	What kind of a threatening event is in question?	Who or what is being threatened? (may receive several scores)	How risky for the self would the threatening event be if it happened in real life?	Does the dream self participate in the course of events?	How does the dream self react to the threatening event?	What is the situation at the end of the dream?	What kind of losses does the dream self suffer in consequence?	What is the likely source of information for the threatening events?
Content of the category	1. Escapes and pursuits 2. Accidents and misfortunes 3. Failures 4. Catastrophes 5. Disease 6. Aggression	1. Self 2. Persons significant for the self 3. Resources significant for the self 4. People and resources not significant for the self	1. Life-threatening event 2. Socially, psychologically or financially severe threat (3. Physically dangerous event*) 4. Minor event	1. The dream self is active 2. The dream self does not or cannot actively participate in the threat	1. Possible & reasonable action 2. Physically impossible but efficient action in the dream 3. Physically possible but irrelevant action 4. No reaction, reaction not possible or not reported	1. Happy End: threat is resolved 2. Unhappy End: threat is realized 3. Discontinuity: resolution remains unclear 4. The dream ends: resolution not reported	1. No losses or damage to self 2. Minor losses or damage to self 3. Severe losses to self 4. Consequen-ces not adequately reported	1. Personal life: realistic threat 2. Media: realistic but unlikely threat 3. Fiction- or fantasy-based threat 4. Source of threat cannot be classified

Note 1: Modified from Revonsuo & Valli (2000)
*Modification of Severity-scale, an additional category, used in many successive studies.

this falls somewhere in a continuum from very low to extremely high. Thus, by using a broad definition of threat, it is possible to capture all the different levels of activation of the system, from low levels (where simulated threats tend to be infrequent and mild) to high (where simulated threats tend to be frequent and severe). This, in turn, allows the testing of hypotheses directly derived from the theory, if only they can be formulated in terms of differences in the activation level of the threat simulation system. For example, it is possible to compare the dream content of different populations, or the effect of different stimulus environments, or the content of daytime experiences and dreams, as to the quantity and quality of overall threat content.

Thus, the broad definition of threat is essential for the testability of the TST in populations where the threat simulation system is not expected to be fully activated. A full activation of the threat simulation system (very frequent, very realistic, and very severe dream threats) can be expected only in an ideal model population where people have been exposed to frequent ecologically valid ancestral threats throughout their lives (Revonsuo, 2000a). In such a population, the threat simulation system is both fully developed and fully activated by the appropriate input (as it is an induced biological defence mechanism), and the predictions of the theory should be fulfilled nearly perfectly. As it cannot be expected that the threat simulation system is in this kind of state in any of the actual populations we are able to study, the more subtle differences in the activation levels of the system would be missed if confining to a narrow definition of threat - that would allow us to see only the tip of the iceberg.

In the DTS, threats merely witnessed by the dreamer, that is, threats directed at other characters were also included (category II, Table 2.). The logic behind this is that threats directed at other dream characters can directly influence the future survival or reproductive success of the dreamer, in the case the threat is directed at significant others (inclusive fitness). For example, young mothers often dream of their newborn child being in danger, instead of themselves (Hartmann, 1998). And young children, especially those who have lost a parent in violent conditions, dream of dangers directed at their parents (Punamäki, 1997). In both of these cases, the future reproductive success or survival of the individual is severely endangered, and would have been also in the ancestral environment. Thus, it is evolutionarily efficient to dream of threats directed at close relatives, allies or friends, affecting the inclusive fitness of the individual.

Even in the case the threat is directed at insignificant strangers, the dreamer can learn of the possibility of such threats in his or her environment when he/she witnesses the event with own eyes. In addition, there is now new evidence from cognitive neuroscience supporting the view that when we observe another person performing an action, our own brain perceives this action by mirroring it, that is, by activating the same brain mechanisms as if we were ourselves carrying out those acts (for example, Rizzolatti & Graighero, 2004). In fact, the mirror neurons are suggested to be the neural basis of action understanding and imitation learning. Thus, observation of threat avoidance behaviors may be functional and enhance a kind of vicarious learning. Although it may not be as efficient as being the target of the threat oneself, it certainly is better for the maintenance of our threat avoidance skills to observe how other people handle threatening events than to dream about something totally unrelated. Thus, while witnessing threats does not give particularly strong support to the TST, it hardly can be used as evidence against it, either. Furthermore, we all learn of the occurrence different types of threats that have happened to insignificant strangers through social interaction. We hear stories about threats that have killed or injured friends of friends or relatives of friends, and probably ancestral humans told stories as well, this way teaching other members of the group, especially young ones, to avoid dangerous situations. Thus, including threats only witnessed by the dreamer into the coding system reflect events that serve as efficient threat avoidance rehearsal.

Threats that are not directly physical, but endanger the 'mental well-being of self' in the dream were also included in the DTS, and scored as psychological, social or financial threats (category III, Table 2.). Even though these threats do not directly threaten the physical well-being of the dreamer, they still can severely affect the fitness of the individual. For instance, an example of a psychologically severe threat is a situation where the life or physical well-being of a close relative, a parent, a spouse, or a child, is at stake. An example of social threat is a situation where the dreamer's status in the community is threatened, and an example of financially severe threat an event where the dreamer's valuable property is lost or destroyed. All these types of events would have indirectly endangered the future reproductive success of the ancestral humans. Thus, threats endangering "the mental well-being of the dreamer" reflect situations that threaten the survival or reproductive success, that is, fitness, of the individual, although not as directly as life-threatening events.

The DTS includes two categories for coding the participation of the dreamer in the threatening event, as the TST predicts frequent participation and appropriate defensive reactions from behalf of the dream self. Category IV addresses whether it is possible, in the first place, to take part in the event, and category V is used to code for the specific types of reactions the dream self engages in in the situation. We also included categories for classifying the resolution and consequences of the threatening events to the dream self to investigate what happens after the actual situation is over. The last, but nevertheless an important category 'the source of the threatening event' was designed to measure the prediction of the TST that threats in dreams should be realistic in nature.

4.2.2. Data analysis

All the dream reports (and daily log and interview descriptions in Study III) were independently content analyzed with the Dream Threat Scale by two (Studies II-V) or three (Study I) judges. The content analysis occurred in two separate stages. In the first stage, the threatening events were identified according to the DTS threat definition criteria. Based on the unanimous or majority identifications, threats were then selected for the second stage. In the second stage, threatening events were further classified based on the quality of the threats, according to the DTS categories I-VIII.

4.3. Statistical analyses

In all studies, the DTS interrater agreement levels were evaluated with simple percent agreement (identification stage), and Cohen's Kappa Coefficient (Κ) (classification stage). The within-study groups (male – female; traumatized – nontraumatized) were compared with nonparametric Mann Whitney U test (U), while Pearson's Chi Square test (χ^2) was used to assess differences in the quality distribution of threats. In Studies II and III, Pearson's Correlation Coefficient (r) was utilized to investigate whether the frequency of threats in dream reports was associated with the number or length of dream reports. In Study III, Wilcoxon Signed Ranks Test was used for determining whether the frequency of threats in different report types (dream reports, daily logs and autobiographical interview reports) were associated within subjects, and repeated measurements logistic regression analyses with Generalized Estimating Equation (*GEE*) method was utilized in comparing the similarities and differences in the nature of current dream threats, current real threats and past real threats. Additionally, in Study III Spearman's Rank-Order Correlation Coefficient (rs) was calculated to determine whether the mean frequency of current or past real threats was associated with the mean frequency of current dream threats.

5. RESULTS

5.1. The reliability of the Dream Threat Scale

Each study in the present thesis was designed to test a specific prediction or predictions of the TST. The participant populations varied accordingly and consequently, in some studies the Dream Threat Scale was modified to fit the unique research problem or participant sample. Nonetheless, the utilized DTS threat identification criteria were the same in each and every study. Also, highly similar content scales were used in these studies; some categories always remained identical or almost identical while some were further modified. Importantly, the whole data sets were always scored by at least two judges which allows us to compare results and give estimates about the reliability of the DTS. Note, however, that neither the participant samples nor the content analysis method are in every case directly comparable between studies, but rather reflect the fact that the TST has been and should be studied in diverse populations, and the method has been fine-tuned accordingly.

In Study I, three judges identified and classified the threatening events, and the strength of agreement between judges varied from fair to strong (Table 3). As two of the judges (AR, KV) had developed the DTS, their pair-wise agreement was much stronger than between either of these two and the third judge. Nevertheless, all the agreement levels were strong enough to render the results reliable. Important for the evaluation of the reliability of the DTS, a different pair of judges (OM, SL) who had not participated in the development of the scale identified and classified the threats in Study II. The new judges reached identification and classification agreement levels that were mostly stronger than in the original Study I (Table 3).

In Studies III, IV, and V, two judges identified and classified the threats, and the first judge had participated in the development of the scale while the other was newly trained to apply the method. The agreement levels were very strong for the identification and coding of dream threats (Table 3). In Study III, also agreement on the coding of the most recent threats in the daily logs and the threats encoded into long term autobiographical memory, acquired through interview reports (see original publication for agreement levels of waking events), were strong.

In Studies IV and V, the analyzed material differed significantly from previous studies, as it was composed of children's dreams that were translated from Kurdish dialects (Study IV) and Arabic (Study V) into English. The DTS was modified in these studies to better suit the analysis of children's dreams collected from different cultural groups. The agreement levels ranged from good to strong (Table 3).

In sum, in all of these studies the DTS has proven to be a reliable tool for identifying and classifying threatening events in written reports. Reliability was independent of source of data (dreams vs. real life experiences), age of subjects (children vs. adults), life-experiences of subjects (traumatized vs. nontraumatized) or the cultural background of participants (Finnish, Swedish, Kurdish, and Palestinian). We therefore recommend the use of the Dream Threat Scale in future studies on threatening dream events or empirical tests of the TST.

Table 3. Threat identification agreement percentages and classification agreement Cohen's Kappa Coefficient values ♠

	University student samples			Traumatized and nontraumatized children	
Study	Study I ♣	Study II	Study III	Study IV	Study V
Judges	AR, KV, VO	OM, SL	KV, TS	KV, OP	KV, OP
Threat identification agreement %	76-84	83.7	84.7/92.9♦	86.3/95.5♦	85.7/94.2♦
Threat classification Kappa Coefficient (K) values					
Nature of threat	0.70-0.74	0.94	0.87	0.92	0.94
Target of threat ♥	0.52-0.79	0.88-0.94	0.84-0.93	0.64-0.93	0.83-0.94
Severity of threat	0.53-0.62	0.89	0.87	0.87	0.89
Participation to threat	0.67-0.73	0.99	0.86	0.83	0.87
Reaction to threat	0.64-0.65	0.95	#	#	#
Consequences of threat	0.43-0.73	0.97	0.85	0.88	0.88
Resolution of threat	0.53-0.59	0.96	0.88	-	-
Source of threat/ Realism	0.52-0.62	0.92	0.88	-	-

♠ According to Fleiss (1981), K values < 0.4 indicate weak agreement, 0.4-0.75 fair to good agreement, and > 0.75 strong agreement.
♣ Three judges identified and classified the threats, thus the range of pair-wise agreement is reported here
♦ Both complete threat identification agreement % and partially overlapping threat identification agreement % are reported
♥ A range of K values is reported: a single threat can have several targets and Kappa can be computed only to separate subcategories
= Not applicable; in the study, categories 'Participation to threat' and 'Reaction to threat' were combined
- = Not reported in the original study

5.2. The frequency of threatening events

5.2.1. University student samples

In Study I, Revonsuo and Valli (2000) found that threatening events are relatively frequent in the dreams of ordinary young adults. Approximately two thirds of all dream reports included a description of a threat, and many dreams included several threatening events (Table 4). On average, there was more than one threat per dream. In those dream reports including threatening events, 34% of words (total recall count, TRC; Antrobus, 1983) were used for describing threatening events whereas two thirds of words depicted other types of events. There were no subjects whose dream reports did not include threatening events, even though the frequency of threats per dream report varied largely between subjects (0.23-3.75). In a comparable Swedish student sample (Study II; Table 4), threatening events were slightly more frequent, averaging 1.7 threats per dream. More than three quarters of all dream reports contained at least one threatening event, and all subjects, even those who managed to report only one dream, had threatening events in their dreams.

Study III was specifically designed for not only to measure threat frequency in dreams but also in waking life to investigate whether threatening events are truly more frequent in dreams. Waking state threat frequency was assessed by systematic daily logs (most recent threats) and by interviewing the subjects about all the threat experiences they could recollect from their long term episodic memory (that is, threatening events that have been so salient that they have left a permanent memory trace).

In Study III, the threat simulation frequency results were highly similar to other student samples (Table 4). Further, the results indicated that current dream threats are far more frequent than the most recent threats experienced during the preceding days, or the past real threats retrievable from autobiographical memory. Of the students' dream reports, almost three quarters included threatening events as compared to less than one fifth of daily logs. In the interviews the students recalled, on average, eighteen real threats from their lives, whereas during the two week diary period they had experienced, on average, fifteen dream threat simulations (Table 5). Thus, it seems that threat simulations in dreams are experienced on a nightly basis, most recent real threats on a weekly basis, and the most memorable threats in our lives occur with the frequency of less than one per year. Also the quality of threats varied in these three samples, in a pattern predicted by the TST (see section 5.3.).

Table 4. The frequency of threatening events in dream samples

		University student samples		Traumatized and nontraumatized children	
Study	Study I	Study II	Study III	Study IV T/C/F *	Study V T/C *
Number of threatening events	672	381	581	563 (338/144/81)	1181 (948/233)
% of dream reports including threats	66.4	77.0	72.8	79.5/55.6/31.0	58.7/47.8
Mean number of threats per dream report	1.2	1.7	1.4	1.2/0.7/0.4	1/0.7
Threat description % of words	34.1	-	37.1	61.1/42.1/20.1	45.7/38.0

* T = Trauma group; C = Control group; F = Finnish children
\- = Not reported in the original study

Table 5. The overall characteristics of dream reports, daily logs, and autobiographical interviews in Study III

	The number of reports	The number of threats in reports	Percentage of reports including threats	Threats per report	Words per report
Study III	*N (M, SD)*	*N (M, SD)*	*M (SD)*	*M*	*M (SD)*
Dream reports	419 (10.7, 6.6)	581 (14.9, 9.5)	72.8 (20.1)	1.4	144.5 (66.9)
Daily logs	490 (12.6, 5.3)	103 (2.6, 2.9)	15.2 (15.6)	0.2	52.2 (44.8)
Autobiographical reports	714 (18.2, 8.0)	714 (18.2, 8.0)	100* (-)	1	- (-)

* By definition, each autobiographical threat report included one threatening event

5.2.2. Children's dreams

Studies IV and V addressed the effect of traumatic life experiences on dream content. In general, in nontraumatized children's dreams the threat simulation frequency was somewhat lower than in adults' dreams (Table 4). By far the lowest threat frequency of any sample was found in the dreams of Finnish children who had lived all their lives in the most peaceful and stable environment of the studied children. Threat simulations occurred in approximately one third of the dream reports of the Finnish children, and the average number of threats per dream report was 0.4 (Study IV). Nontraumatized Palestinian children, who had also led relatively safe lives but almost certainly had heard about the restless situation in the Gaza district, had an average threat simulation frequency of 0.7 per dream report (Study VI). In nontraumatized samples, the threat description percentages of words varied between 20% and 40%.

In contrast, exposure to traumatic events significantly increased the frequency of threat simulations in dreams (Studies IV and V, Table 4). The more severe the trauma, the higher number of dreams included threat simulations, equalling to or surpassing the threat simulation frequencies of ordinary young adults. Of the severely traumatized Kurdish children's dreams, approximately 80% included threatening events (highest of any sample), and on average, there were 1.2 threatening events per dream report. Similarly, the percentages of words used for describing threats exceeded the values seen in any other sample (61.1% vs. adult average 35.6%) indicating that in the traumatized children the content of dreams is more focused on threat simulation.

5.3. The quality of threatening events

Although the distribution of specific types of threatening events varies from study to study, and slightly different versions of the DTS have been used in different studies, certain regularities clearly emerge from the results.

5.3.1. The nature of threatening events

In the university student samples, threats including aggressive components (that is, non-physical aggression, escape and pursuit situations, and direct physical aggression) are the most prominent type of threatening event, accounting for approximately 40% of all threatening events (Table 6). Failures, varying between 26% to 36% of all threats, and accidents and misfortunes (approximately 20% of threats) are the second and the third most common type of threat, whereas catastrophic events (3% of threats) and disease and illness (3% to 8% of threats) are rare.

Table 6. The specific content distribution (%) of threatening events

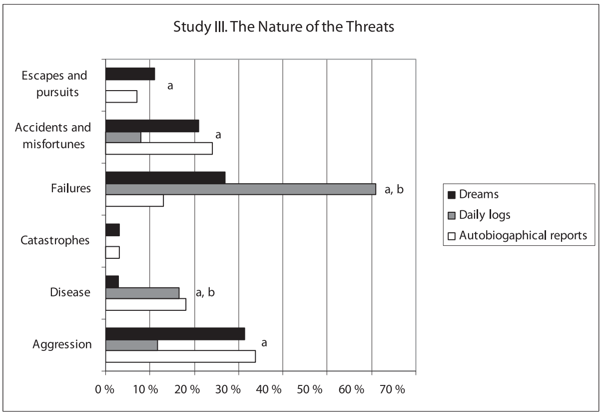
		University student samples		Traumatized and nontraumatized children	
Study	Study I	Study II	Study III	Study IV T/C/F *	Study V T/C *
I Nature of threat					
1. Escapes	11	7	11	19/17/16	13/15
2. Accidents	22	17	21	9/15/16	10/16
3. Failures	26	36	27	8/18/12	8/18
4. Catastrophes	3	3	3	4/2/3	2/2
5. Disease	8	3	3	1/5/11	1/2
6. Aggression	31	34	31	45/37/37	63/45
II Target of threat					
1. Self	73	67	80	88/88/85	77/86
2. Significant others	27	27	30	47/41/29	43/32
3. Sig.resources	12	10	13	7/8/4	20/10
4. Insig. people and resources	27	20	43	11/10/13	32/18
III Severity of threat					
1. Life-threatening	22	18	22	35/31/24	26/28
2. Otherwise severe	17	50	22	24/17/6	30/19
(3. Physically sig.)	#	#	9	8/12/27	10/11
4. Minor	61	32	47	34/40/52	34/42
IV Participation					
1. Active	56	60	46	36/33/40	26/32
2. Does not / cannot actively participate	44	40	54	64/67/60	74/68
V Reaction					
1. Relevant action**	94	93	#	#	#
2. Impossible action**	2	1	#	#	#
3. Irrelevant action**	4	3	#	#	#
4. No reaction, not possible, not reported**	46	40	24	#	#
VI Resolution					
1. Threat resolved	32	23	22	#	#
2. Threat realized	37	40	54	#	#
3. Discontinuity	14	19	6	4/8/6	7/4
4. Disrupted	17	18	8	10/13/21	15/20
VII Consequences					
1. No losses	37	30	25	18/15/24	14/17
2. Minor losses	22	49	31	14/17/13	32/31
3. Severe losses	<2	3	3	7/6/2	9/6
4. Not reported	28	18	30	41/39/45	45/46
VIII Source of threat					
1. Realistic threat	63	60	68	#	#
2. Unlikely threat	33	33	21	#	#
3. Fictitious threat	4	7	8	#	#
4. Not classifiable	<1	0	4	#	#

* T = Trauma group; C = Control group; F = Finnish children

** Type of reaction (relevant, impossible, irrelevant) calculated only from those cases where reaction was reported, and cases where there is no reaction, reaction is not possible, or reaction is not reported are presented separately.

= Not applicable; category not used in the study

In Study III where the nature of the dream threats was compared to the nature of the most recent threats and to the nature of the most salient threats encoded into and retrievable from long term memory, the results revealed that the dream threats much more closely resemble the old but most salient than the new most recent threats (Figure 3). Failures were most frequently reported in the daily logs, whereas aggressive events as well as accidents and misfortunes were prominent types of dream threats and the most salient real autobiographical threats. Thus, the themes of dream threats seem to be constructed from the old memory traces of the most threatening events ever encountered rather than from the new minor threats experienced during the preceding days.



a = a significant difference between the Current Dream Threats and the Current Real Threats, p < .001
b = a significant difference between the Current Dream Threats and the Past Real Threats, p < .001

Fig. 3. The nature of the Current Dream Threats closely resembled the nature of the Past Real Threats while Current Real Threats and Current Dream Threats differed statistically significantly on every subcategory.

Studies IV and V on dreams of traumatized and nontraumatized children show that aggression is very prevalent in children's dreams, ranging from 53% of all threats in Finnish children's dreams to 76% in traumatized Palestinian children's dreams (Table 6). This result is consistent with previous findings on the high levels of aggression in children's dreams (Hall & Domhoff, 1963). Furthermore, the traumatized children had significantly more aggressive threats in their dreams than the nontraumatized children or ordinary young adults, on the expense of Accidents and Misfortunes, and Failures. The threat simulation system of traumatized children thus seems to be more active in constructing threat simulations including aggressive components than that of the nontraumatized children or nontraumatized adults.

5.3.2. The targets of the threatening events

In all studies, the threatening events were targeted mainly against the dream self, followed by persons significant for the future success and inclusive fitness of the dream self, that is close kin, friends and allies (Table 6). Insignificant persons were less frequently threatened, but altogether, threats were more people- than resource –centred. Both resources significant for the dream self, such as physical property or territory, and insignificant resources, such as property of insignificant strangers, were seldom targeted in the threatening events. In Study III, the distribution of the targets of threats was similar in the current dream threats, most recent threats, and most salient threats, indicating that dream threats reflect the waking life threats when it comes to targets of threats (Figure 4).

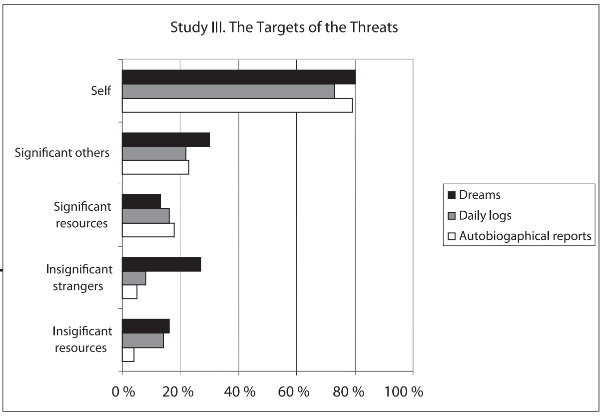


Fig. 4. The distribution of the targets of threats is statistically similar in the Current Dream Threats, the Current Real Threats in daily logs, and the Past Real Threats in autobiographical reports.

5.3.3. The severity of threatening events

In the dreams of ordinary young adults 18% to 22% of all threatening situations were life-threatening to the dreamer (Table 6). On average, one third of threats simulated situations where the physical or psychological well-being of the self, or the social or financial resources of the dreamer were threatened. The rest, one to two thirds of threats (depending on the study) represented minor everyday mishaps that did not threaten the future survival of the self, but nevertheless, presented the dreamer with situations that required attention and actions aimed at dealing with the event.

Compared to the most recent and to the most salient real life threats (Study III), dream threats were significantly more severe (Figure 5 a.). Severe threats are composed of life-threatening events, socially, psychologically, or financially significant threats, and threats endangering the physical well-being of the dream self, that is, all other threats apart from events categorized as minor. While the most recent threats consisted mainly of minor everyday mishaps (no life-threatening events were reported in the daily logs), almost half of the dream threats simulated severe events (Figures 5 a. and 5 b.). In general, the dream threats more closely resembled the most salient autobiographical threats in severity than the most recent threats reported in the daily logs, although the dream threats were more often life threatening or socially, psychologically, or financially severe (Figures 5 a. and 5 b.) Taken into account that most of the participants had experienced a life-threatening event only once (some a few times) in their lives, in their dreams they were forced to face life-endangering situations on a weekly basis. Thus, in our dreams we more frequently experience life-threatening and other severe events than in our waking lives, and our dreams exaggerate the dangerousness of those threatening events that we have experienced during the waking hours.

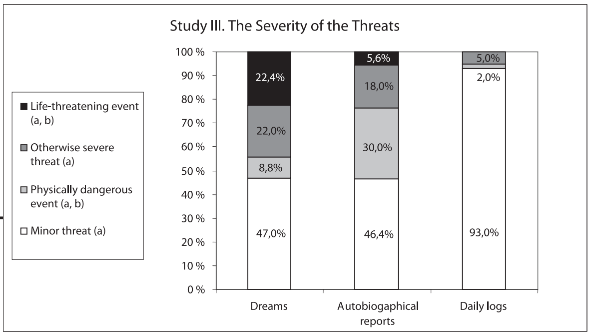


Fig. 5 a. The Current Dream Threats were significantly more severe than the Past Real Threats in autobiographical reports, or the Current Real Threats in daily logs.

a = a significant difference between the Current Dream Threats and the Current Real Threats, p < .001
b = a significant difference between the Current Dream Threats and the Past Real Threats, p < .001

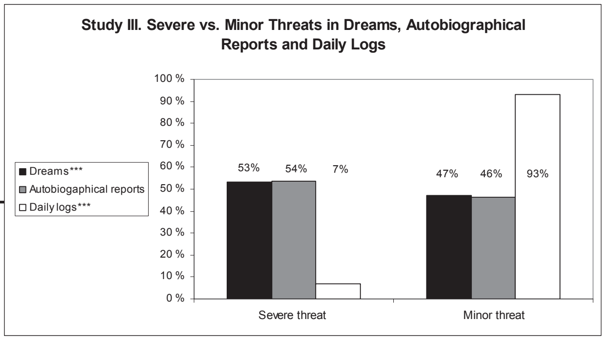


Fig. 5 b. The Current Dream Threats resembled the Past Real Threats in the amount of severe versus minor threats, and both differed significantly from the Current Real Threats reported in the daily logs.

*** = a significant difference between the Current Dream Threats and the Past Real Threats versus the Current Real Threats, *p* < .001

In contrast, repeated personal exposure to life-threatening events increases the amount of life-threatening and other severe types of dream threat simulations (Studies IV and V; Table 6). Not only did the traumatized children simulate threatening events more frequently in their dreams, the simulated threats were significantly more severe (that is, life threatening events, socially, psychologically or financially significant events, and physically harmful events vs. minor events) in their dreams than in the nontraumatized children's or the nontraumatized young adults' dreams (Table 6). In fact, when the much higher overall threat simulation frequency for the traumatized children is accounted for (Table 4), life-threatening and other severe threats were experienced by the severely traumatized Kurdish children twice as often as by the less traumatized Kurdish children, and six times more frequently than by the nontraumatized Finnish children.

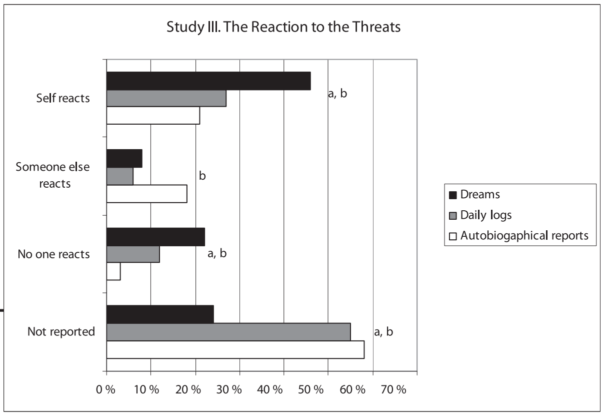
5.3.4. The participation and reactions of the dream self in the threatening events

In Studies I and II, a slightly different participation and reactions coding scales were used than in Studies III, IV, and V. In Studies I and II, a separate scale was used for the possibility of participation and for the specific type of reactions (Table 6), whereas in Studies III, IV, and V the scales were combined to code for occasions of: Self reacts, someone else reacts, no one reacts, and reactions are not reported.

In adults' dreams, the dreamer could and did actively participate in the course of the threatening events in 46% to 60% of cases (Table 6). Thus, in approximately half of the threatening events the dreamer could not or did not actively partake in the events. Even though reacting to the threat was not always possible in dreams, when reactions occurred, they were almost without exception relevant, reasonable and appropriate to the dreamed situation (Table 6). Only rarely did the dreamer engage in actions that are impossible in the physical realm but efficient within the dream (for example, flying away from an attacking animal), or physically possible but inappropriate in a comparable waking situation (for example, jumping off a cliff to escape an attacking animal).

Participation rates were lower in children's than in adults' dreams. Thus, participation in children's dreams is not as often possible, the children do not take an advantage of the opportunity, or participation is not reported. Children's and adults' dreams are not, however, directly comparable (Foulkes, 1982). For example, the younger the child, the less the dream self is involved or active in the dreams. The degree of trauma did not have an effect on the participation rates, and in fact, when a threatening dream event arose, the nontraumatized children participated in the event with a slightly higher probability than the traumatized children. Nevertheless, as the absolute threat simulation rates were as much as three times more frequent in severely traumatized than in nontraumatized children's dreams (Table 4), the traumatized children got altogether more frequent practice in dealing with threatening events. In other words, participation frequencies reported in percentages do not reveal the whole truth, but the actual simulation rates also need to be accounted for.

The main reason for why participation rates remain relatively low both in adults' and in children's dreams seems to be that participation cannot be coded for due to lack of information in the dream report, mainly because of disruption of or discontinuity within the dream. Surprisingly, in Study III we noticed that descriptions of participation were also lacking from many daily logs and interview reports concerning the most recent and the most salient real-life threats (Figure 6). In fact, descriptions were more often absent in daily logs and interview reports than in dream reports. Thus, people “participated” in dream threats more actively than in real-life threats. We suspect that people may have the tendency not to report aspects of their own actions, unless specifically inquired.



a = a significant difference between Current Dream Threats and Current Real Threats, $p < .001$
b = a significant difference between Current Dream Threats and Past Real Threats, $p < .001$

Fig. 6. The reported reactions to the Current Dream Threats, Current Real Threats in the daily logs, and the Past Real Threats in the autobiographical reports.

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5.3.5. The resolution and consequences of the threatening event

The threatening events more often became fully realized (37% to 54%) than dissolved (22% to 32%) (Table 6). By fully realized threats, we refer to events than ran their course, and could not be prevented regardless of the actions of dream characters (so-called unhappy ends). Dissolved threats refer to cases were the resolution of the event was positive, and the threat did not become realized (so-called happy ends). As mentioned above, discontinuity within the dream and disruption of the dream were also quite frequent. Interestingly, though, in all studies in which the statistics could be conducted, the threatening events were significantly more often resolved than realized when the dream self actively participated in the course of the events than when the dreamer remained passive (Study I: χ^2 (3, n = 638) = 54.69, $p < .001$; Study II: χ^2 (3, N = 381) = 27.94, $p < .001$; Study III: χ^2 (12, N = 581) = 46.15, $p < .001$). Thus, the activity of the dream self positively affected the outcome of the situation.

More contradictory results were found concerning the effect of life-threatening events on the dreamer’s activity. In Study I (χ^2 (1, n = 643) = 18.58, $p < .001$), and Study III (χ^2 (9, n = 581) = 18.37, $p < .05$), the dreamer was more likely to react to the threat when it was life-threatening than to other, less severe events. Similarly, in Study V, traumatized children’s dream threats showed this connection (χ^2 (1, n = 948) = 42.81, $p < .001$), but not the nontraumatized children’s dream threats. In contrast, no significant connection between severity of threats and activity of the dream self were observed in Studies II, and IV.

As to consequences of threats, they often go unreported or there are no consequences at all (Table 6). Severe consequences were, in general, very rarely experienced, although they were more frequent in the dreams of the traumatized than the nontraumatized children. The threat simulation mechanism therefore does not seem to be interested in simulating what happens after the threat has been recognized, encountered and appropriate actions have been taken to avert the threat.

5.3.6. The source of threatening events

A majority of threats in the student samples, 60% to 68%, were based on information about events that are realistic and possible in the living environment of the subject (Table 6). That is to say, the person has likely heard about such threats occurring to someone in that environment, or possibly has been in contact with somebody who has experienced such a threat, or may have personally been exposed to such an event in his or her life. Threats that are realistic in some parts of the world, but are highly unlikely to occur in the lives of Finnish or Swedish university students in their normal environment formed 21% to 33% of all threats. These types of threats usually come to our knowledge through the mass media, and include elements such as exotic animals, war, floods and other natural catastrophes. In contrast, threatening events based on fantasy, fiction, or folk-lore were rare in student samples, ranging from 4% to 8% of all threats.

We did not code for the source of threats in the samples of children's dreams due to cultural differences that made the coding procedure complicated. Punamäki (1997) and Punamäki, Ali, Ismahil and Nuutinen (2005) have found in the same dream samples that the dreams of traumatized children are less bizarre and more realistic than the dreams of nontraumatized children. Exposure to real life threats thus seems to yield threat simulations more realistic.

5.4. Reanalysis of data: repetitive training and threat simulation rates

As in the learning or maintenance of any skill, repetition is the key to improved performance. If repetition is essential in improving performance, then this must also be the case in threat simulation. But how much practice in dealing with threatening situations do we actually get?

5.4.1. Threat simulation rates in spontaneously recalled dreams

Based on the data from Studies I, II, and III, weekly (seven days), monthly (30 days) and annual (365 days) threat simulation rates were calculated (Table 7)[2]. The aim here is to explicate how often threat simulations occur in the population, on average, and what types of threatening events we frequently have to deal with in our dreams. Based on averaging the results of Studies I, II, and III, the subjects recalled 3.6 dreams per week (SD = 1.5, range = 2.5 – 5.3) (Table 7). Of these, 72.1% (SD = 5.3, range 66.4% – 77.0%), that is, 2.6 dreams included at least one threatening event, while the average threat simulation frequency per dream was 1.4 (SD = 0.3, range = 1.2 – 1.7). Consequently, in the dreams of young adults, threat simulations occur, on average, five times per week. Thus, the monthly threat simulation repetition rate is approximately twenty, and the annual simulation rate more than two hundred and fifty threatening events per year. Note, however, that these rates are based only on spontaneously recalled dreams, reported after the morning awakening. Indirect evidence suggests that we experience several dreams per night, but are usually unable to recall all of them.

Table 7. Estimated dreaming and threat repetition rates in young adults

University student samples*	Weekly *M*	Monthly *M*	Annually *M*
Dream recall rate	3.6	15.4	187.7
Dreams including at least one threatening event	2.6	11.1	135.6
Threat repetition rate	5.0	21.4	260.7
Estimated threat repetition rate in REM dreams **			
REM dreaming rate	23.1	99.0	1 204.5
REM dreams including at least one threatening event	16.7	71.4	868.4
REM dream threat repetition rate	32.3	138.6	1 686.3

* Figures based on results of Studies I, II, and III. On average, 72.1% include at least one threatening event, and on average, there are 1.4 threatening events per dream

** Figures based on estimation that people have, on average, 3.3 REM dreams per night, of which 72.1% include at least one threatening event, and on average, there are 1.4 threatening events per dream

5.4.2. Estimated threat simulation rates in REM dreams

In addition to spontaneously recalled threat simulation rates, weekly, monthly and annual threat simulation frequencies were also estimated, based on what is currently known about the frequency of dreaming (Table 7)[3]. The most optimal stage of sleep

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[2] Similar calculations have been presented in Study VI (Valli & Revonsuo, in press), but with larger participant and dream samples.

[3] Similar calculations have been presented in Study VI (Valli & Revonsuo, in press), but with larger participant and dream samples.

for dreaming to occur is REM sleep (Pivik, 1991). In a review by Nielsen (2000), laboratory awakenings from REM phase of sleep yielded, on average, a dream report in 81.9% of awakenings (SD = 9.0, range 60% - 93%). Similarly, Strauch and Meier (1996) managed to collect nearly 1 000 REM dreams from more than 100 subjects during approximately 300 laboratory nights.

Second, depending on sleep length, humans normally have three to five REM periods per night, and this amounts to approximately 20%-25% of total sleep time (Roffwarg, Muzio & Dement, 1966). Thus, if we experienced one dream per each REM period, and would be able to remember them, we could recall on average 2.5 – 4.1 REM sleep dreams per night (recall rate being 81.9%). In 2002, mean sleep length for Americans aged 18 to 29 years was 6.9 hours on weekdays and 7.8 hours on weekends (The National Sleep Foundation, 2002). On workdays, 35% slept more than 8 hours per night, whereas on weekends 60% of subjects slept over 8 hours. Six years later, the average amount of sleep on workdays was 6.6 hours, and 7.5 hours on weekends (The National Sleep Foundation, 2008). In Finnish health survey conducted on year 2000, the average sleep length for 18 to 29 year old males was 7.6 hours and 7.9 hours for females (Kronholm, Härmä, Hublin, Aro & Partonen, 2006). In Croatian university students (mean age 20.8 yrs), average sleep length on weekdays was 7 hours 37 minutes, and on weekends 8 hours 15 minutes (Bakotic, Radosevic-Vidacek & Koscek, 2005). No comparable data could be found for Finnish or Swedish university students.

Regardless, if we estimate that ordinary young adults in Scandinavia sleep 7 to 8 hours per night, they consequently have four REM periods per night (if sleep is not disrupted). If they have one dream per each REM period, and dream recall in REM awakenings is 81.9%, they experience on average 3.3 REM dreams per night. If we also assume that threat simulation rate remains stable over sleep cycles and is therefore similar to spontaneously recalled dreams, we can calculate estimates of threat simulation frequencies in REM dreams. As indicated in Table 7, weekly, monthly, and annual threat simulation rates then become remarkably high compared to spontaneously recalled dreams. Nevertheless, the actual average threat simulation rate in different sleep stages (Sleep onset/REM/NREM) and over sleep cycles is thus far unknown.

5.4.3. Rates of specific types of threat simulations

The threat simulation frequency estimates and information about the specific quality of threatening events allow us also to calculate how often young adults are exposed to particular types of threat simulations in their dreams. Based on the threat simulation frequency estimates (Table 7), and the specific quality of threatening events in Studies I, II, and III (Table 6), we calculated monthly and annual exposure rates for specific types of threatening events. Similarly, based on estimated threat repetition rates in REM dreams, we reckoned the monthly and annual

Table 8. Estimated frequencies of simulation of specific threat content

		University student samples ♠		Estimated TRR in REM dreams ♦	
Threat content category	Mean % of threats (*SD*, range)	Monthly *N*	Annually *N*	Monthly *N*	Annually *N*
I Nature of threat					
1. Escapes	9.7 (2.6, 7-11)	2.08	25.29	13.44	163.57
2. Accidents	20.0 (2.6, 17-22)	4.28	52.14	27.72	337.26
3. Failures	29.7 (5.5, 26-36)	6.36	77.43	41.16	500.83
4. Catastrophes	3.0 (0.0, 0)	0.64	7.82	4.16	50.60
5. Disease	4.7 (2.9, 3-8)	1.01	12.25	6.51	79.26
6. Aggression	32.0 (1.7, 31-34)	6.85	83.42	44.35	539.62
II Target of threat					
1. Self	73.3 (6.5, 67-80)	15.69	191.09	101.59	1 236.06
2. Significant others	28.0 (1.7, 27-30)	5.99	73.00	38.81	472.16
3. Sig. resources	11.7 (1.5, 10-13)	2.50	30.50	16.22	197.30
4. Insig. people and resources	30.0 (11.7, 20-43)	6.42	78.21	41.58	505.89
III Severity of threat					
1. Life-threatening	20.7 (2.3, 18-22)	4.43	53.96	28.69	349.06
2. Otherwise severe	29.7 (1.9, 17-50)	6.36	77.43	41.16	500.83
3. Physically sig.	9 (0, 0)	1.93	23.46	12.47	151.77
4. Minor	46.7 (14.5, 32-61)	9.99	121.75	64.73	787.50
IV Participation					
1. Active	54.0 (7.2, 46-60)	11.56	140.78	74.84	910.60
2. Does not / cannot actively participate	46.0 (7.2, 40-54)	9.84	119.92	63.76	775.70
V Reaction **					
1. Relevant action	93.5 (0.5, 93.94)	20.01	243.75	129.59	1 576.69
2. Impossible action	1.5 (0.5, 1-2)	0.32	3.91	2.08	25.29
3. Irrelevant action	3.5 (0.5, 3-4)	0.75	9.12	4.85	59.02
4. No reaction, not possible / reported	36.7 (11.4, 24-46)	7.85	95.68	50.87	618.87
VI Resolution					
1. Threat resolved	25.7 (5.5, 22-32)	5.50	67.00	35.62	433.38
2. Threat realized	43.7 (9.1, 37-54)	9.35	113.93	60.57	736.91
3. Discontinuity	13.0 (6.6, 6-19)	2.78	33.89	18.02	219.22
4. Disrupted	14.3 (5.5, 8-18)	3.06	37.28	19.82	241.14
VII Consequences					
1. No losses	30.7 (6.0, 25-37)	6.57	80.03	42.55	517.69
2. Minor losses	34.0 (13.7, 22-49)	7.28	88.64	47.12	573.34
3. Severe losses	2.7 (0.6, 2-3)	0.58	7.04	3.74	45.53
4. Not reported	25.3 (6.4, 18-30)	5.41	65.96	35.07	426.63
VIII Source of threat					
1. Realistic threat	63.7 (4.0, 60-68)	13.63	166.07	88.29	1 074.17
2. Unlikely threat	29.0 (6.9, 21-33)	6.21	75.60	40.19	489.03
3. Fictitious threat	6.3 (2.1, 4-8)	1.35	16.42	8.73	106.24
4. Not classifiable	1.7 (2.1, 0-4)	0.36	4.43	2.36	28.67

♠ Based on weekly, monthly and annual threat frequency estimates (Table 6), and percentages of specific content of threatening events in Studies I, II, III.

♦ Based on weekly, monthly and annual REM dream threat repetition rate (Table 6) and percentages of specific content of threatening events in Studies I, II, and III.

** Type of reaction (relevant, impossible, irrelevant action) calculated only from those cases where a reaction was reported frequencies of specific types of threat simulations. The specific threat repetition rates are depicted in Table 8.

Rehearsal of threats including aggression (escape situations and non-physical and direct physical aggression) is the most prominent type of threat practice (41.7%), averaging altogether to a conservative estimate of more than one hundred annual simulations (Table 8). In addition, the estimated liberal repetition rate of aggressive threats in REM dreams amounts to seven hundred annual simulations (based on 1 686/year). Failures to achieve a set goal are the second most common topic of threat simulations (29.7%), averaging to a liberal estimate of five hundred REM dream simulations per year. Dealing with accidents is also frequently practiced (20.0%) whereas catastrophic events and illnesses are rarely encountered. The threats are mostly targeted against the dream self, the self being the target of the threat in approximately two hundred (conservative estimate) or one thousand and two hundred times per year (liberal estimate). Significant and insignificant people are also frequently in focus while significant and insignificant resources are seldom endangered.

About half of the threats in normative dreams are of minor importance to the dream self (although might be severe to insignificant people), and therefore do not threaten the future survival of the self in any significant way. Threats endangering the future success of the self (life-threatening events, psychologically, socially or financially severe events, and situations compromising the physical well-being of the self) are, however, altogether slightly more frequent than minor mishaps (annual conservative estimate 155 vs. 122; annual liberal estimate 1 002 vs. 787) (Table 8). The dream self participates in the course of the threatening events more often than not, although discontinuities within dreams and disruption of dreams frequently prevent the dream self from reacting to the threats. Whenever specific reactions to threats are reported in dreams, they are almost always relevant in the dreamed situation and would also be adequate in a comparable situation in waking life (93.5%). According to a conservative estimate, relevant reactions to the threats are practiced 244 times per year, and according to liberal estimate, more than one thousand five hundred times per year (Table 8). Furthermore, majority of threatening events are either completely realistic and possible in the dreamer's waking life (63.7%) or realistic but unlikely to occur to the person in reality (29.0%). Altogether, realistic, and realistic but unlikely, threats may be simulated even up to 1 500 times per year (liberal estimate) (Table 8). In contrast, only six or seven threats out of one hundred are based on fantastic or fictitious sources, and these unrealistic threats are simulated approximately one hundred times per year (in nontraumatized subjects who have not been exposed to severe threatening events in reality).

6. DISCUSSION

The first aim in empirically exploring the Threat Simulation Theory was to define an exact criteria for what is a 'threatening event' in dreams, and to develop a detailed and reliable content analysis scale and theoretical categories with which it is possible to empirically explore and quantify threatening events in dreams. The second aim was to empirically test some of the predictions derived from TST, using the developed threat criteria and systematic, detailed content analysis of the content of dreams in varying participant samples. The specific hypotheses tested in this thesis were: threatening events should be more frequent in dreams than in the waking lives of subjects; the threatening events should be severe, realistic, targeted against the dream self and significant others, and include simulations of relevant and appropriate defensive actions; dream content should be modulated by the activation of long term memory traces with highest negative saliency, that is, dream simulations should be based on memories of events representing the most severe threats ever encountered, and; real threat experiences should activate the threat simulation system in a unique manner, leading to more frequent and more severe threat simulation dreams.

6.1. The Dream Threat Scale

The threat criteria and the Dream Threat Scale (DTS) developed in Revonsuo and Valli (2000) was used in all studies included the present thesis. The DTS was proven to be a reliable tool for identifying and classifying threatening events in written reports, independent of source of data (dreams vs. real life experiences), age of subjects (children vs. adults), life-experiences of subjects (traumatized vs. nontraumatized) or the cultural background of participants (Finnish, Swedish, Kurdish, and Palestinian). Nevertheless, the data was mostly analyzed by raters who were not blind to the TST or to the predictions derived from the TST. Thus, data samples analyzed by different judges, preferably ones with no prior knowledge of the TST, are needed before making any definitive conclusion about the reliability of the DTS. In fact, two studies where the DTS was used by different judges have been recently published (Desjardins & Zadra, 2004; Zadra, Desjardins & Marcotte, 2006), and in these, the interrater agreement levels varied from moderate to strong. I do not, however, have information whether these raters were blind to the TST or not. I would, nevertheless, recommend the use of the Dream Threat Scale in future studies on threatening dream events or empirical tests of the TST.

One modification to the DTS, however, can be made without compromising the results. This modification is the exclusion of subjective threats from the threat identification criteria. At the time Study I was conducted, we had no idea how frequent subjective threats might be in the data, so they were included in the definition. For studies I and II the number of subjective versus objective threats was not available, but in Study III, only 6 threats out of 581 (= 1%) were subjective. In a later unpublished study, 3% of threats were found to be subjective (Aitta-aho, 2006). Thus, the results show that subjective threats form only a minor proportion of all threats. Furthermore, in addition to being rare, subjective threats are often very difficult to code (often being unscorable), and it seems that they cannot be used to test any predictions derived from the TST. Therefore, it seems unlikely that the inclusion of subjective threats into threat content analysis affects the results in any way, and they can thus be omitted.

6.2. The TST in the light of evidence from the present thesis

The content analysis results reveal that threatening events are relatively frequent in the dreams of ordinary young adults (Studies I, II, and III), very frequent in dreams of traumatized children, and least frequent in the dreams of nontraumatized children (Studies IV and V). Approximately two thirds of nontraumatized adults' dream reports include a description of a threat, and, on average, more than one threatening event per dream is simulated. Up to four out of five dreams of traumatized children include threats, whereas majority of dreams reported by nontraumatized children include no threat simulations. Thus, exposure to traumatic events significantly increases the frequency of threat simulations in dreams. The more severe the trauma, the higher number of dreams includes threat simulations.

In Study III, current dream threats were found to be far more frequent than the most recent threats experienced during the preceding days, or the past real threats retrievable from autobiographical memory. Almost three quarters of the students' dream reports included threatening events as compared to less than one fifth of daily logs. In the interviews the students recalled, on average, eighteen real threats from their lives, whereas during the two week diary period they had experienced, on average, fifteen dream threat simulations. Thus, it seems that threat simulations in dreams are experienced on a nightly basis, most recent real threats on a weekly basis, and the most memorable threats in our lives occur with the frequency of less than once per year.

Threats including aggressive components are the most prominent type of threatening event in dreams of both adults and children. Aggression is very prevalent in all children's dreams, but the traumatized children simulated aggressive and severe threats significantly more often in their dreams than did nontraumatized children or nontraumatized young adults. Failures, and accidents and misfortunes are also common, whereas catastrophic events and disease and illness are rare.

In all studies, the threatening events were targeted mainly against the dream self, followed by persons significant for the future success of the dream self. Insignificant persons were less frequently threatened, and altogether, threats were more people- than resource –centred. In student samples, one fifth of threats were life-threatening for the dream self, one third of threats simulated situations where the physical or psychological well-being of the self, or the social status or financial resources of the dreamer, were threatened. The traumatized children's dreams included proportionally more life-threatening and other types of severe threats than the dreams of nontraumatized children or adults.

The results of Study III revealed that on most aspects the quality of dream threats much more closely resembles the old but most salient than the most recent threats. Thus, the themes of dream threats seem to be constructed from the old memory traces of the most threatening events ever encountered rather than from the recent, often minor threats experienced during the preceding days. Compared to the most recent and to the most salient real life threats, however, dream threats were significantly more severe. Thus, in our dreams we more frequently face life-threatening and other severe events than in our waking lives, and our dreams exaggerate the dangerousness of those threatening events that we have experienced during the waking hours.

Even though reaction to the threat was not always possible in dreams, or was not reported, when reactions occurred, they were almost without exception relevant, reasonable and appropriate to the dreamed situation. Only rarely did the dreamer engage in actions that are impossible in the physical realm but efficient within the dream, or physically possible but inappropriate in a comparable waking situation. In Study III, we noticed that descriptions of participation were also lacking from many daily logs and interview reports concerning most recent and most salient real life threats. We suspect that people may have the tendency not to report aspects of their own actions, unless specifically inquired.

The threatening events more often became fully realized than dissolved. However, the threatening events were significantly more often resolved than realized when the dream self actively participated in the course of the events than when the dreamer remained passive. Thus, the activity of the dream self positively affected the outcome of the situation. In addition, in Studies I and III, and in traumatized children's dreams, the dreamer was more likely to react to the threat when it was life-threatening than to other, less severe events, but this relationship was not found in Study II. As to consequences of threats, they often went unreported or there were no consequences at all. The threat simulation mechanisms therefore does not seem to simulate what happens after the threat has been recognized, encountered and appropriate actions have been taken to cope with the threat.

A majority of threats in the student samples were based on information about events that are realistic and possible in the living environment of the subject. Threats that are realistic in some parts of the world, but are highly unlikely to happen to Finnish or Swedish university students in their normal environment were also often simulated, whereas threatening events based on fantasy, fiction, or folk-lore were rare. A comparable analysis could not be carried out in Palestinian or Kurdish children's dreams due to the raters' lack of information concerning their everyday lives.

To sum up, most of the predictions of the TST tested in this thesis received considerable support. For some predictions (such as the participation of the dream self in threatening events), the evidence could have been stronger. Regardless, no contradictory findings to TST's predictions were observed.

6.3. The TST in light of other empirical evidence

Despite that fact that the TST was rather recently proposed, other studies testing the predictions of the TST than the ones included in the present thesis have also been carried out. In this section, these studies are reviewed, and also findings from other studies relevant to the TST are discussed. Next, I will return to the six propositions of the TST presented in the original formulation of the theory (Revonsuo, 2000a), and summarize what kind of new evidence has been accumulating for or against the propositions of the TST. Some of the discussion that follows in this section has also been presented in Valli and Revonsuo (in press).

6.3.1. Proposition 1.

Dream consciousness is an organized and selective off-line simulation of the real perceptual world

The original idea that overall dream imagery is *not* organized, but random, chaotic, incoherent, bizarre and disorganized was presented in the Activation – Synthesis theory (Hobson & McCarley, 1977). This influential view was then accepted in all later following random activation theories (for example, Antrobus, 2000; Crick & Mitchison, 1983; 1995; Flanagan, 1995; 2000; Hobson, 1988; Hobson et al., 2000). The original Activation – Synthesis hypothesis was based on animal research that revealed that phasic signals, that is, the ponto-geniculo-occipital (PGO) waves, arise in the pontine brain stem during REM sleep. The PGO-waves were thought to be chaotic and random rather than organized or carrying some systematic, coded information. Furthermore, the PGO waves were assumed to activate the cortex and the limbic forebrain in an unpredictable, chaotic, random manner, and lead directly to a synthesizing process that in turn creates visual hallucinations, motor imagery, emotions and bizarre dream cognition from the chaotic stimulation. Thus, the Activation-Synthesis hypothesis states that chaotic signals originating from the brain stem initiate a process that results in random and disorganized dream mentation, that is, that the cortex tries to make some sense of and tries to impose a narrative structure on the random brain activation (Hobson & McCarley, 1977).

Nevertheless, the belief that dreams are disorganised and incoherent, as to their form and content, is not based on empirical evidence. Dream content studies systematically show that perceptual and sensory contents of dreams closely resemble the form and content of our waking life experiences (Revonsuo, 2006). At the moment, no new evidence has been presented that would contradict previous findings. Consequently, almost all researchers accept that dreams are well organized phenomenal experiences. This does not mean, however, that the occurrence bizarre dream imagery is refuted. Bizarreness is rather seen as bringing only some degree of disorganization and unpredictability into an overall well-organized dream experience.

Regardless, not all accept that dreams are *selective* simulations of waking life. For example, the Continuity Hypothesis states that dreaming simply *reflects* waking experiences in a passive manner. There is a vast amount of evidence that real life events are incorporated into dream content, but not all types of events, however, end up being simulated in dreams (Hartmann, 2000; Schredl, 2000, Schredl & Hofmann, 2003), and other types of content get overrepresented. Therefore, some type of active selection process seems to be going on in the brain when dream content is under construction. The continuity hypothesis cannot explain these patterns of under- and overrepresentation of specific dream content (Revonsuo 2000b).

6.3.2. Proposition 2.

Dream consciousness is specialized in simulating threatening events

Revonsuo and Valli (2000) developed a content analysis scale to study dream threats and to test the predictions of TST. As evident by the results presented in this thesis, threat simulations frequently occur in dreams, much more frequently than real threatening events are encountered in the waking realm, and the threat simulations are severe, realistic and efficient rehearsals of real situations for the dream self. Revonsuo and Valli (2000) were not, however, the first ones to explore threatening events in dreams[4].

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[4] Revonsuo and Valli (2000) were not the first to categorize threats in dreams, although at the time they devised their scale, they were not aware of the previous work by Framo, Osterweil and Boszormenyi-Nagy (1962). Moreover, also Framo et al. (1962) had developed a dream threat coding system, and had named their coding system the Dream Threat Scale!

6.3.2.1. Dreams of psychotic patients

Framo et al. (1962) studied the incidence of threats in dreams of psychotic patients, guided by the psychoanalytic paradigm. They used very similar threat identification criteria as were later introduced by Revonsuo and Valli (2000). Of the 98 patients enrolled in Framo et al.'s study (1962), 92 (90.2%) reported at least one dream in an interview, and all but five patients (80%) reported a threatening dream. The self was the main target of the threat in 60% of the dreams, and other persons in the remaining 40%. Even though psychotic patients are not an ideal sample for studying threatening events in dreams, because nightmares, or the reported distress associated with the nightmare experience, are related to psychological disturbance (Claridge, Clark & Davis, 1997; Levin & Fireman, 2002), the findings of Framo et al. (1962) are consistent with results presented in this thesis.

6.3.2.2. Recurrent dreams and nightmares

Zadra et al. (2006) utilized the Dream Threat Scale of Valli and Revonsuo (2000) in a Canadian sample to explore threatening events in recurrent dreams. They aimed to clarify whether recurrent dreams could be seen as exemplary cases of threat simulation dreams, as suggested by Revonsuo (2000b). The data was collected with a retrospective questionnaire, from subjects recruited to studies on dreams and personality. One dream report was selected from each participant, although some of them reported more than one recurrent dream. Desjardins and Zadra (2004) also explored with the DTS the extent to which nightmares could be interpreted as extreme threat simulation dreams The data was collected using a two- to four-week dream diary, and from the diaries, a maximum of two nightmares per subject were randomly selected.

The overall threat frequency in recurrent dreams and nightmares was strikingly similar to dreams collected with systematic dream diaries from university students, with two thirds of dreams including threats. This indicates that recurrent dreams and nightmares simulate threatening events equally often as normal dreams but not more frequently. The quality of threats, however, was different in normative and recurrent dreams and nightmares. Threatening events including aggressive components were more prominent in recurrent dreams and nightmares than in normative dreams while accidents and failures are less frequent (Desjardins & Zadra, 2004; Zadra et al., 2006). Cases of disease or illness were never simulated in these special types of dreams. Recurrent dreams and nightmares concentrated on simulating specifically life-threatening situations: sixty-five percent of all threats in recurrent dreams, and seventy-two percent in nightmares, were life-threatening whereas minor mishaps were seldom the topic of threat simulations. This finding is very specific for recurrent dreams and nightmares, indicating that these special dreams seem to focus on very primitive, extreme types of threat simulations.

Zadra et al. (2006) also report interesting findings concerning the reactions of the dream self to threatening events. In recurrent dreams, the dreamer actively fought the threat in 34% of cases, fled from the event in 39%, or did both (5%). Similarly, in nightmares 58% of threatening events were met by fighting or fleeing the situation. Zadra et al. (2006) also investigated the factors behind the inactivity of the dreamer, and found that in 21% of threats the participation could not be coded for due to missing information, in 15% the dreamer did not participate because it was impossible (dreamer was not present in the situation, or the threat had already taken place), in 5% of cases someone prevented the dream self from participating, and in only 2% of cases the dreamer was passive or indifferent to the situation. In sum, inactivity of the dreamer most often results from external factors that prevent participation, not from passivity on behalf of the dreamer.

Surprisingly, completely realistic threats accounted for only one quarter of all threats in recurrent dreams, unlikely but possible threats one third, and fictitious threats constituted the majority (40%). Recurrent dreams thus seem to include more unrealistic and bizarre threat simulations than normative dreams. Nightmares fall somewhere between normative dreams and recurrent dreams, as more than half of the threats in nightmares were realistic, a quarter realistic but unlikely, and a quarter fantasy- or fiction based.

6.3.2.3. Earliest remembered dreams

Bulkeley, Broughton, Sanchez and Stiller (2005) tested several dream theories in a sample of 85 earliest remembered dreams (ERDs). They interviewed people of varying ages and collected the first dream the person remembered that he or she had ever had. The earliest remembered dreams originated from ages between 3 and 12, and twenty-two of the reported dreams were described as recurrent (19%). The dreams were content analyzed with the classic Hall and Van de Castle (1966) method. Physical aggression was strikingly frequent in ERDs when compared to Hall and Van de Castle (1966; Domhoff, 1996) norms, and almost all of it was directed against the dream self.

Bulkeley et al. (2005) also studied the motifs and themes in the ERDs from the following perspectives: wish-fulfilment dreams, flying dreams, titanic dreams, mystical dreams, and threat simulation dreams. A majority of dreams (61%) included explicit threat themes, and altogether, three quarters of dreams were considered as unpleasant or disturbing. Bulkeley et al. (2005) interpreted the results from theoretical perspectives proposed by Freud (1900/1965), Jung (1965; 1974), Foulkes (1982; 1999), Domhoff (1996; 2003), and Revonsuo (2000a), and concluded that the threat simulation theory received strongest support in the context of ERDs. Nevertheless, as the earliest remembered dreams tend to be unpleasant and disturbing, thus more comparable to nightmares and recurrent dreams than to normative dreams, they are not the most representative sample to test any dream theory. On the other hand, ERDs test directly the TST's prediction that the evolutionary bias to simulate threats should be at its strongest early in life (Revonsuo, 2000a), and this prediction receives further support from the results of Bulkeley et al. (2005).

6.3.2.4. Most recent dreams

Malcolm-Smith and Solms (2004), and Malcolm-Smith, Solms, Turnbull and Tredoux (in press, a) have recently studied the effect of threatening real life events on dream content. They have, however, used much narrower threat identification criteria than the one used in the present thesis, including only realistic direct physical threats to the dream self. Thus, their results are not directly comparable to ours, but may be best comparable to our results on life-threatening and physically dangerous dream threats.

Malcolm-Smith and Solms (2004) collected, by applying a questionnaire in the classroom, 401 most recent dreams (MRD). The term most recent dream may be slightly misleading as the dream the subject happens to recall may, as a matter of fact, originate from the previous night or as far as from months ago. In this study, the subjects were South-African university students, of whom 44.6% reported an exposure to a real life threatening event. In Malcolm-Smith et al.'s (in press, a) study, participants were also undergraduate psychology students at the University of Cape Town in the Western Cape, South Africa (*n* = 208), and in addition from the University of Wales in Bangor, UK (*n* = 116). This latter study was designed to test differences in threat simulation system activation in these student samples, because there is a marked contrast across the regions with high levels of violent crime occurring in the Western Cape, and a low level in the Wales. Approximately half of South African participants in this sample had experienced a life-threatening event during the past four years, compared to one fifth of Welsh participants. Again, most recent dreams were collected with a retrospective questionnaire.

In Malcolm-Smith and Solms's (2004) study, approximately every fifth most recent dream (21.2%) included an event threatening the dreamer's physical well-being, of which about one third were life-threatening (8.5%). Successful threat avoidance responses took place in half of the threats (13% of all threats; 2.7% of all dreams). In Malcolm-Smith et al.'s (in press, a) study, the MRD reports of

Welsh participants contained more realistic physical threats than those of South Africans (18.63% vs. 8.65%). Thus, the students living in the low crime context reported a higher proportion of threat dreams.

Malcolm-Smith and Solms (2004) and Malcolm-Smith et al. (in press, a) interpret these results as falsifying evidence for the predictions of TST. They regard that the TST is incorrect in predicting that threatening events are more frequently experienced in dreams than in waking life, and that exposure to real ecologically valid threat cues fully activates the threat simulation system. These interpretations are, however, open to some criticism. The following critical comments are mainly based on Revonsuo and Valli (in press).

First, in both studies the incidence of dream threats and threats encountered in the waking life was measured by collecting 1) only a single most recent dream, that is, a report that covered only a few minutes of the subject's dream life, and 2) an autobiographical threat incidence history, that is, a report that covered the subject's entire lifetime (Malcolm-Smith & Solms, 2004) or the most recent four years (Malcolm-Smith et al., in press, a). Thus, the two sample ranges are inherently incomparable, as years of subjective experiences during wakefulness were contrasted against maybe five minutes of subjective experiences during sleep (Revonsuo & Valli, in press).

Second, the MRD data collection method delivers an inadequate sample of an individual's dream life to tell us much about the threat-simulation system. In MRD, an individual's entire dream life is represented by one single spontaneously recalled dream report. This report is not written down immediately after waking up, but with an unknown delay of several hours, days, or even weeks. Furthermore, immediately after having had the dream, the subject has not had any intention, motivation, or practise, to formulate accurate long-term memories of the dream. The subject only finds out that he or she is a participant in dream research when the questionnaire is presented to him or her perhaps days or weeks later. Therefore, a sample of dream reports collected with this method is biased and too limited compared with more systematic data collection methods. MRD is bound to represent only a distorted fragment of the richness of an individual's dream life, including his or her dream threats. Consequently, the MRD studies are not methodologically valid tests of the prediction of TST that threatening events are overrepresented in dreams (Revonsuo & Valli, in press).

Furthermore, when using the MRD method to study dream threats, the results do not seem to be reliable or replicable. When we compared the recent results of Malcolm-Smith et al. (in press, a) and their previous results reported in Malcolm-

Smith and Solms (2004), we observed large variation in the results despite identical methods and comparable subject samples (Revonsuo & Valli, in press). In the previous study, Malcolm-Smith and Solms (2004) report that 21.2% of 401 MRDs collected from South-African university students included a threat to physical survival of the dream self. In the second sample of 208 MRDs (Malcolm-Smith et al., in press, a), also collected from South-African students (that is, the samples should be comparable in all respects), the threat inclusion rate was 8.65%. A significant difference in the results thus emerged. Malcolm-Smith et al. (in press, b) later reported that these samples were independent. This, in turn, indicates that MRD is not the most reliable method for studying dream threat content.

Third, Malcolm-Smith and Solms (2004), and Malcolm-Smith et al. (in press, a) have not measured the graded activity level of the threat-simulation system in any way that would allow an estimation of the level of activation of an individual's threat simulation system in terms of the quantity and the quality of the threatening events produced by the system (Revonsuo & Valli, in press). In fact, individuals and dreams in their samples are represented dichotomously. Each individual has contributed only one single dream report to the data set, and that report has been classified as either including a "realistic physical threat to survival of dream self" or not. Thus, the chosen measures represent a variable as dichotomous although in reality the phenomenon (the graded activity level of threat-simulation system) is continuous. This way of measuring the "graded activity level" of the system is invalid, as it is incapable of detecting any gradation in the activity level at the individual level. What Malcolm-Smith and Solms (2004) and Malcolm-Smith et al. (in press, a) actually do report in their studies is the proportion of individuals who, when asked to describe a single dream, describe a dream with a "realistic physical threat to survival of dream self".

Another issue is that Malcolm-Smith and Solms (2004), and Malcolm-Smith et al. (in press, a) use a very narrow definition of dream threat (Revonsuo & Valli, in press). Their definition only includes "*realistic physical threats targeted against the dream self and directly relevant to survival*" (in the ancestral environment). While this surely is an important category of threats, it does not cover all the different kinds of threatening events that potentially endangered the reproductive success of our ancestors (that is, that threatened their *inclusive fitness*). The threat simulation theory itself does not imply such a narrow definition of threats, but takes threats to be any adverse events that potentially endanger future reproductive success. In the ancestral environment, these would have included such things as injury or death of close genetic relatives, social isolation or rejection by group members, loss of valuable material resources (tools or weapons, hunting grounds, sources of nutrition etc.), or loss of social status. Although these threats are not necessarily classified as life-threatening or physical threats, there is little doubt that they were highly important for an individual's fitness in ancestral populations, that is, for future reproductive success.

Finally, if we adopt the view that threatening events are repetitively simulated in dreams, throughout the night in subsequent REM periods (and most likely also during NREM sleep), the data presented by Malcolm-Smith and Solms's (2004) and Malcolm-Smith et al. (in press, a) can be compared with repetition rates calculated from other datasets (Valli & Revonsuo, in press). Their data, then, turn out to be consistent with ours. If we assume that the students in Malcolm-Smith and Solms's (2004) and Malcolm-Smith et al.'s (in press, a) study have 3.3 REM dreams per night (as estimated for Finnish and Swedish university students), and as the reported results indicated, 8.7% to 21.2% of dreams include either a life-threat or a threat to physical well-being, the subjects will consequently encounter, on average, 105 to 255 threatening dream events per year. The annual frequency estimations of life-threatening and physically dangerous events based on Malcolm-Smith and Solms's (2004) and Malcolm-Smith et al.'s (in press, a) data are, in fact, higher than our conservative annual threat simulation estimates (80 life threatening and physically dangerous events), although lower than our liberal estimates (427 life threatening and physically dangerous events). Thus, when the perspective of threat repetition rates is taken, Malcolm-Smith and Solms's (2004) and Malcolm-Smith et al.'s (in press, a) data seems to actually support the predictions of the TST approximately to the same extent as our data. It would also seem that 105 to 255 severely threatening events in dreams per year must vastly outnumber the frequency of threats with comparable severity in the real lives of the studied individuals, supporting the finding that dream threats are more frequent and more dangerous than real threats (Valli et al., 2008).

6.3.3. Proposition 3.

Real threat experiences trigger the activation of the threat simulation system and the material for dream simulations is derived from episodic LTM

The TST claims that the triggering and construction of threat simulations is systematically modulated by the negative emotional charge attached to the episodic memory traces in the amygdala-centred "hot" emotional memory systems (Revonsuo, 2000a). The currently available evidence from both dream content and brain imaging studies seems to offer support for these predictions, although more direct tests are needed.

First, several previous studies on traumatized individuals' dreams, already mentioned in the original publication of the TST (Revonsuo, 2000a) have shown that posttraumatic nightmares are commonly reported by both children (Nader, 1996; Nader, et al., 1990; Pynoos & Nader, 1988; Pynoos, et al., 1987; Terr, 1979; 1983) and adults (Barrett, 1996; Hartmann, 1984; 1996; 1998; Lavie, 1996; Wilmer, 1996) who have been exposed to life-threatening events. Other older, and many new studies, as well as reviews in the field of trauma and dreams offer confirmatory findings (Esposito, Benitez, Barza & Mellman, 1999; Kuch & Cox, 1992; Levin & Nielsen, 2007; Schreuder, van Egmond, Kleijn & Visser, 1998; Schreuder, Kleijn & Rooijmans, 2000; van der Kolk, Blitz, Burr, Sherry & Hartmann, 1984; Wittmann, Schredl & Kramer, 2007; Wood, Bootzin, Rosenhan, Nolen-Hoeksema & Jourden, 1992). Even simply watching highly traumatic real events on television, such as the 9/11 attacks, has an impact on dream content (Hartmann & Brezler, 2008; Propper, Stickgold, Keeley & Christman, 2007).

Second, Peterson, Henke and Hayes (2002) recently tested the idea of the TST that dreams are an evolutionary mechanism designed to facilitate the rehearsal of coping strategies in dangerous situations. Their study was based on the fact that the limbic system is active both during times of threat and during REM sleep. Consequently, they hypothesized that individuals with relative limbic hyperfunction, as indexed by increased scores on the Limbic System Checklist (LSCL-33), would report more threatening dream content. They measured threat content in dreams by a recollection of the Most Recent Dream. Subjects who received high scores on LSCL-33 reported more threatening dream content than subjects with low scores in limbic system function (Peterson et al., 2000). In addition, subjects who attained low scores in limbic system function reported more pleasant dream content (Peterson et al., 2000). Participants with limbic system hyperfunction also reported recurrent dreams with more threatening dream content while subjects with low limbic system function had more pleasant recurrent dreams (Peterson et al., 2002). The results of Peterson et al. (2002) thus support the idea that the limbic system plays a role in the generation of threatening dream content.

Third, the amygdaloid complexes and those brain areas receiving abundant amygdalar efferents are highly active during REM sleep and dreaming (Braun et al., 1997; Dang-Vu et al., 2005; Hamann et al., 1999; Maquet, 1999; 2000; Maquet et al., 1996; 2004; Schwartz et al., 2005; Schwartz & Maquet, 2002). This indicates that episodic memories paired with emotional stimuli, especially aversive and threatening stimuli, are activated and processed during dreaming, thus most likely contributing to negatively biased dream content. Amygdaloid activity during REM sleep is also highly compatible with the findings of the present thesis that the threat simulations are constructed from negative and threatening episodic memory traces (Valli et al., 2008), and that the threat simulation system functions more actively in traumatized than nontraumatized individuals, producing more frequent and more severe threat simulation dreams (Valli et al., 2005; 2006).

There might, however, be interindividual differences in the sensitivity to produce threat simulation dreams. Whether these differences are innate, due to environmental factors, or require an interaction between genetic and environmental components (as most psychological characteristics do), some people may be more prone to threat simulation dreams than others (for example, due to ontogenetically early exposure to life threats, or those with limbic hyperfunction as suggested by Peterson et al., 2002). In fact, an evolutionary hypothesis of the function of dreaming readily accepts, even demands, variation within the population in the dream production and threat simulation activity. Thus, the findings that some people have high dream recall and threat simulation rates whereas other report never having dreamed (Pagel, 2003) are compatible with an evolutionary approach to dreaming.

6.3.4. Proposition 4.

Threat simulations are behaviorally and perceptually realistic

As far as the brain mechanisms responsible for the planning and execution of motor commands are concerned, mentally simulated actions are equivalent to real actions (Decety, 1995; Jeannerod, 1994; 1995). Recent evidence from REM dreams supports the notion that dreamed actions are compatible with neural simulations of real actions (Erlacher & Schredl, 2008). Moreover, motor skills practised during lucid dreams in REM sleep seem to lead to improved skills on subsequent real performance (Erlacher, 2005), although the results need to be replicated in larger samples.

Motor commands are created at the cortical level, but their execution is inhibited by the brain stem mechanisms producing muscular atonia during REM sleep. The TST predicts that if the muscular atonia during REM sleep is removed, we should be able to observe, in the physical realm, behaviors that the dreamer is simultaneously performing within the dream (Revonsuo, 2000a). Complex behaviors manifesting during REM sleep have been studied in cats by surgically removing REM sleep atonia. REM sleep without muscle tone leads to species specific behaviors in cats, inducing postures and motions typical for visual exploration, orienting, searching, stalking, running, hunting, predatory aggression and attacking, but also for fear, defence and rage (Jouvet, 1999; Morrison, 1983).

Anecdotal evidence concerning whether the movements performed within the dream context are isomorphic to real movements carried out simultaneously in the physical realm is available from REM sleep behavior disorder (RBD) patients. According to Schenck (1993), there is a very close link between the actions performed within the dream experience and the observed enacting behaviors. In the very first RBD study by Schenck, Bundlie, Ettiger and Mahowald (1986), three of the five studied patients directly linked dreaming with sleep behaviors, and the relationship was inferred by the spouses of the two other patients. Similar cases have also been reported by Boeve, Silber, Ferman, Kokmen, Smith, Ivnik, et al. (1998), Comella, Nardine, Diedrich and Stebbins (1998), and Dyken, Lin-Dyken, Seaba and Yamada (1995). Upon awakening after manifested movements, the explanation for the taken actions in 87% of the RBD patients is of defence against attack (Olson, Boeve & Silber, 2000). Thus, dreamed actions seem to isomorphically correspond to real actions, and dream enactment behaviors seem to be elicited especially by threatening dream content.

Nevertheless, only few systematic studies have been conducted on the nocturnal movements and dream content of RBD patients. Fantini, Corona, Clerici and Ferini-Strambi (2005) compared, in an interview study, the dream content of RBD patients to the dream content of age- and sex-matched controls, also accounting for levels of daytime aggressiveness. The dreams were analyzed with the Hall and Van de Castle system (1996; Domhoff, 1996; 2003). Fantini et al. (2005) found that RBD patients' dream content is characterized by increase in aggressive contents, especially in physical aggressiveness, without simultaneous increase in the levels of daytime aggressiveness. This study does not, however, provide an answer whether nocturnal enactment behaviors are directly linked to dream content, and especially to threatening dream content. Fantini et al. (2005) and Fantini and Ferini-Strambi (2007) acknowledge, however, that RBD may originate from an inappropriately activated threat simulation mechanism, leading to intense threat simulation dreams and enacted behavioural responses. This interpretation of RBD was first proposed by Revonsuo (2000a), and the data that has emerged seems to support the idea that RBD (and some other parasomnias) involve an overactivated threat simulation system.

Santamaria, Carrasco, Kumru, Iranzo, Pintor, De Pablo, et al. (2004) also compared, in a sleep laboratory study, the dream content of RBD patients to that of healthy controls, and found that dreams with violent or highly anxious content were only reported by patients. Furthermore, they compared the dream recall frequency and dream content to the intensity of nocturnal movements, and discovered that dream recall increased with intensity of movements, but that severe movements were not always linked to dream recall nor to violent or highly anxious dream content. Thus, the exact relationship between nocturnal enactment behaviors and dream content remains unclear. The currently available evidence suggests that dream content and nocturnal movements are, at least sometimes, directly causally related to each other, although they may also occur independently, dissociated from each other.

6.3.5. Proposition 5.

Repeated rehearsal leads to improved performance, even in the absence of recall of the training episodes

The TST states that through implicit memory, and especially procedural learning, simulation training is likely to lead to improved performance in real threat avoidance situations (Revonsuo, 2006). Glisky (1992), Glisky, Schacter and Tulving (1986), Glisky and Schacter (1988; 1989), and Schacter (1996) have shown that enhancement in subsequent performance can be gained even by amnesic patients who have no recall of training episodes. Therefore, if people were deprived of dreaming, their performance in tasks requiring implicit memory should deteriorate. At the moment, in the absence of any physiological marker for dreaming, it is impossible to deprive people of dreams without simultaneously preventing them from being asleep. Nevertheless, as dreaming is tightly coupled with REM sleep, REM sleep deprivation should have a detrimental effect on performance requiring implicit or procedural memory or skills rather than on explicit semantic or episodic representations.

The role of sleep in learning and memory consolidation is a vastly researched topic, and too extensive to be reviewed here in detail, especially as few studies in the field are directly related to the TST's predictions. Although the results have varied, and even been contradictory, there now seems to be compelling evidence that sleep promotes the long-term consolidation of declarative and procedural memories (for recent reviews, see for example Ellenbogen, Payne & Stickgold, 2006; Marshall & Born, 2007; Stickgold & Walker, 2007). Smith (1995) found that memory for implicit procedural tasks is impaired by REM sleep deprivation, while the memory for explicit tasks is not. Hippocampus-dependent declarative memory seems to benefit particularly from slow-wave sleep (SWS), whereas REM sleep seems to benefit procedural aspects of memory (for example, Marshall & Born, 2007). Thus, recent evidence seems to lead to a conclusion that unique neurobiological processes within sleep actively enhance memories, thus supporting the idea that REM and dream deprivation lead to deficits in implicit learning.

Martinez-Gonzalez, Obermeyer, Fahy, Riboh, Kalin and Benca (2004) studied, in rats, the effects of REM deprivation on defensive and coping behaviors elicited by threatening stimuli. They found that REM sleep deprived rats spent more time on open fields, had decreased freezing time and exhibited less defensive burying behavior, that is, the species-typical threat avoidance and coping behaviors were widely affected by REM deprivation. Even the administration of amphetamine to compensate for sleep loss did not reverse the harmful effects of REM deprivation, and in some cases, the deficits were even exacerbated. Thus, loss of dreaming through REM deprivation might result in weakened threat avoidance responses also in humans, although dreaming and REM sleep are not identical concepts to each other, and should not be confused.

6.3.6. Proposition 6.

Ecologically valid threat cues in the ancestral environment fully activated the threat simulation system and an active threat simulation mechanism led to enhanced reproductive success

Consider that the threat simulation system develops and matures from early childhood on, as soon as the child is capable of perceiving and recognizing threats in his or her environment. In the ancestral environment, real ecologically valid threat cues were ever present, for instance, in the form of encounters with wild animals, and fully activated the threat simulation mechanism. Nightmares have been reported by children as young as two-year-olds, and are prominent in three to six-year-olds (Hartmann, 1998). The themes are often about being chased or hurt (Hartmann, 1998). Thus, under ideal ecologically valid conditions, that is, an ancestral environment full of threat cues, the threat simulation system was most likely activated by the age of six, probably before (Valli & Revonsuo, in press).

Ontogenetically early activation of the simulation system is essential if the person is to be able to respond efficiently to environmental demands as soon as he or she faces them. As the mean life expectancy in Pleistocene humans was well below 25 years (Meindl, 1992), the critical period when an active threat simulation system would have yielded survival benefits would have been after the child started to explore the world independently and before his or her offspring was old enough to survive independent of parental care (Valli & Revonsuo, in press). Thus, in the ancestral environment the greatest benefits offered by an active threat simulation system would have been approximately between ages six and twenty. Altogether, a person who lived long enough to produce offspring, and raise them to the age when they were able to provide for themselves, would have been simulating threats in his or her dreams for about fifteen years.

Threat scenarios are, based on our liberal threat simulation rate estimates, encountered several times per night, and up to 1 600 times per year or more, although we only remember a small proportion of them. The dreamer engages in hundreds of REM dream threat simulations that deal with aggressive situations, failures and accidents, which most often threaten the dreamer. The dreamer also repeatedly uses relevant and efficient defensive tactics to avoid the threats. Even though about half of the REM dream threat simulations in nontraumatized subjects deal with minor mishaps in the current western adult populations, the other half, that is almost thousand simulations, focuses on mimicking events that would endanger the future reproductive success of the individual if experienced during waking hours.

The liberal threat simulation rate estimate was based on what is currently known about dream recall frequency when awakened from REM sleep, assuming that only one dream per each REM period takes place. However, as REM periods become longer towards the morning, they might include more than one dream experience or more than one threat. At least, the dreams experienced in later REM phases are longer if not more numerous. Dream report word count and the subjectively estimated duration of dreams increase with length of preceding REM stage (Dement & Kleitman, 1957; Stickgold, Pace-Schott & Hobson, 1994). We already know that the number and length of dream reports (thus probably also the underlying length of dream experience) correlates positively with the number of threat simulations: The more and the longer the dream reports, the more threatening events they include (Aitta-aho, 2006; Valli et al., 2007; 2008). In contrast, the quality of threatening events in short vs. long threat descriptions is not statistically significantly different (Valli, Suominen & Revonsuo, unpublished result). Thus, we could expect more numerous threat simulations in late versus early night REM stages. Consequently, the estimated threat repetition rates could well undermine the true simulation rates.

Further, threat simulations may not be linked only to length of REM periods, but also to intensity of REM sleep. The intensity of REM sleep is measured by the level of phasic activation (for example, number of eye movements), and the intensity of REM sleep increases progressively across successive REM periods (Takahashi, 1999). Thus, threat simulation in dreams might be less frequent in early than late night REM periods, that is, when REM sleep is less intense. Strauch and Meier (1996), however, conclude in their review that more strongly activated REM sleep (measured by level of phasic activation) is not necessarily linked to particularly vivid and intense dreaming. Consequently, the exact relationship between the intensity of REM sleep and the number or quality of threat simulations remains open to investigation.

As mentioned previously, dreaming is not restricted only to REM phase of sleep, but also occurs in NREM sleep. Average dream recall rate in NREM awakenings is 43% (*SD* = 20.8, range = 0% - 75%) (Nielsen, 2000), that is, half as frequent as in REM awakenings. Although the debate whether REM and NREM dreams are qualitatively similar is ongoing (Fosse et al., 2001: Hobson et al., 2000; Nielsen, 2000; Strauch & Meier, 1996), the conclusion that can be currently made is that full-blown off-line world simulations are more likely to be present in REM sleep dreams than in NREM sleep dreams, and in late NREM than in early NREM dreams. Regardless, full-blown world simulations are present in some proportion of NREM dreaming. This suggests that threat simulation is not restricted to REM sleep, but occurs whenever the brain manages to produce complex contents of phenomenal consciousness that amount to a world simulation. Consequently, the combined threat simulation rates from NREM and REM sleep are probably much higher than estimated only for REM dreams.

If the liberal estimation of annual REM dream threat repetition rate is even close to the actual minimum threat simulation rate, fifteen years of dreaming in the ancestral environment would have amounted to over twenty-five thousand threat simulations during an ancestral individual's most productive years, that is, between ages of six and twenty. This estimation is, nonetheless, calculated from the dreams of modern day students that have not been frequently exposed to severe threats in their environment. Compared to Scandinavian university students, our ancestors lived in an environment full of dangers and were much more often exposed to real severe threatening situations. Exposure to real threatening events would probably have rendered the estimated threat repetition rates higher, and the threat simulations more severe, as indicated by the data from traumatized children. Furthermore, sleep length seems to have decreased in the modern environment. Although historical data is hard to come by, and we have no rates for average sleep duration in ancestral environment, in Finland in the past 33 years sleep length has decreased by 18 minutes (Kronholm, Partonen, Laatikainen, Peltonen, Härmä, Hublin, et al., 2008). In the United States, the decrease has been 0.3 hours, that is, 18 minutes, during the past six years (The National Sleep Foundation, 2002; 2008). Even though the exact decrease in average sleep length from Pleistocene to present is unknown, our ancestors most likely slept longer, and children and adolescents slept longer than adults (as also nowadays). Thus, ancestral humans between ages of six and twenty most likely had one extra REM period per night compared to modern humans. Further, the younger the individual, the higher the proportion of REM sleep compared to total sleep time (Roffwarg et al., 1966). An extra REM period and proportionally more REM sleep probably equals to more dreams and more threat simulations. Consequently, twenty-five thousand threat simulations during an individual's life span in the ancestral environment is likely to be an underestimation.

In the Pleistocene environment, major causes of death included infectious diseases, parasites and poor living conditions, exposure to natural elements, risky activities in food acquisition, predation by large carnivores, and aggressive encounters with conspecifics (Dobson, 1992; Landers, 1992; Meindl, 1992). How are the various most likely causes of death reflected in the dream content of modern humans? Is the threat simulation system still wired in such a way that it is more sensitive to simulating events most critical in the EEA? What exactly were the most critical events in the EEA like, in terms of stable and recurrent selection pressures and overt threat avoidance responses? After all, threats that cannot be avoided are useless to rehearse.

The matches between the nature of dream threats and the threats most beneficial to simulate in the ancestral environment are striking. Aggressive encounters in defence of territories or valuable property, both between and within group rivals, were likely regular features of the social environment, and the rehearsal of how to deal with such threats could have led to better chances of survival. Risky activities during hunting and gathering, such as avoiding predators and other harmful animals, or accidental injuries or other misfortunes, were probably frequently encountered. Behavioral strategies to avoid such dangers were various and could have been rehearsed in different combinations in dreams, as indicated in the amount of threats focusing in escapes, accidents and misfortunes.

As we now know, disease and illness are seldom simulated in dreams. Not surprisingly, infections and diseases are hard to avoid, and in the absence of medication, difficult to cure. Thus, simulating infectious illnesses and how to deal with them would have been rather futile in the EEA. The avoidance of macroparasitic agents or poisonous animals, detectable with a naked eye, such as Helminth worms or snakes, scorpions and spiders, is easier. In fact, we have natural defences, for example, disgust and fear reactions, to help us avoid many unhealthy substances (faeces, bloody wounds, contaminated foods) or harmful animals. Thus, the simulation of these types of dangers in dreams, that is, scary or disgusting animals, might have been useful for our ancestors. Insects, spiders and snakes are, in fact, one of the universal dream themes, although not on the top of the list (Nielsen et al., 2003). In addition, exposure to natural elements, such as cold, drought, or storms, was probably frequent in the evolutionary environment, whereas large scale catastrophes were likely rare. Thus, rehearsing how to survive a large scale natural disaster would not have been very effective, as there were no stable and recurrent selection pressures of such kind to begin with, and on the other hand, one could do very little to avoid such perils.

To summarize, the main components of effective threat simulation, that is, perception and recognition of the threatening agent, and the selection and implementation of an efficacious behavioral strategy, are rehearsed frequently in dreams. During an individual's life span threat recognition and avoidance is practiced thousands or tens of thousands of times (Valli & Revonsuo, in press). But would the estimated amount of threat recognition and avoidance rehearsal have been sufficient in our ancestors' lives to lead to maintained or improved performance in subsequent comparable real situations? I argue that even if we assume that the mean threat simulation frequency was about the same in our ancestors as in modern day nontraumatized students, and there was similar variation in threat simulation frequency in the population, it might well have been enough in the original evolutionary environment to result in differential reproduction rates between those who frequently simulated threats in their dreams and those whose threat simulation mechanism was poorly activated.

6.4. The strengths of the TST

The TST correctly predicts that threatening events are more frequent and severe in dreams than in waking life, that the threats are mainly targeted against the dream self and significant others, that the threat simulations are largely realistic, and that the dream self engages in relevant reactions that would also be adequate and efficient in a comparable waking life situation. Furthermore, the threat simulations are constructed from episodic memory traces containing the highest negative emotional charge, as opposed to recently encoded memory traces representing minor everyday mishaps. Similarly, the prediction that only personal exposure to ecologically valid threat cues in the environment fully activates the threat simulation mechanism is supported by evidence from dreams of traumatized and nontraumatized children.

If we rank the dream content studies exploring threatening events in dreams, the proportion of dreams containing threatening events is highest in the sample of severely traumatized Kurdish children, intermediate in nontraumatized adults and lowest in nontraumatized Finnish children who have had very little exposure to any threatening events in their environment (Revonsuo & Valli, 2000; Valli et al., 2005; 2006; 2007; 2008). Even in adulthood, nontraumatized individuals do not reach the threat simulation levels present in traumatized children.[5] In individuals not exposed to ecologically valid threat cues the threat simulation system develops and matures slower, and consequently the threat simulation dreams remain less frequent and milder, exactly as was predicted by the TST (Revonsuo, 2000a, Note 5, p. 899).

The severely traumatized children's dreams also include more severe threat simulations than nontraumatized children's dreams or normative dreams, as postulated by the TST. Notably, nontraumatized children's dreams include a higher proportion of

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[5] Note that if we look at the mean number of threat simulations per dream, not the proportion of dreams including at least one threat, nontraumatized adults have the highest ratings. Thus, many of their dream reports include more than one threatening event, whereas children's dreams, or at least their relatively short dream reports, focus on simulating single and separate events.

life-threatening events than nontraumatized adults' dreams. Similarly, aggressive threats are extremely prominent in traumatized children's dreams, but also frequent in nontraumatized children's dreams compared to nontraumatized adults dreams. In contrast, average participation rates are significantly lower for all children than for adults.

A finding posing a problem to the TST is that, although reactions to the threats are almost always relevant and adequate, not all threat simulation dreams allow the rehearsal of reactions. On average, more than one third of threat simulations are interrupted by discontinuity or awakening, or for some other reason the dream report lacks a description of a reaction. People, nevertheless, also fail to report their reactions when writing daily logs or recalling long term autobiographical threat descriptions.

Another finding that partially contradicts TST's assumption is that children traumatized by modern military violence do not react to the threats proportionally more often than nontraumatized children. Nevertheless, proportions do not tell the whole story. Even though the percentage of reacting to threats is not higher in dream reports of traumatized children, they get much more practice in total because the absolute threat simulation frequencies in their dreams are significantly higher to begin with.

An explanation for low participation rates may be that exposure to military violence may not well model ancestral threats. The children were likely to be helpless and overwhelmed in the face of military violence, unable to react to or protect themselves from these types of threats. Thus, the finding that reacting to threats is often absent in dreams of war-traumatized children may only be a realistic reflection of threats they have encountered in their waking lives, and of the possibility to react to these kinds of threats.

The proportion of normative dreams including threatening events is about equal (Revonsuo & Valli, 2000; Valli et al., 2007; 2008) to the proportion of recurrent dreams and nightmares including threats (Desjardins & Zadra, 2004; Zadra et al., 2006), although the severity of threats is significantly graver in special than normative dreams. Threats including aggression are especially frequent in recurrent dreams and nightmares compared to normative dreams. Also the participation rates are highest in recurrent dreams and nightmares, and the behavioral strategies employed in avoiding the threats consist mainly of fight- or flight –responses. These results fit nicely to the predictions of the TST that recurrent dreams and nightmares are paradigm cases of intense threat simulation dreams.

Even though the most prominent themes of recurrent dreams and nightmares are that of the dreamer being chased or attacked (Robbins & Houshi, 1983; Zadra, 1996; Zadra & Donderi, 2000), and the most often experienced affects fear and apprehension (Zadra, 1996), in threatening situations the degree of realism is lower in nightmares, and especially in recurrent dreams, than in normative dreams. The threats in recurrent dreams and nightmares are more often based on fantasy or fiction than the threats in normative dreams. An explanation might be that in the modern environment fictional threats (such as seen in movies) may well be the most emotionally salient and powerful threat cues we are exposed to. In the absence of ecologically valid real threat cues, the most intense threat simulations are constructed from any memory source containing the highest negative emotional charge, and thus fictional threats, based for example on horror films and science fiction movies, end up being simulated in our dreams.

Nevertheless, not all fiction-based threats are necessarily inefficient simulations. Rehearsing how to escape from the jaws of a werewolf or a vampire might be just as efficient as running away from a regular human character or a wild animal. In fact, these types of exaggerated threatening agents may even increase the emotional activation level, and consequently make the focusing of attention to the threat more intense, and the motivation to escape it or defend oneself stronger, thus rendering the threat simulation more efficient. These claims, however, require empirical testing.

To sum up, the TST takes into account the selection pressures most likely present in the human ancestral environment. It proposes a plausible explanation for how dreaming of negative and threatening events might have provided a slight advantage to our ancestors in maintaining and enhancing their threat recognition and avoidance skills. By referring to a single threat simulation mechanism it furthermore manages to explain a wide variety of dream content data that already exists in the research literature, and to predict the overall statistical patterns of threat content in different samples of dreams. Moreover, none of the potentially falsifying pieces of evidence, as described by Revonsuo (2000b), has emerged in the literature so far.[6]

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[6] Adopted from Revonsuo (2000b):

1. There is no unique threat simulation response that would be any different from the effects of non-threatening, positive events
2. There were ancestral threats that posed selection pressures on humans, and for which they had potentially efficient, rehearsable behavioral avoidance strategies, but we never dream about such threats.
3. The dreams of children and adolescents who have been exposed to ancestral-like threats from early on do not simulate threats or efficient responses to them in their dreams.
4. There is a population of hunter-gatherers that are a good model of ancestral humans, but whose dreams infrequently include ancestral threats.
5. There is a culture whose members never simulate threats in their dreams.
6. Threat simulation in dreams does not support or improve later perceptual or motor performance

6.5. The weaknesses of the TST

When the TST was originally published (Revonsuo, 2000a), it received a wide range of peer reviewed commentaries, many of them critical. This criticism has been handled in the original author's response (Revonsuo, 2000b), and is thus only briefly reviewed here, for the purpose of bringing forth new evidence or arguments unavailable at the time the author's response was published. The typical counterarguments against the TST include the following.

6.5.1. Memory bias

Conduit, Crewther and Coleman (2000), Mealey (2000), and Montangero (2000) have argued that the results of dream research do not reflect the true nature of dreaming, but rather a sampling bias: the dreams recalled and reported are the emotionally most intense ones, thus a negativity bias is created by selective memory for dreams. Consequently, perhaps the high amount of threat-related content is only the result of selective memory for emotionally charged content (Bednar, 2000; Conduit, Crewther & Coleman, 2000; Mealey, 2000; Montangero, 2000; Thompson, 2000). They suggest that the dream production system itself may not be selective (that is, all types of content, negative, positive and neutral, are represented in dreams), but it is our memory for dreams that is distorted. Thus, all dream research relying on spontaneously reported dreams is inherently flawed.

Chapman and Underwood (2000), Conduit et al. (2000), and Mealey (2000), however, have also pointed out that the memory bias is not unique to memory for dreams, but for all memory processing. Even though emotionally charged dream content is easier to recall than mundane content, the same applies for our everyday memories (Chapman & Underwood, 2000). We tend to forget the ordinary events in our lives, and only remember those that had an emotional impact. When the frequency of threatening events experienced during a specific time period in the waking life was compared with threats simulated in dreams during the same period, it was clear that the dream world contains threats much more frequently than the waking life does (Valli et al., 2008). Thus, when a proper baseline is used for comparison, the memory bias can be avoided.

6.5.2. Bizarreness renders simulations unrealistic

The claim that dreams are so bizarre and disorganized that no realistic simulation of reality or real threats can take place was presented by several proponents of random activation theories (Ardito, 2000; Antrobus, 2000; Flanagan, 2000; Mealey, 2000; Moorcroft, 2000). Nevertheless, as evident in dream content studies, practically all dreams are well-organized simulations of a world including the self, other characters, objects, and a setting or an environment where the dream takes place. Bizarreness disrupts some parts or features of this otherwise coherent organized world, but although dreams include bizarre elements, bizarreness appears to be a relatively small deviation in the otherwise coherently organized dream experience (Revonsuo & Salmivalli, 1995; Revonsuo & Tarkko, 2001; Snyder, 1970; Strauch & Meier, 1996).

In addition, recurrent dreams and nightmares including a high proportion of bizarre threats were otherwise exemplary threat simulations (Desjardins & Zadra, 2004; Zadra et al., 2006), thus indicating that fantasy or fiction -based threats are not necessarily inefficient simulations. In fact, the TST predicts that the threat simulation system is maximally activated by the most negatively charged emotional memory traces, and these traces contain information about the most frightening threatening agents ever encountered. In the current environment, memory traces containing information about real threats can be substituted with memory traces including fictional threats, such as offered by media. These then work as ‘overstimuli’ to the dream production system, which builds frequent threat simulations based on them, producing fiction-based rehearsals. Nonetheless, an analysis of bizarre dream qualities and their effects on threatening events, that is, whether bizarreness renders threat simulations more or less efficient, or has no effect at all, should be conducted to directly answer this critique.

6.5.3. Dream rehearsal does not lead to enhanced skills

There is no evidence that dreams simulate defensive actions, and that dream practice leads to enhanced threat avoidance skills (Domhoff, 2000; Hunt, 2000; Zadra & Donderi, 2000). This criticism that dreams do not simulate defensive actions is not, however, supported by empirical evidence. Our results, as well as the results of Desjardins & Zadra (2004), and Zadra et al. (2006), clearly point out that the dream self reacts to the threats in an appropriate manner in most cases when reactions can and take place, although not in all dreams participating to the threats is possible or reported.

The claim that dream practice does not lead to enhanced threat avoidance is far more complicated to verify or falsify. Thus far, there is no direct evidence of the effect of dream rehearsal (or the lack of it) on performance in threatening situations. Erlacher (2005), however, presents initial empirical evidence of the positive effect of dream and lucid dream rehearsal on subsequent motor performance. His conclusions, nevertheless, are based on laboratory data from single lucid dreamer expert, and on data collected via Internet from 18 subjects. Therefore, before it is possible or recommendable to draw any definitive conclusions of the effect of dream training, more empirical evidence needs to accumulate.

Nonetheless, REM sleep and the maintenance of threat avoidance behaviors seem to be coupled. The violent, vigorous and powerful behaviors of RBD patients show that dream reactions to threatening events during REM sleep are fast, efficient and forceful. Moreover, Martinez-Gonzalez et al. (2004) showed that REM sleep deprivation (and thus possibly the deprivation of dreaming) led to decrease in species-typical threat coping and avoidance behaviors in rats.

In support for a positive effect of mental training during wakefulness, Pascual-Leone, Dang, Cohen, Brasil-Neto, Cammarota and Hallett (1995) found that mental rehearsal alone results in significant improvement in performance in five-digit piano playing exercise compared to the control group. However, the improvement was significantly less than produced by physical practice. Interestingly, Pascual-Leone et al. (1995) also report that mental training led to similar plastic changes in the cortical motor areas controlling finger movements as the actual physical training. Yet, more direct studies are needed to test the effects of mental simulation on performance.

6.5.4. Threat dreams are psychologically dysfunctional

PTSD and frequent nightmares are dysfunctional and disturb sleep, therefore they cannot be regarded as good or functional for the individual who suffers from them (Kramer, 2000; Levin, 2000; Nielsen & Germain, 2000). While it is true that many severely traumatized individuals suffer from sleep disturbances due to terrifying nightmares, there are also reasons to believe that ancestral humans did not suffer from the effects of posttraumatic stress disorder to the same extent as some individuals in the present environment (Revonsuo, 2000b). The threats in the ancestral environment were frequent, and the ancestral humans were most likely adapted to higher levels of stress and trauma from early childhood on than most contemporary humans. Moreover, in the ancestral setting the threats were often related to everyday activities and thus predictable. In contrast, the present environment is relatively safe for most of us, and thus we are adapted to low levels of stress and trauma. Further, many of the threats that we may encounter are not easily predictable from preceding cues, and are thus difficult to avoid.

Also the most severe types of threats in the present environment, such as wars, differ qualitatively from comparable ancestral events to such a degree that the most severe modern threats can be regarded as much more traumatizing than any events in the EEA. In fact, an evolutionary psychological theory on PTSD suggests that PTSD was non-existent or very rare in the ancestral environment, but in the modern environment follows from the discrepancy between adaptation to low levels of stress and rapid, unpredictable exposure to a highly traumatizing event. For example, Christopher (2004), Flannelly, Koenig, Galek and Ellison (2007), and Nielsen and Levin (2007) suggest that primitive brain mechanisms that evolved to assess environmental threats underlie psychiatric disorders, such as PTSD. Psychopathology is thus seen as a function of maladaptive modulation of the stress response (Christopher, 2004; Flannelly et al., 2007; Nielsen & Levin, 2007).

6.5.5. Dreams have many simulations functions

Dreaming simulates so many other things too that surely threat simulation cannot be the (only) function of dreams (Cheyne, 2000; Clancey, 2000; Humphrey, 2000; Nielsen & Germain, 2000; Peterson & DeYoung, 2000). Although some researchers are willing to accept the idea that dreams are simulations of significant selection pressures, they disagree on what types of events are simulated in dreams. Rehearsal of skills such as adjustment to novelty, social interactions, interpersonal understanding, motor functions and spatial learning has been suggested (Brereton, 2000; Bulkeley, 2004; Cheyne, 2000; Franklin & Zyphur, 2005; Humphrey, 2000; McNamara, 2004; Nielsen & Germain, 2000; Peterson & DeYoung, 2000). Thus far, however, none of these suggestions has undergone a similar evolutionary cost-benefit –analysis as the Threat Simulation Theory.

The suggested alternative evolutionary functions involve little costs if practiced during waking hours, while real threats often result in fatal consequences. Thus, fitness benefits for simulating threats during dreaming are higher than for simulating situations that yield no or little costs if practiced during wakefulness. The claim that dreams have other simulation functions than threats is not evidence either for or against TST, and thus irrelevant for the testing of the theory. Still, anyone who puts forth a new statement concerning a new simulation function of dreams also has the burden of proof to show the evidence for the function in question. The proposed alternative simulation function theories await to be empirically tested.

6.5.6. The TST is untestable

Finally, the main concern faced by the Threat Simulation Theory is its empirical testability. For example, Hunt (2000) claims that the Threat Simulation Theory is in principle untestable, and thus cannot be falsified or verified. This concern is not unique only to the TST, but to all evolutionary psychological theories that infer cognitive mechanisms from the selection pressures operating in the evolutionary environment of the species. We will never be able to acquire data that would tell us what our ancestors dreamed about thousands and thousands of years ago. But the more we learn about ancestral life and threats in that environment, the more specific hypotheses we can draw concerning what types of events should be simulated in dreams, and thus, indirectly test whether contemporary dream content is compatible with ancestral selection pressures.

In fact, this whole thesis is a counter argument to the claim that the TST cannot be empirically tested. All of the reported studies in this thesis tested predictions derived from the TST. The question is thus not whether the TST can be empirically tested at all, but rather how directly can it be tested, and here it shares the same weaknesses with other evolutionary and historical hypotheses.

Also, I need to point out that all the predictions of the TST are intended to apply fully only to an ideal model population. The theoretically ideal model population consists of a group of individuals that would mimic a population living in an ancestral environment all their lives. As far as we know, such populations are both extremely rare and difficult to reach for research purposes. Thus, we have to rely on indirect evidence based on the dreams of available subjects who are more or less distant from an ideal sample.

6.6. How to test TST in the future?

Despite the support offered for the TST by the present thesis and other related studies, many of its predictions still remain untested, or require further testing. Tooby and Cosmides (1995) have pointed out that adaptations are well-organized and represent such a good engineering solution to the specific adaptive problem that it would be extremely unlikely for the solution to have arisen by chance. However, there are no strict criteria for what kind of evidence can be interpreted as yielding the phenomenon under investigation as "extremely unlikely to have arisen by chance". Thus, the decision of whether a certain property or a trait is an adaptation is, in the end, based on a probability assessment (Tooby & Cosmides, 1995). This probability assessment can only be made after all the evidence for or against the predictions under investigation is reviewed. Thus, I cannot state with certainty whether the threat simulation system is an adaptation or not, but I can present the currently available evidence, and offer a probability assessment of the likelihood that the threat simulation system has arisen by chance.

Here, I present the detailed predictions of the TST, indicate whether a specific prediction has been tested or not, and summarize if there is any evidence for or against the predictions. These are also summarized in Table 9. In addition, I will specify what kind of evidence would pose problems for the TST. This chapter also functions as a future guide for testing the TST.

6.6.1. Is dream content organized and selective?

In order to test the claim that dream consciousness is an organized and selective off-line model of the real world (Revonsuo, 2000a), we need to investigate 1) the organization of the phenomenal level itself, 2) whether the neural mechanisms directly underlying dream production and threat simulation function in an orderly and organized manner rather than randomly, and 3) whether the triggering and construction of threat simulations is systematically modulated by the negative emotional charge attached to the episodic memory traces in the amygdala-centred emotional memory systems.

The currently available evidence from both dream content and brain imaging studies seems to offer support for these predictions, although more direct tests are still needed. First, dream content studies confirm the relatively well-organized form of the phenomenal level in dreaming. Second, brain activation patterns during sleep are highly similar across subjects and experiments (Braun et al., 1997; Dang-Vu et al., 2005; Maquet, 1999; 2000; Maquet et al., 1996; 2004; Nofzinger et al., 1997). Third, research on emotionally charged memories indicates that there is a separable "hot" amygdala centered emotional memory system distinct from the "cool" hippocampally centred episodic memory system, and that these systems serve different functions (Metcalfe & Jacobs, 1998; 1999).

The "hot" memory is the basis of emotionality, and is believed to play a central role in releasing species-specific behaviors in response to emotionally charged stimuli. Öhman (2005) recently proposed that the specific role of amygdala in human fear is the automatic detection of threatening stimuli in the environment. In addition, amygdaloid complexes have been implicated in the formation and consolidation of memories paired with emotional stimuli, and amygdala activity has been shown to be related to enhanced episodic memory for aversive stimuli, and especially to emotionally salient aversive stimuli (Hamann et al., 1999). Amygdala mediates responses to threatening stimuli or stressful situations (Hamann et al., 1999; LeDoux, 1996; Metcalfe & Jacobs, 1999), and stimulation of amygdala in humans leads to autonomic fear reactions and to reported feelings of fear (Metcalfe & Jacobs, 1999). Thus, amygdala activation possibly favors fearful and threatening dream experiences (Dang-Vu et al., 2005; Schwartz & Maquet, 2002). Amygdaloid complexes also have reciprocal connections with many cortical areas, and those areas receiving high amydaloid input are highly active during REM, whereas regions low in amygdaloid efferents are not likely to be activated (Maquet et al., 1996). Thus, active functional interactions between amygdaloid complexes, anterior cingulate cortex and various posterior areas during REM sleep might lead to reactivation of affective components of memories, explaining the emotional nature of REM dreams.

The proposition that dreams are well-organized, coherent and selective simulations of the real perceptual world, and the three predictions derived from this statement of the TST, could be falsified by showing that dream content is random, the neural mechanisms underlying dream production function in a random, disorganized manner, and that the negative emotional charge of the memory trace, stored in amygdala-centred memory systems, does not function as a triggering factor in dream content construction.

6.6.2. Is dream content specialized in threat simulation?

The second claim of the TST is that dream consciousness is specialized in the simulation of threatening events (Revonsuo, 2000a), thus predicting that 1) if a content analysis system for specifying the frequency and quality of threatening events in dreams is constructed, we should find that threatening events are overrepresented in dreams compared to negative events in real life and to positive events in dream life. The positive/negative emotions ratio should be opposite in dreams versus waking life. 2) The threatening events should include severe and mortally dangerous threats more often than our waking life typically does during the same time period. Furthermore, 3) if activated by various kinds of real threats, the threat simulation system should be more capable of simulating ancestral threats (animal attacks, physical aggression) than modern threats highly unlike ancestral ones (traffic accidents, electric shocks, smoking). Because the threat simulation system evolved to simulate threats in the ancestral environment, it comes preloaded with threat-scripts containing models of most frequent ancestral threats, and is only gradually adapting to simulate threats present in the modern environment. As evidence for the above listed predictions has already been presented in this thesis, the studies are only listed in Table 9.

To disconfirm the proposition that dreams are specialized in the simulation of threatening events, one would have to provide evidence that threatening events are not overrepresented in dreams during any given time period, that the threats in dreams only simulate trivial, everyday mishaps that never endanger the future reproductive success of the dream self, and that dream content is more equipped to simulate modern threats than ancestral types of threats, especially after exposure to real life threatening events.

6.6.3. Do real threat experiences activate the threat simulation system?

The TST predicts that only real threatening events can fully activate the threat simulation system (Revonsuo, 2000a). Thus, 1) none of the nonthreatening real-life events will activate the threat simulation system in a manner comparable to

Table 9. The predictions of the TST, the tests conducted thus far, and the nature of evidence.

Prediction	Tests	Evidence*	Study
I Organization in and selectiveness of dreams			
1a. Dream content is organized	Tested	Strong	Among others: Calkins, 1893; Domhoff, 1996; Foulkes & Kerr, 1994; Hall & Van de Castle, 1966; Rechtschaffen & Buchignani, 1992; Revonsuo & Salmivalli, 1995; Snyder, 1970; Strauch & Meier, 1996; Weed et al., 1896
1b. Dream content is selective	Tested	Strong	Among others: Calkins, 1893; Cicogna & Bosinelli, 2001; Domhoff, 1996; Foulkes & Kerr, 1994; Foulkes et al., 1988; Hall & Van de Castle, 1966; Hartmann, 2000; Kahn & Hobson, 2005; Kahan, 1994: Kahan & LaBerge, 1996; Kahan et al., 1997; McCarley & Hoffman, 1983; Purcell et al., 1993; Schredl, 2000; Schredl & Doll, 1998; Schredl & Hofmann, 2003; Snyder, 1970; Strauch & Meier, 1996; Revonsuo & Valli, 2000; Valli et al., 2005, 2006, 2007, 2008; Weed et al., 1896; Zadra et al., 1998.
2. Brain activation during REM sleep and dreaming is organized on neural level	Tested	Moderate	Dang-Vu et al., 2005; Braun et al., 1997; Maquet, 2000; Maquet et al., 1996; 2004; Nofzinger et al., 1997
3. The saliency of episodic memories in the amygdala-centred 'hot' memory systems modulates threat content	Tested	Moderate	Amaral et al., 1992; Hamann, et al., 1999; Maquet et al., 1996; 2004; Metcalfe & Jacobs, 1998, 1999; LeDoux, 1996; Schwartz & Maquet, 2002; Öhman, 2005
II Threat are overrepresented in dreams			
1. Frequency of dream threats is higher than frequency of wake threats	Tested	Strong	Desjardins & Zadra, 2004; Framo et al., 1962; Malcolm-Smith & Solms (2004), Malcolm-Smith et al., in press; Revonsuo & Valli, 2000; Valli et al., 2005, 2006, 2007, 2008; Zadra et al., 2006
2. Dream threats are more severe than wake threats	Tested	Strong and/ or moderate	Desjardins & Zadra, 2004; Framo et al., 1962; Malcolm-Smith & Solms (2004), Malcolm-Smith et al., in press; Revonsuo & Valli, 2000; Valli et al., 2005, 2006, 2007, 2008; Zadra et al., 2006
3. Threat simulation system more capable of simulating ancestral vs. modern threats	Tested	Strong and/ or moderate	Domhoff, 1996; Garfield, 2001; Griffith et al.,1958; Hartmann, 1984; Nielsen, et al., 1998, 1999, 2003; Robbins & Houshi, 1983; Schredl et al., 2004; Zadra & Nielsen, 1997; 1999
III Effect of real threats			
1. Threat simulation system is activated by real threats	Tested	Strong and/ or moderate	Valli et al., 2005, 2006, 2008
2. The activation pattern of threat simulation system by real threats is universal	Tested	Strong	Barrett, 1996; Esposito et al.,1999; Hartmann, 1984, 1996; Kuch & Cox, 1992; Lavie, 1996; Levin & Nielsen, 2007; Nader, 1996; Nader, et al., 1990; Pynoos & Nader, 1988; Pynoos, et al., 1987; Terr, 1979; 1983; Schreuder et al., 1998, 2000; Valli et al., 2005, 2006; van der Kolk et al.,1984; Wilmer, 1996; Wittmann et al., 2007; Wood et al., 1992
3. Degree of threat simulation system activation depends on degree of experienced wake threat	Tested	Strong and/ or moderate	Nader, 1996; Schreuder et al., 1998; Valli et al., 2005, 2006; van der Kolk et al.,1984; Wood et al., 1992
IV Threat simulation is realistic			
1. Defensive reactions are elicited in response to threats	Tested	Strong	Desjardins & Zadra, 2004; Valli et al., 2005, 2006, 2008; Zadra et al., 2006
2. Neural correlates of subjective awareness are identical during wakefulness and dreaming	Tested	Moderate and/or weak	Schwartz & Maquet, 2002; Maquet et al., 1996; 2004
3. Dreamed action are isomorphic with real actions	Tested	Moderate and/or weak	Boeve et al., 1998; Comella et al., 1998, Dyken et al., 1995; Fantini et al., 2005; Olson et al., 2000; Santamaria et al., 2004; Schenck, 1993; Schenck et al., 1986

Continued

Continued

Prediction	Tests	Evidence	Study
V Threat simulation leads to improved performance			
1. Perceptual, cognitive, and motor skills involved in threats are enhanced via simulation	Tested	Indirect and/ or weak	Erlacher, 2005; Erlacher & Schredl, 2008; Karni et al., 1994; Kudrimoti et al., 1999; Louie & Wilson, 2001; Pavlides & Winson, 1989; Smith, 1995; Wilson & McNaughton, 1994
2. Recall of rehearsal is not necessary for enhanced performance	Tested	Strong	Glisky, 1992; Glisky et al., 1986; Glisky & Schacter, 1988, 1989; Schacter, 1996
VI Threat simulation system activation is dependent on ontogenetic development			
1. Threat simulation system activation is dependent on cognitive development	Not tested	No evidence	
2. Threat simulation system activation is dependent on exposure to real life threats	Tested	Moderate and/or weak	Valli et al., 2005, 2006

* The terms strong, moderate, weak, and falsifying evidence are defined as follows:

1) Strong evidence = many studies have been made and majority or all studies found strong and statistically significant patterns of data in the direction predicted by TST
2) Moderate evidence = a number of studies made and most studies find results to the direction predicted by TST (but some studies may have given inconclusive results)
3) Weak evidence = few studies made and/or the studies only indirectly test the hypothesis or the results are only weakly to the direction predicted by TST
4) Indirect evidence = studies have been conducted that find results offering indirect support for TST, but these studies have not directly tested the TST, or have not been linked to dreaming per se, or have been conducted on very small participant samples, or on animals
5) No evidence = no studies made, or the studies made have found no consistent evidence either for or against the hypothesis
6) Falsifying evidence = some studies made and all or most studies have found results to the opposite direction of TST predictions

real-life threats, that is, a single exposure to any non-threatening event will not lead to simulation of such events in dreams so that they would be overrepresented in dream content compared to waking life. Moreover, 2) the activation of the threat simulation system after exposure to life-threatening trauma is a universal phenomenon, not dependent on any specific culture, and 3) the intensity of the simulations (frequency and persistence) will be directly related to the degree of personal threat experienced when the event was encountered in reality. There seems to be ample support for each of these predictions, especially for the second one, but the first and the third prediction could be tested in more detail (Table 9).

In sum, the third prediction of the TST that only real ecologically valid threat cues in the environment fully activate the threat simulation system could be falsified by finding evidence showing that 1) also nonthreatening situations lead to repeated simulations, 2) there is a group of people in whom the threat simulation system is never activated after exposure to real life-threatening events, and that 3) the higher the personal exposure to the threatening real life event, the less frequent, less severe and less persistent are the following threat simulations or simply, the level of exposure has no systematic correlation with the frequency or severity of threat simulation (Revonsuo, 2000b).

6.6.4. Are dream simulations realistic?

The fourth proposition of the TST states that threat simulations are perceptually and behaviorally realistic rehearsals of real threatening events (Revonsuo, 2000a). Thus, 1) when dream self is in mortal danger, he should be more likely than not to display appropriate defensive reactions to shield himself from the threat. Furthermore, 2) the neural correlates of subjective awareness in dreams should be identical with the neural correlates in charge of subjective awareness in waking experience. Last, 3) all movements performed by the dreamer within the dream can be externally observed if muscular atonia during REM sleep is completely removed.

To falsify the hypotheses derived from the fourth proposition of TST, one would have to show that dream simulations are not behaviorally or perceptually realistic. First, evidence should be found that when dream self is facing a life-threatening event, he is no more likely to display appropriate defensive reactions to shield himself from the threat than in situations irrelevant for future reproductive success. Second, one would need to verify that the neural correlates of subjective visual awareness in dreams are not identical with the neural correlates in charge of subjective visual awareness in waking experience, that is, to show that simulations are not perceptually realistic. Last, to determine that threat simulations are not behaviorally realistic, one would need to prove that if muscular atonia during REM sleep is completely removed, dreamed movements do not isomorphically correspond to movements performed by the dreamer in the physical realm.

6.6.5. Does dream rehearsal lead to improved performance?

The fifth proposition claims that perceptually and behaviorally realistic simulation and rehearsal of any skills (in this case threat recognition, avoidance, and coping skills) leads to enhanced performance regardless of whether the training episodes are explicitly remembered (Revonsuo, 2000a). Thus, we can predict that 1) the threat perception and avoidance skills and behaviors employed in threat simulation dreams consist of such perceptual, cognitive and motor skill components that became faster and more efficient through implicit, procedural learning. In addition, 2) even amnesic patients who are not able to explicitly remember the training episodes will become faster and more efficient in threat recognition and avoidance tasks when exposed to such tasks during wakefulness, thus demonstrating implicit, procedural learning.

Only indirect evidence seems to support the notion that those neural circuits involved in threat perception and avoidance are active during sleep. In rats, the firing patterns of hippocampal neurons, most likely responsible for encoding of spatial memory, have been studied under waking behavior and during slow wave (SWS) and REM sleep. The hypothesis has been that the spontaneous reactivation of these memory traces reflects memory consolidation in neural circuits.

First, Pavlides and Winson (1989) showed that hippocampal neurons that were highly active during waking behavior have increased firing rates during subsequent sleep compared to previous sleep. Wilson and McNaughton (1994) recorded, in three rats, the short timescale activity of hippocampal "place cells" during behavioral spatial task and during subsequent SWS. Those cells that fired together during waking behavior had an increased tendency to fire together during subsequent, but not preceding, SWS sleep. Wilson and McNaughton (1994) suggested that neuronal play-back during SWS is a part of the consolidation process where hippocampal information is transferred to neocortex. Similar results for SWS sleep neuronal replay were later obtained by Kudrimoti, Barnes and McNaughton (1999), but could not be observed during subsequent REM sleep.

In contrast, when Louie and Wilson (2001) recorded waking hippocampal neural activity in four rats during a maze task and compared it to hippocampal activity during REM sleep, they found that, in a timescale of tens of seconds to minutes, temporally sequenced firing rate patterns are reproduced in subsequent REM sleep at an equivalent timescale. Consequently, they believe that they managed to demonstrate the reactivation of episodic memory traces related to motor rehearsal during subsequent REM sleep. They also suggest that the reactivation of previous behavioral episode representations may be important for the learning of procedural tasks. The significance of REM sleep in implicit and procedural learning has already been demonstrated in animals and humans (Karni, Tanne, Rubenstain, Askenasy & Sagi, 1994; Smith, 1995)

To disprove the above predictions of TST, one should be able to demonstrate that the threat recognition and avoidance skills and behaviors employed in threat simulation dreams do not consist of such perceptual, cognitive and motor skill components that became faster and more efficient through implicit, procedural learning, that is, threat simulation training is not an efficient way to practise procedural skills. Second, one would have to show that a recollection of training episodes is essential in improving performance, that is, learning of procedural skills requires intact memory systems capable of storing information about training episodes into long term autobiographical memory.

Also, in order to accept the threat simulation theory, many seem to demand an experiment that would demonstrate higher survival rates for people with frequent versus infrequent threat simulations. Obviously, this kind of a study has not been conducted, but the question whether dreams containing threat scenarios exert a real effect on the explicit waking responses is to be addressed. Natural selection operates only on actual, overtly expressed changes in phenotypal traits, and according to TST, during evolutionary history the constant repeated nocturnal training was followed by enhanced performance in comparable real life situations, which led to higher survival rate and more successful reproduction. According to Tooby and Cosmides (1995), a cognitive system is functional in the evolutionary sense if and only if it promotes the organism's (inclusive) fitness. Thus, the 'evolutionary' measurements we can use for better adaptedness are higher survival rate and ultimately, the number of offspring produced by the individual and his kin carrying a set of same genes.

Consequently, to study whether dreams containing threat scenarios exert a real effect on the explicit waking responses and lead to higher survival and reproduction rates would require us to examine the effects of threat simulation frequencies on survival and reproduction over successive generations, in low versus high simulators. In addition, such a study would need to be conducted on participant samples housed in an environment closely resembling the ancestral environment because in the modern environment the threat simulation system may not be able to simulate threats most relevant in the present context. Obviously, the present data are unable provide any evidence that people dreaming frequently about threatening events have or have had any behavioral advantage in dealing with subsequent future threats, leading to higher survival rate and greater number of surviving offspring.

If it could, however, be shown that threat perception and avoidance behaviors are enhanced after dreaming about threats, the TST would gain support. Even though there are many practical problems in testing the effect of rehearsal on performance, the relation between threat simulation and performance (speed and accuracy) could in the future be investigated by exposing subjects to severe threats in a virtual reality environment or immersive video game, and by studying the dream rehearsal rates and the performance in relation to each other. One other possible option would be to conduct a study on animals by exposing them to ecologically valid threat cues, but then the problem how to verify the existence and frequency of threat simulations, a mental phenomenon, will arise.

6.6.6. Is threat simulation dependent on cognitive development and exposure to threats?

The sixth proposition of the TST states that the original human evolutionary environment included frequent dangerous events which imposed severe selection pressures upon ancestral populations, and that the ecologically valid threat cues in the environment fully activated the threat simulation system (Revonsuo, 2000a). Repeated rehearsal of threatening events in dreams led to improved threat recognition and avoidance skills, increasing the probability of survival and successful reproduction. Thus, 1) children old enough to implement threat recognition and avoidance skills during wakefulness should be capable of simulating threatening events in their dreams, especially when exposed to real valid threat cues, and 2) ontogenetically early exposure to real threat cues will lead to earlier, more frequent and more intensive threat simulation dreams whereas lack of exposure will lead to slower development of the dream production system and less frequent and milder threat simulation dreams.

To falsify these predictions, one would need to show that threat simulation does not take place in children's dreams, not even after personal exposure to ecologically valid threat cues. The TST also predicts that dream content of people who live in environments that closely resemble the original human ancestral environment, that is, environments that include frequent survival challenges from natural sources, and where external threats are similar to the ones present in the ancestral environment, should be even more biased towards representing threatening events. When dreams (N = 276) collected from Mehinaku men (an aboriginal ethnic group of Brazil) by Gregor (1981) were classified as including either objective or subjective threats, or reflecting daily peaceful activities, threat-related dreams accounted for 63% of the sample, while peaceful daily activities were conducted in only 20.3% (Revonsuo, 2000a, Note 13). Thus, this prediction of the TST has gained at least preliminary support, although further investigations into dream content of people living under ancestral-mimicking conditions would be welcome.

6.7. The TST in the multilevel framework

The main theoretical aim and contribution of the present thesis is to integrate various disciplines and fields of science to explain dreaming. The multilevel framework was chosen as an explanatory model. In this framework, the phenomenon under investigation is decomposed into subproblems related to the constitutive level underlying the phenomenon, the etiological level preceding the phenomenon, and the contextual level linking the phenomenon to other phenomena on a higher level.

The threat simulation theory was chosen as a starting point, as the TST includes constitutive level, proximate, developmental and ultimate level etiological, and contextual level explanations for dream phenomena. No other dream theory has thus far included explanations from all the levels indicated in the multilevel framework. Next, the explanations offered by the TST are outlined briefly. The explanations are also presented in Figure 7.

6.7.1. The constitutive level

The constitutive level explanations for dreaming, according to the TST, include the neural activation of the dream generator system. The dream generator system is distinct from the REM sleep generator system, as dreaming and REM sleep can double dissociate. The dream generator or dream production system actively selects emotionally negatively charged memory traces from long term memory, and builds dream experiences based on the activated memories. The dream production system is, however, creative: the memory traces are combined in novel ways and simulations of threatening events are produced in various combinations.

In the constitutive level explanations, the TST runs into the 'hard and easy problems' of consciousness (Chalmers, 1996). The easy problems concern the neural or cognitive correlates or constituents of consciousness. Thus far, they remain largely unexplained. This is also the case for dreaming: we know neither how the brain creates dream experiences nor where this process takes place. The hard problem of consciousness is why we have qualitative *phenomenal experiences* at all. What makes the hard problem so hard, according Chalmers (1996), is that even if we could explain the performance of all the relevant neural and cognitive systems and functions underlying phenomenal consciousness, we still would not know why physical processes in the brain should give rise to the inner presence of mind. The TST in itself cannot, and does not even try to, solve either the easy or the hard problems. Rather, it only acknowledges that dreaming is created by the brain within the confines of the brain. The easy and hard problems, however, are addressed by biological realism (Revonsuo, 2006).

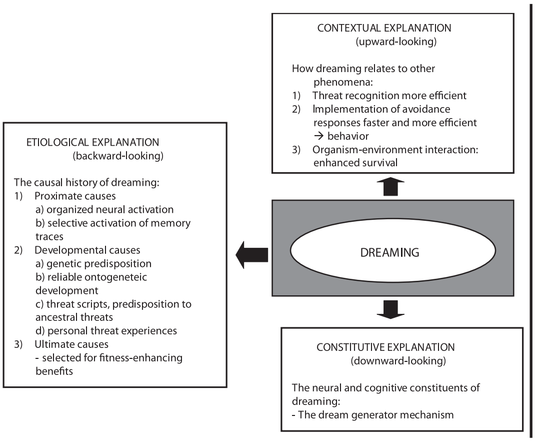

Fig. 7. The Threat Simulation Theory in the multilevel framework

6.7.2. The etiological level

The proximate etiological level explanations that the TST offers for dreaming are, of course, also related to the constitutive level explanations. The selective and organized neural and cognitive processes are required in order for dreaming to take place. Again, the easy and hard problems for explaining phenomenal consciousness follow.

The developmental level explanations for dreaming put forth by the TST are that dreaming has a genetic basis, and that dreaming is reliably manufactured over the developmental life history of the organism according to the specifications contained in its genetic code. Moreover, the maturation rate in early childhood and the activity level of the threat simulation system is highly dependent on the activity level of the dream production mechanisms and the level of ecologically valid threat cue input. Even though written records about dreaming go back only a couple of thousands of years, humans throughout the history seem to have tried to explain dreaming. Thus, it seems that the ability of the human brain to produce hallucinatory experiences during sleep is a cross-generationally occurring ancient phenomenon, and a recurring characteristic of our phenotype, determined by our common genetic heritage.

Dreaming seems to be reliably manufactured over the developmental cycle of the individual. Though the genetic basis of dreaming has not been widely studied, some evidence for hereditary characteristics can be found. Dreaming develops gradually as the child matures, and reaches adult level and characteristics between ages nine and thirteen (Foulkes, 1982; 1985; 1999). Also the findings that most people can recall dreams (Pagel, 2003; Strauch & Meier, 1996) support the idea that that dreaming develops in a majority of individuals. Of course, dream recall is not an exact measure of whether a person experiences dreams, as non-recallers might just have an exceptionally bad memory for dreams.

Relatedly, the frequency of dream recall varies inter-individually (for example, Schredl, 2004; Strauch & Meier, 1996), and the recall rates indicate that dreaming is normally distributed in the population. Majority of people are moderate dream recallers, some remember dreams frequently, and few report dreaming rarely or never (Pagel, 2003; Strauch & Meier, 1996). Moreover, it seems that dream recall frequency is related between mothers and their children (Schredl, 2006). This can, of course, be due to genetic (tendency to dream) as well as environmental factors (attitude towards dreams).

The best evidence for hereditary characteristics of dreaming is obtained in twin studies. Hublin, Kaprio, Partinen and Koskenvuo (1999) quantified the genetic influences affecting the liability to nightmares in a sample of 1 298 monozygotic and 2 419 dizygotic twin pairs. They found that having nightmares is a stable trait from childhood to middle age, and that there are persistent genetic effects on the disposition to nightmares both in childhood and adulthood. In sum, dreaming seems to be reliably manufactured in an individual according to instructions contained in its genetic specification.

During ontogenetic development, modern children dream more of animals, aggression, and aggression by wild animals than modern adults (Domhoff, 1996; Hall & Domhoff, 1963). Nightmares are also common in children between ages of three and six, and the most common themes consist of the dreamer being chased or pursued by strange males, animal or monsters (Domhoff, 1996; Hartmann, 1984; 1998). As the children mature, the level of aggression and amount of animal figures reach adult values, usually by early teenage (Domhoff, 1996). Revonsuo (2000a) interprets this as evidence that the threat simulation system has a predisposition to produce ancestral-type threat simulations in the relative absence of real threat cues. The threat simulation system comes preloaded with threat scripts, that is, default values, for simulating ancestral threats. Only when the child's brain gradually adapts to modern environment, that is, is modified by environmental cues present in his or her surroundings, the threat simulations start to include situation relevant in the present context.

The activity level of the threat simulation system seems to be highly dependent on the activity level of the dream production mechanism. If we measure the activity of the dream production mechanism with dream recall frequency and dream report length, we see that the more and the longer the dreams, the more threat simulations they include (Aitta-aho, 2006; Valli et al., 2007; 2008). The ecologically valid threat cue input also activates the threat simulation system in manner no other type of input seems to do. The more often the individual is exposed to threats in his or her waking life, and the more severe threats are, the more likely are subsequent realistic threat simulation dreams (Punamäki, 1997; Punamäki et al., 2005; Valli et al., 2005; 2006). This is also evident from posttraumatic nightmares.

The ultimate etiological level explanation for dreaming, as proposed in the TST (Revonsuo, 2000a; 2000b), is that recurring threat simulations of the most relevant threatening agents present in the ancestral environment led to enhanced threat recognition, avoidance and response skills. Individuals with highly efficient threat coping skills were more likely to survive and leave offspring, and as dreaming and the threat simulation system are hereditary characteristics, transmit an efficient threat simulation system to their children. Gradually, the genetic basis of threat simulation system became established and organized in our species over evolutionary time, because the mechanism systematically interacted with stable and recurring selection pressures present in the ancestral environment.

Thus, the TST states that the threat simulation system is an adaptation, regardless of whether it originally evolved to serve an adaptive purpose or whether it was first a sleep-related spandrel that was later adopted for its beneficial fitness-enhancing characteristics. Nevertheless, once the threat simulation system was established as an adaptation, it gradually spread in the population. Eventually, the threat simulation system reached a fixation point. A fixed psychological adaptation means that all the individuals in the population share the same underlying neural and psychological structures required for the phenomenon to reliably develop during ontogeny.

The TST makes no specific claim as to when exactly the threat simulation system evolved, or became adopted to, as an adaptation. This feature might have been inherited from earlier mammals, in which species-specific survival skills were practiced during sleep, and possibly dreaming. The TST only claims that in humans those types of threatening events that were present in the evolutionary environment of our species are simulated in during dreaming. Thus, the evolution of the dream production mechanism may well predate our species, and the species-specific adaptation in humans may only concern specific threat content and effective responses to threats most relevant to us.

6.7.3. The contextual level

Contextual explanations tie dreaming to other subjective and psychological phenomena, and also to behavior and interactions with the environment. The TST (Revonsuo, 2000a; 2000b) states that repeated threat simulation in dreams causally led to enhanced threat recognition and avoidance skills, that is, the individual was better equipped on psychological (faster threat recognition and assessment of situation) and behavioral (faster responses and implementation of avoidance behaviors) levels to survive a subsequent threatening situation. The organism-environment –interaction was the evolutionary selection criteria for the threat simulation mechanism. Thus, the phenomenal level, the dream experience, causally contributed to adaptive behavior, via various other mental and cognitive phenomena. Consequently, on the contextual level mental phenomenon is one of the etiological explanations for observable behavior.

Peterson and DeYoung (2000) suggest also a contextual level explanation for dreaming that can be related to the threat simulation theory. They propose that, after the advent of language, the capacity to communicate dreams to other group members could have been selected for (Peterson & DeYoung, 2000). When a dream is shared, especially a threatening dream, the members of the community can then help solve the problem posed in the dream. As a memory bias for negative and threatening dreams exists, these types of dreams were likely to be told and shared.

If I continue the thought, it could even be said that the sharing of threatening dreams and nightmares in a social context is a sign that the whole group should prepare for the type of threat presented in the dream. In many cultures, it is believed that dreams convey information of or foretell the future. Maybe this belief could be interpreted as a generalization of the threat detection function of dreams. Simultaneously, the original biological threat detection function of dreaming has blurred and become more indistinct.

6.8. Dreaming – A spandrel or an adaptation?

The Threat Simulation Theory claims that dreaming originated either as an adaptation, or was a sleep-related epiphenomenon that was later co-opted as an adaptation for its beneficial fitness effects in the ancestral environment. The idea that dreaming is an adaptation has not, thus far, been subjected to evolutionary analysis. In order to provide any probability assessment as to whether dreaming is an adaptation, we need to show that dreaming as a biological phenomenon fulfils the criteria for an adaptation. Similarly, we need to address whether the explanation for dreaming as offered by the TST survives the evolutionary functional analysis.

6.8.1 Definition of an adaptation

Tooby and Cosmides (1995) define adaptations as mechanisms crafted by natural selection to solve the specific problems posed by the environments encountered by ancestral populations during the course of the species' evolution. One of the main criteria for an adaptation is that is shows clear design for a function, that is, seems to be specifically engineered to solving a specific adaptive problem. Further, as proposed by Tooby and Cosmides (1990; 1992; 1995), an adaptation is 1) a cross-generationally recurring set of characteristics of the phenotype, 2) that are developmentally manufactured, 3) according to instructions contained in the genetic specification or basis of the species, 4) in interaction with stable and recurring features of the environment (that is, the characteristic reliably develops normally when exposed to normal ontogenetic environments), 5) whose genetic basis became established and organized in the species over evolutionary time, because 6) the set of characteristics systematically interacted with stable and recurring features of the ancestral environment 7) in a way that systematically promoted the propagation of the genetic basis of the set of characteristics better than the alternative designs existing in the population during the period of selection.

In contrast, a set of phenotypic characteristics is not an adaptation if 1) it is transient, varying form one individual to the next, and it is not a part of the recurrent design of individuals of that genotype, 2) it was absent in the environment of evolutionary adaptedness, 3) it did not solve an adaptive problem in the EEA even though might be fitness-promoting in current environment, 4) the description of the adaptation involves terms and elements for things that were not present in the EEA, and 5) the set of characteristics is not species-typical for species with open population structure (Tooby & Cosmides, 1990).

6.8.2. Evolutionary functional analysis

The tool that evolutionary psychologist use in investigation of whether a specific characteristic is an adaptation or not is called evolutionary functional analysis. This analysis involves three steps. First, we must define those recurrent structures of the Pleistocene environment that presented the selection pressures for the design in question. Second, we need to determine what kind of a behavioral sequence counts as a biologically successful outcome in those given situations. Third, we have to be able to identify the central features of the proposed design in an organism, and to define and to evaluate the performance of the design. Thus, in the context of dreaming, we must be able to identify the selection pressures that posed a threat to survival. Second, we have to decide what kinds of behaviors would have been useful and successful in these threatening situations. Finally, we have to identify the central, universal features of phenomenal dream experience, to determine what are the biologically successful outcomes dreaming should be able to produce, and to test whether dreams are capable of producing such outcomes. Then, we can evaluate how well the design performs in producing the set of biologically successful outcomes under current conditions, and especially under conditions that are representative of ancestral selection pressures that were operational in the EEA.

6.8.3. Probability assessment: Is dreaming an adaptation?

Dreaming itself, as a process capable of producing hallucinations during sleep independent of what is being hallucinated, seems to fulfill the first four requirements set for an adaptation (see section 6.8.1.), that is, it is a cross-generationally recurring set of characteristics of the phenotype that are manufactured in an individual according to instructions contained in the genetic code, in interaction with stable and recurring features of the environment. The TST (Revonsuo, 2000a; 2000b), in addition, presents a rather convincing argument that explains the specific design of the dreams, and offers an evolutionary argument for why the design would have been selected for (requirements 5 to 7, see section 6.8.1.). The TST offers a plausible explanation for why the genetic basis of dreaming would have been selected for, that is, because dreaming interacted with the environment in such a way that enhanced fitness. It is compatible with what we know of the central, universal features of phenomenal dream experience. What we cannot test directly is whether threat simulation dreams are capable of producing biologically successful outcomes, but indirect evidence supports this.

What comes to alternative designs, the TST claims that the benefits carried with dreaming and the threat simulation system far outweighed the costs that went into producing them. Other threat rehearsal systems than dreaming might have also been useful (such as mammalian play), but alternative designs could have come with additional costs. If an alternative threat rehearsal mechanism is proposed, it needs to be subjected to similar cost-benefit analysis that the TST. Similarly, the TST accepts that dreaming may have other functions besides threat simulation, but the explication of these alternative functional designs is beyond the scope of the theory. As mentioned previously, any alternative explanation proposed for the biological function of dreaming has to be also subjected to cost-benefit –analysis. Nevertheless, in the light of the present evidence the TST's proponents may well have grounds to argue that the TST is a plausible explanation for the design and function of dreaming. In probability assessment terms; it would be extremely unlikely that the design and function of dreaming as presented in the light of the TST would have arisen by chance.

Evolutionary processes also create spandrels, by-products of adaptations (Gould & Lewontin, 1979). These by-products are coupled with properties that have adaptive functions, but do not contribute to organism's fitness in themselves (Tooby & Cosmides, 1990; 1992; 1995). As spandrels are closely linked to adaptations, they were dragged along into the species typical architecture. Spandrels are selectively neutral, that is, they do not have negative or positive consequences to the organism's fitness, and thus they are functionally arbitrary (Tooby & Cosmides, 1992; 1995). Occasionally, however, by-products of adaptations can later be co-opted for their beneficial effects (Gould & Lewontin, 1979), and some traits that were originally spandrels can eventually become adaptively functional.

A question that we can address, but not solve, in this context, is whether dreaming originally evolved as an adaptation or whether it was (and maybe still is) a sleep-related spandrel. The TST does not claim anything about the origin of dreaming, that is, whether dreaming was selected for from the beginning because it had the capacity to produce simulated threats to begin with, or whether dreaming was originally a spandrel, and was later selected for because at some point along the line threats started to be simulated in dreams, and this proved useful. Nevertheless, the TST does not accept the idea that dreaming still is a spandrel, regardless of its original nature.

Finally, what evolutionary psychologists seldom acknowledge is that random factors, such as random events in the species' environment, new mutations, or genetic drift, can also change the allele frequencies in a population, and thus contribute to genetic polymorphism (Gould & Lewontin, 1979). Genetic drift can, in spite of natural selection, lead to fixation of an allele, even a fitness-reducing allele, depending upon the product of population size and selection intensity (Gould & Lewontin, 1979). EP regards random effects as functional disorders in the design of organisms, and assumes that they are recognizable by the lack of coordination they produce within the architecture of the species, or between the architecture and the environment, and by the fact that they also frequently vary between individuals (Tooby & Cosmides, 1992; 1995). Dreaming and threat simulation do not seem to resemble random effects as defined above.

6.9. The implications of the present thesis

6.9.1. The loop of 150 years: Putting dreaming back where it belongs

Published in 1859, one-hundred and forty-nine years ago, Darwin's masterpiece '*On the Origin of Species by Means of Natural Selection, or the Preservation of Favoured Races in the Struggle for Life*'[7] laid the grounds for evolutionary biology. The book was highly controversial because it contradicted widespread religious beliefs at that time. Scientific reaction to Darwin's theory was also mixed, and during Darwin's lifetime cumulative changes and revisions were made to deal with the counter-arguments. After Darwin, modifications and revisions to the theory of evolution by natural selection still continue to be published. Similarly, the creation (or intelligent design) and evolution controversy continues to this day

At the time the 'On the origin of species' was published, psychology was gradually establishing itself as a science. Wilhelm Wundt gave psychology its first definition: the study of mental experience, of *consciousness*, to be studied by introspection, *aided* by the experimental protocols of the natural sciences (Stanford Dictionary of Philosophy). William James also defined psychology as a science aiming to describe and explain states of consciousness as such.

At the advent of experimental psychology, dream consciousness was also established as a topic of scientific study. Ingenious neurocognitive theories of dream formation were proposed (Delbouef, 1885/1993; Maury, 1862; de Saint-Denys, 1867/1982),

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[7] In the 1872 edition, the name was changed into 'On the origin of species'

and the first content analysis on study on dreams, based on introspective dream reports, was published (Calkins, 1893). More soon followed (Weed et al., 1896), and the focus in research was on the phenomenology of dreams rather than on the meanings the dreams might have for a particular dreamer.

In the beginning of the 20th century, a paradigm shift took place in psychology. After the publication of '*The interpretation of dreams*', dream experience as such was discredited, and the focus was turned to the discovery of the hidden meaning of dreams (Freud, 1900/1965). Psychoanalytic dream interpretation system discouraged all efforts to explain dreaming in neuropsychological or neurocognitive terms, but dreaming itself was considered essential in psychology, as a protector of sleep and as a 'royal road to the unconscious' (Freud, 1900/1965).

In a concurrently running school of thought in psychology, dreaming was not, however, favourably regarded, independent of the approach. In Wittgensteinian philosophy and logical behaviorism (Malcolm, 1959; Ryle, 1949), and later in functionalism (Dennett, 1976), the importance, and even the existence of dreams was denied. In fact, all mental phenomena were considered as unverifiable by empirical means, and therefore not empirically real at all. Because of the influence of behaviorism and functionalism in psychology, introspection was rejected, and experimental methods preferred. In less than fifty years, psychology was transformed from the study of mental phenomena, of consciousness, to the objective study of behavior.

Dreaming, however, was not completely forgotten. In 1953, Calvin S. Hall, who had a background both in the psychoanalytic school and behaviorism, published 'The meaning of dreams'. In his book he described the phenomenology of dreams, based on thousands of introspective dream reports collected from normal subjects (Hall, 1953). A decade later, Hall authored together with Robert Van de Castle the classic '*The content analysis of dreams*', in which they described a detailed content analysis system for the statistical study of dream phenomena (Hall & Van de Castle, 1966). The renewed interest in dream phenomenology coincided with a revolutionary discovery of REM stage of sleep by Aserinsky and Kleitman in 1953. Moreover, as in the early studies REM sleep was considered to be the neurophysiological correlate of dreaming (Dement & Kleitman, 1957), the discovery led to numerous REM sleep dream studies.

Now that dreaming was back on the map, and intensely studied in conjunction with REM sleep, new theories trying to explain the formation of dreams from a neurophysiological perspective started to appear. These theories, such as the Activation-Synthesis hypothesis (Hobson & McCarley, 1977), show striking similarities with the neurocognitive theories presented more than a hundred years earlier (Schwartz, 2000). The psychoanalytic paradigm has not been forgotten, either. The views of Freud (1900/1965), Jung (1965; 1974), and Adler (1929) still persist in psychological theories on dreaming (Hartmann, 1995; 1996; 1998; Solms, 2000). What has been largely missing from the science of dreams until recently is the evolutionary perspective.

The contribution that evolutionary psychology has offered to dream research is the angle of biological functionalism. Evolutionary psychology is founded on the view that the function of all psychological phenomena in human evolution, including dreaming, is a necessary perspective to their scientific explanation (this is the ultimate etiological explanation in Biological Realism). Even studying the evolutionary functions of consciousness (originally defined by Wundt and James as the explanandum in psychology) is now an active field of study. Not surprisingly, evolutionary psychology is based on two classical standpoints: functionalism and evolution by natural selection.

Functionalism refers to a school of thought accepting the philosophical view that mental states are constituted solely by their functional role. William James was one of the leading proponents of functionalism in psychology, and James recognized that mental processes, just as physical traits, were subject to the same evolutionary processes. Not surprisingly, with a background in medicine, physiology, and biology, James had not been blind to Darwin's theory of natural selection. In fact, Darwin himself had already stated in 'On the origin of species' that: "Psychology will be based on a new foundation, that of the necessary acquirement of each mental power and capacity by gradation." (Darwin, 1859). To me, it seems that both psychology and dream research have found their way back to their roots.

6.9.2. And where does it belong?

The main contribution of the present thesis lies in putting dreaming back where it belongs, that is, into the spotlight at the cross-road of various disciplines. The present thesis reflects the currently ongoing, more general transition or shift in psychology. Mental phenomena and consciousness are, again, in the research core, as originally defined by Wundt and James. Consciousness is, again, regarded a biological phenomenon, explainable with naturalistic terms. Evolutionary psychology, anew, sees biology as an indispensable aid in explaining consciousness and all mental phenomena. The tail of the snake has found the way into its mouth.

Multidisciplinary integration and methodological meticulousness have been in the centre of this work. Further, the current thesis has focused on the systematic and draconian testing of one of the theories suggested for the function of dreaming.

Thus far, the ambiguous formulation of theories has been a significant weakness in dream research, and in the absence of well-defined predictions, most dream theories have been difficult or impossible to test. The approach this thesis stands for, that is, integration of multidisciplinary explanations, theoretical exactness, testability of predictions, methodological soundness, and systematic empirical testing of hypotheses, are prayed for in future dream studies. These are the requirements dream research needs to fulfil to truly become a mainstream science, and to take its place in the limelight.

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APPENDIX: THE ORIGINAL PUBLICATIONS