The Avatars in the Machine

Dreaming as a Simulation of Social Reality

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The idea that dreaming is a simulation of the waking world is currently becoming a far more widely shared and accepted view among dream researchers. Several philosophers, psychologists, and neuroscientists have recently characterized dreaming in terms of virtual reality, immersive spatiotemporal simulation, or realistic and useful world simulation. Thus, the conception of dreaming as a simulated world now unifies definitions of the basic nature of dreaming within dream and consciousness research. This novel concept of dreaming has consequently led to the idea that social interactions in dreams, known to be a universal and abundant feature of human dream content, can best be characterized as a simulation of human social reality, simulating the social skills, bonds, interactions, and networks that we engage in during our waking lives. Yet this tempting idea has never before been formulated into a clear and empirically testable theory of dreaming. Here we show that a testable Social Simulation Theory (SST) of dreaming can be formulated, from which empirical predictions can be derived. Some of the predictions can gain initial support by relying on already existing data in the literature, but many more remain to be tested by further research. We argue that the SST should be tested by directly contrasting its predictions with the major competing theories on the nature and function of dreaming, such as the Continuity Hypothesis (CH) and the Threat Simulation Theory (TST). These three major theories of dreaming make differing predictions as to the quality and the quantity of social simulations in dreams. We will outline the first steps towards a theory-and-hypothesis-driven research program in dream research that treats dreaming as a simulated world in general and as a social simulation in particular. By following this research program it will be possible to find out whether dreaming is a relatively unselective and thus probably non-functional simulation of the waking world (CH), a simulation primarily specialized in the simulation of dangerous and threatening events that present important challenges for our survival and prosperity (TST), or whether it is a simulation primarily specialized in training the social skills and bonds most important for us humans as a social species (SST). Whatever the evidence for or against the specific theories turn out to be, in any case the conception of dreaming as a simulated world has already proved to be a fruitful theoretical approach to understanding the nature of dreaming and consciousness.

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1 Introduction

There may be no Cartesian ghosts residing within the machinery of the brain, but still, something rather peculiar is going on in there, especially during the darkest hours of the night. As we sleep and our bodies cease to interact behaviourally with the surrounding physical world, our conscious experiences do not entirely disappear. On the contrary, during sleep we often find ourselves embodied and immersed in an experiential reality, an altered state of consciousness called dreaming. The Dream Self—the character with which we identify ourselves in the dream world, and from whose embodied perspective the dream world is experienced—is who *I* am in the dream world (Revonsuo 2005).

But we are not alone in this alternative reality—there are other apparently living, intelligent beings present, who seem to share this reality with us. We see and interact with realistic human characters in our dreams. Their behaviour and their very existence in the dream world seem to be autonomous. The dream people who I encounter within the dream seem to go about their own business: I cannot predict or control what they will say or do. Yet, they, too, are somehow produced by my own dreaming brain.

On the one hand, dreaming is a solipsistic experience: when we dream, we dream alone, and outsiders have no way of participating in our dream. Yet on the other hand, dreaming is an intensely *social* experience, even if the social contacts and interactions in the dream world are merely virtual. In this paper, we will explore the idea that dreaming is a *simulated* world, but not only a simulation of the *physical* world. It is equally or perhaps even more importantly a simulation of the *social* world. We will proceed in the following way:

First, we will argue that a remarkable convergence has gradually emerged in theories about the nature of dreaming. The field used to be a disunified battleground of directly opposing views on what dreams are, how exactly the concept of "dreaming" should be defined, and on the proper level of description and explanation for dreaming. Recently, the field has converged towards a more unified understanding of the basic nature of dreams. A widely shared conceptualization of dreaming now depicts it as the *simulation* of waking reality. We will briefly describe how this theoretical shift has taken place and where we currently are in the theoretical definition of dreaming. This theoretical development has paved the way for understanding the *social* nature of dreams in terms of social simulation.

Second, we will explore the nature of social dream simulation in more detail. In what sense can dreaming be taken as a simulation of our human *social* reality? How much and what types of social perception and interaction occur in dreams? This question can be broken down into a number of more detailed questions. We will try to answer some of these questions based on the already existing knowledge and empirical evidence about the social nature of dreams. Furthermore, we will try to formulate more clearly the questions that cannot yet be answered empirically due to the lack of appropriate data.

Third, we will review hypotheses that already address the question of the social nature of dreams or assign a social simulation function for dreams. Finally, we will outline some basic ideas of a Social Simulation Theory (SST) of dreaming that might offer some explanations for the social nature of dreams, or at least might produce well-defined, testable research questions concerning the possible *functions* of social dream simulations.

To describe and explain the social nature of dreams as social simulation, concepts borrowed from virtual reality technology may be applied, in this case to the social aspects of dreaming. One of these concepts is the notion of "avatar": *A simulated virtual human character* who plays the role of a corresponding real human within a virtual reality. If dreams are virtual realities in the brain (Revonsuo 1995), then we ourselves within the dream world are avatars, and we interact with other avatars inside the simulated reality. Somehow, the dreaming brain is capable of creating credible, autonomous human simulations out of neural

activities in the sleeping brain. A theory of dreaming as a social simulation should predict what kind of avatars are represented in our dreams, what types of interactions we engage in with them, and in particular, *why* it would be useful to simulate such avatars and interactions in our dreams—what functions, if any, do they serve for us.

2 Consciousness as reality–modeling and world–simulation

Dreaming is the most universal and most regularly occurring, as well as a perfectly natural and physiological (as opposed to pathological), altered state of consciousness. Thus, any plausible (empirical or philosophical) theory of consciousness should also describe and explain dreaming as a major state of consciousness. Most theories of consciousness, however, do not consider dreaming at all or at least do not discuss the results of dream research in any detail (Revonsuo 2006).

Dreaming presents a particularly difficult challenge for externalist, embodied, and enactive types of theories of consciousness.[1] They all anchor the existence and nature of consciousness to something in the world external to the brain, or to some kind of brain-world relations that, at least partly, reside outside the brain. By contrast, the empirical evidence from dream research shows that full-blown, complex subjective experiences similar with or identical to experiences during wakefulness (e.g., Rechtschaffen & Buchignani 1992), regularly and universally happen during rapid eye movement (REM) sleep. The conscious experiences we have during dreaming are isolated from behavioural and perceptual interactions with the environment, which refutes any theory that states that organism-environment interaction or other external relationships are constitutive of the existence of consciousness (Revonsuo 2006).

A few theories of consciousness have, however, taken dreaming as a central starting point in their conceptualization and explanation of

consciousness. When dreaming is taken seriously, ideas about the nature of consciousness tend to converge on internalist theories of consciousness that take consciousness and dreaming to be varieties of the same internal phenomenon, whose main function is to simulate reality.

One of the earliest attempts to conceptualize both waking consciousness and dreaming as the expressions of the same internally-activated neural mechanism, only differently stimulated, was put forward by Llinás & Paré in 1991:

> [C]onsciousness is an intrinsic property arising from the expression of existing dispositions of the brain to be active in certain ways. It is a close kin to dreaming, where sensory input by constraining the intrinsic functional states specifies, rather than informs, the brain of those properties of external reality that are important for survival. [...] That consciousness is generated intrinsically is not difficult to understand when one considers the completeness of the sensory representations in our dreams. (1991, p. 531)

The argument by Llinás & Paré (1991) was mostly based on considerations of the shared neurophysiological mechanisms (in the thalamo-cortical system) that could act as the final common path for both dreaming and waking consciousness. Binding information together within this system intrinsically generates consciousness ("It binds, therefore I am", Llinás 2001, p. 261); but only during wakefulness is consciousness modulated by sensory-perceptual information—in this model, wakefulness can be seen as a dream-like state (Llinás & Ribary 1994).

Although the idea that dreaming *simulates* waking consciousness was implicit in this neuroscientific theory, Llinás & Paré (1991) did not consider the phenomenology of dreaming and consciousness in any detail. Theoretical approaches characterizing the nature of dreaming as simulation, based on a combination of philosophical arguments and empirical facts about dreaming, started to emerge during the 1990s. In Revonsuo (1995) the idea was put forward

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[1] The same criticism may to some extent also apply to representationalist theories of consciousness and dreaming, depending on which externalist or internalist version of representationalism the theory is committed to.

that consciousness in general and dreaming in particular may best be characterized as a virtual reality in the brain, or a model of the world that places a (virtual) self in the centre of a (virtual) world. All experiences are virtual in the sense that they are world-models rather than the external physical world somehow directly apprehended. While the causal chains that modulate the virtual reality are different during wakefulness and dreaming, the virtual world is ontologically the same biological phenomenon: the *phenomenal level of organization* in the brain (Revonsuo 1995). All experiences are, according to this view, in their intrinsic phenomenal character, no different from dreams.

Metzinger (2003) took this line of thought further and analysed dreams as complex, multimodal, sequentially organized models of the world that satisfy several important constraints of consciousness. Dreams activate a *global* model of the world (globality), they integrate this model into a *window of presence* (presentationality), and this model is *transparent* to the experiencing subject, who takes it to be a real world and not a mere model of the world (transparency) (see also Windt & Metzinger 2007).

In *Inner Presence* Revonsuo (2006) presented a lengthy analysis and defence of the idea that dreams are internal virtual realities, or *world-simulations*, and argued that consciousness in general would be best described and explained by treating dreaming as a paradigmatic model system for consciousness. The world-simulation contains the *virtual self* and its *sense of presence* in the centre of the simulation. The virtual self is perceptually surrounded by the *virtual place*; the virtual place in turn contains multiple perceptual contents in the form of animate and inanimate *virtual objects*, including human characters. The virtual objects are bound together from phenomenal features like color, shape, and motion, but this binding in dreams does not always work coherently, thereby resulting in bizarre feature combinations and incongruous or discontinuous objects and persons in dreams (Revonsuo 2006).

Recently, Windt (2010) has formulated a definition of dreams that stems from similar ba-

sic ideas. Windt's definition aims to capture the minimal set of phenomenological features that an experience during sleep should have in order to count as a "dream" (as opposed to other types of sleep mentation). This definition, although not explicitly applying the concept of "simulation", is consistent with the world-simulation model of dreaming. According to Windt, dreams are Immersive Spatiotemporal Hallucinations (ISTH): there is a sense of spatial and temporal presence in dreams; there is a hallucinatory scene organized around a first-person perspective, and there is a sense of "now", along with temporal duration. The core feature of a dream experience is, in Windt's ISTH, *the sense of immersion or presence in a spatiotemporal frame of reference*. Thus, Windt's ISTH, as well as Metzinger and Revonsuo's earlier definitions, all involve similar ideas of dreams as involving an immersive presence of a virtual self in a virtual, spatiotemporally organized world-model or simulation.

3 Dreaming as simulation: Converging definitions from dream research

Within empirical dream research, definitions of dreaming have been highly variable and often motivated by underlying theoretical background assumptions held by the theorist. Thus, the pure description of the *explanandum*, which should come first in any scientific inquiry, has perhaps been biased by a pre-existing theory as to what might count as the *explanans*—the entities, processes, and concepts that are supposed to explain the phenomenon. We will only briefly mention three approaches to defining (and explaining) dreams in the recent history of dream research, where the definition and description of the data seem to have been theoretically motivated.

The field of dream research was, in the 1970–1990s, a theoretically disunified field. The deep disagreements over finding a definition of "dreaming" that would be acceptable across the field were noted by Nielsen (2000, p. 853)

> [T]here is currently no widely accepted or standardized definition of dreaming.

as well as by Hobson et al. (2000, p. 1019):

> […T]here is no clearly agreed upon definition of what a dream is […] and we are not even close to agreement.

Hobson's (1988, 1997, 2001) own definition of dreaming is (or at least was in his earlier writings) a list of some features of dream experience. According to him, a dream is mentation during sleep that has most of the following features: *hallucination, delusion, narrative structure, hyperemotionality, and bizarreness*. This definition may be (and was) criticized as including only paradigmatic late-night REM dreams that are spontaneously remembered and on which our everyday stereotype of what dreams are like is based. This bias in the definition towards REM dreams might be seen to reflect the underlying theoretical idea or commitment, obvious in Hobson's earlier theories, that dream phenomenology should be (reductively) explained by referring to the features of REM neurophysiology.

The opposing, cognitive–psychological view of the 1980s and 1990s conceptualized dreaming as a cognitive process that should be explained at the cognitive–psychological level (Foulkes 1985). References to the neurophysiological level were unnecessary. In that time and in the spirit of functionalism and classical cognitive science, the cognitive levels of description and explanation were in general seen to be completely independent of implementation levels, such as neurophysiology. Furthermore, dreaming was thought to occur in every stage of sleep, not only REM sleep, and rather than being full of bizarreness was mostly a credible replica of the waking world. Thus, according to the cognitive approach, an explanation of dreaming cannot be based on neurophysiological mechanisms in general, or for REM sleep on neurophysiology in particular. The explanation should be given at cognitive levels rather than neurobiological ones. Interestingly, it was probably Foulkes (1985) who first characterized dreams in terms of the idea and the concept of simulation. In 1985 he described dreams as *credible world analogs*, an organized form of consciousness that *simulates* what life is like in a nearly perfect manner.

A third theoretical definition of dreaming came from clinical dream research, and reflected the long and widespread idea in clinical psychology that dreams restore our emotional balance and have a psychotherapeutic function. Hartmann formulated this definition of dreaming most clearly, when he said that "Dreaming, like therapy, is the making of connections in a safe place" (1996, p. 13).

During recent years in dream research, the concept of simulation has become a widely accepted way of characterizing and defining dreaming, as well as a way of formulating theoretical ideas about the potential functions of dreaming. Thus, the idea that *dreaming is a multimodal, complex, dynamic world-simulation in consciousness during sleep*, may be a type of conception and definition of dreaming that many if not most dream researchers are ready to accept (Nielsen 2010). The various contents of dreams—their events and objects and characters—can be taken to be simulations of their real-world counterparts.

Taking Foulkes's idea of dreams as credible world analogs and as the simulation of what life is like as a starting point for defining dreaming, Revonsuo (1995) formulated the Virtual Reality metaphor and later the TST (Threat Simulation Theory) of the evolutionary function of dreaming. This theory is built on two background assumptions, the first of which is precisely the definition of dreaming as "an organized simulation of the perceptual world" (Revonsuo 2000, p. 883). An additional, more specific assumption of this theory is that dream experience is *specialized* in particular in the simulation of *threatening* events: it tends to select and include various types of dangerous enemies and events and then simulates what it is like to perceive and recognize them (simulation of threat perception) as well as how to react and behaviourally respond to them (simulation of threat avoidance behaviours and strategies). Threat simulations appear in a paradigmatic and powerful form especially in nightmares, bad dreams, and post-traumatic dreams, but are also abundant in many other types of dreams

such as everyday dreams, recurrent dreams, and in various parasomnias such as RBD (REM-Sleep Behaviour Disorder).

Domhoff (2007), who represents a similar psychological and content-analysis approach to dream research as Foulkes (1985), also characterizes dreams as mostly realistic and reasonable *simulations* of waking life. By emphasizing that, according to convincing empirical data from content-analysis studies of dreams, dream simulations are mostly *realistic* rather than overly bizarre and hyperemotional, Domhoff argues against the Hobsonian definition of dreaming as being full of bizarre contents.

Still, despite their disagreements, both camps now seem to accept the notion of *simulation* as a valid description of the core nature of dreaming. Hobson, in his new *protoconsciousness* theory of dreaming and REM sleep (2009), uses the concept of simulation to characterize the root phenomenon, protoconsciousness, from which both our waking and dreaming consciousness arise. According to Hobson, protoconsciousness is the simulated experiential reality or a virtual reality model of the world that the developing brain turns on during REM sleep even before birth, to prepare the conscious brain to simulate the external reality that it will encounter through the senses after birth. This model of the world is genetic, innate, and a human universal. Protoconsciousness acts as the template on which both waking and dreaming consciousness are built after birth. Thus, according to this theory, protoconscious dream consciousness—a very basic form of an internally simulated world—comes into being prior to waking consciousness, and is causally necessary for waking consciousness. As Hobson (2011, p. 30) puts it: "I REM, therefore I will be". According to Hobson & Friston (2012), *predictive coding* is an underlying mechanism in the brain that produces predictive simulations of the world. Therefore, dreaming may also function as a preparatory simulation of the waking world; thus their idea is closely related to the other simulation-theories of dreaming (Hobson & Friston 2012).

In conclusion, while there still are disagreements about many details of dream content and function, there seems to be relatively widespread agreement that the definition of dreaming includes the idea of "simulation" of the waking world. The use of the concept of "simulation" to characterize dreaming has recently gained wide acceptance in the field. The simulation is variously characterized as the simulation of waking life, of waking reality, or of waking consciousness, and variously called by different authors a realistic world-simulation, a virtual reality, an immersive spatiotemporal model of the world, and so on—but despite the somewhat varying terminology, the different terms seem to describe the same basic idea. This conceptual unification is a significant step forward in the theoretical description and explanation of dreams. It paves the way for a more unified theory of dreaming.

4 The simulation of social reality in dreams

Dreaming not only places us into an immersive (virtual) physical reality, but also immerses us into a (virtual) *social* reality: in dreams we are surrounded by close friends and family members, schoolmates, teachers and students, spouses, romantic partners, old crushes, colleagues and bosses, celebrities, politicians, acquaintances, strangers, and mobs as well as monsters and other fictitious characters from movies and video games. All are there in dream simulation with us as simulated characters—avatars—and we interact with these avatars in multiple ways: we perceive, recognize, and semantically classify them, we communicate and talk with them, we collaborate with them, help them, criticize them, fight them, escape them, fear them, and love them. At least intuitively, there is no doubt that in our dreams, we live rich and colourful social lives, even if only simulated ones.

If dreaming in general can be defined as a simulated world, the question arises whether the concept of "simulation" can also be usefully applied to describe the social reality of dreams. The first task for a theory that takes the concept of simulation seriously is to simply *describe* the social contents of dreams as simula-

tions of human social reality. The descriptive questions can be formulated in more detail along the following lines:

1. What kind of social perception, social interaction, and social behaviours are simulated in dreams?
2. How frequently are different kinds of social perception, interaction, and behaviour simulated in dreams? How much variation is there in the frequency of different social simulations as a function of gender, age, culture, and as a function of the quality and quantity of social interactions during waking life?

It is possible to find answers to many of the above descriptive questions from the already-existing dream research literature where various aspects of the social contents of dreams have been reported, even if they have not been conceptualized as social simulations. In what follows, we will first briefly review some of the major findings in the literature that describe the quality and the quantity of social simulation in dreams. Once we have detailed empirical descriptions of the quality and quantity of social simulations in dreams, we may seek explanatory theories and testable hypotheses that could account for why we have social simulation in dreams.

4.1 Evidence for simulation of social perception in dreams

From the already existing literature, it is possible to find statistics that describe the quality and quantity of social simulations in dreams. However, the theoretical concept of "social simulation" is rarely used in dream research literature for interpreting the descriptive results. Here, we will briefly summarize only some of the major findings.

The minimal criterion for a dream to count as a social simulation is that the Dream Self is not alone in the dream but in the presence of at least some other animate character or characters. In less than 5% of dreams is the dreamer alone (Domhoff 1996); thus, on this minimal criterion, dreaming seems to consist-

ently simulate social reality. The other animate characters simulated in dreams are predominantly human (normative finding in adults is about 95% human, 5% animal), but the proportion of animal characters varies in different cultures and age groups, being highest (up to 30–40%) in young children and in adults in hunter-gatherer societies (Domhoff 1996; Revonsuo 2000). As human characters are reported in almost all dreams, and typically there are two to four non-self characters in a dream (Nielsen & Lara-Carrasco 2007), the presence of simulated human characters must be perceptually detected and registered in the dream by the dreamer. Thus, during dreaming, *our neurocognitive mechanisms constantly simulate social perception.*

The minimal form of social perception is to *detect or register the presence* of some human character. A more sophisticated form is the perceptual *recognition* and *identification* of the human characters who are present, first in terms of some basic perceptual and semantic categories (male/female; familiar/stranger), and then in terms of more detailed semantic and autobiographical information about the precise identity and name of the person. According to the Hall and Van de Castle norms, about 90% of simulated human characters have sufficiently definite characteristics to be semantically categorized, for example as male or female, or as familiar or unfamiliar (Domhoff 1996). Thus, social recognition and identification mechanisms are highly engaged in almost all cases of social perception in dreams. The dreamer knows, both during the dream and afterwards when reporting it, whether the simulated characters present in the dream are (or were) male or female, familiar or strange, friend or family; and in most cases, the familiar characters are identified as particular persons from real life.

Typically, a slight majority of dream characters are avatars for familiar persons, although there are well-established gender differences (Domhoff 1996) that might, however, partly depend on the gender distribution encountered in the real-world social environment (Paul & Schredl 2012). In a sample of five hundred REM dreams (Strauch & Meier 1996) familiar people

(friends, acquaintances, and relatives) were simulated most frequently (44% of all characters), strangers represented about 25% of dream characters, and undefined people about 19%. In most dreams, both familiar and unfamiliar people were simulated, but in 30% only strangers and in 20% only familiar people appeared. The mixture of familiar and unfamiliar people was true also at the individual level—there were no participants who would have simulated only strangers or only familiar people in their dreams.

For the most part, the human avatars in the dream world are quite *realistic* simulations of their waking counterparts. The degree of realism, however, is difficult to express with accuracy by any single measure or quantity, as there are several features of human characters that may independently vary along the dimension of realism (Revonsuo & Tarkko 2002). The opposite pole for realism is called *bizarreness,* which in dream research refers to deviation from the corresponding entity in waking life.

If any kind and degree of deviation from a waking counterpart is counted as a bizarre feature of a simulated person, then over half of the simulated humans in dreams (over 60% according to Kahn et al. 2002; 53% according to Revonsuo & Tarkko 2002) are not perfectly realistic simulations. In contrast to other dream characters the Dream Self is rarely distorted in any way (Revonsuo & Salmivalli 1995). Revonsuo & Tarkko (2002) also found that in the vast majority of cases (around 90% of dream characters), non-self dream characters are *perceptually* entirely realistic—they *look* the same as their counterparts look in real life. Where they deviate from their counterparts is most often their verbal and nonverbal behaviour. Thus, although the perceptual simulation of human characters is nearly flawless in dreams, the simulation of expected or predicted *behaviours* deviate from waking norms relatively often, though still at least a slight majority of behaviours by dream characters are no different from waking life.

Dream characters are also spatially and temporally quite stable and continuous within the dream, although transformations and discontinuities sometimes do happen (Nielsen & Lara-Carrasco 2007). A simulated person sometimes appears from nowhere, is magically transformed into someone else, or suddenly disappears without a trace. But these kind of discontinuous features account for less than 5% of dream character features (Revonsuo & Salmivalli 1995; see also Revonsuo & Tarkko 2002).

By contrast, the behaviours expressed by dream characters are relatively often to some extent odd or unpredictable. Thus, the simulated social reality in dreams is *less predictable* than the corresponding social reality during wakefulness. However, it is unclear how this unpredictability should be interpreted: does it simply reflect the difficulty (and consequently failure) of simulating complex human behaviours and interactions realistically by the dreaming brain, or is there some other more functional explanation as to why the avatars in our dreams tend to behave in more erratic ways compared to their waking-life counterparts? We will come back to this question when we consider the possible functions of social simulation in dreams.

4.2 Evidence for simulation of social interactions in dreams

The Dream Self and other dream characters are simulated in almost all dreams, but how often are they engaged in mutual social interactions? According to Strauch & Meier's (1996) data (140 REM dreams in which a Dream Self was present and had an active role), in nearly 50% of these dreams the Dream Self and characters interacted, in an additional 20% they acted together, and in 20% they acted independently of each other. In the rest, the Dream Self acted alone. Thus, social interaction or acting together is typically simulated in dreams where the Dream Self is present together with some other dream characters. When social interaction takes place, there is almost always verbal communication or conversation between the Dream Self and the other characters, which tends to be focused on concrete topics (Strauch & Meier 1996), and it is understandable and something that would be sayable in waking life (Heynick 1993).

The more detailed nature of social interactions has typically been categorized in terms of "friendly" and "aggressive" interactions. Friendly interactions are on average found in about 40% of dreams, whereas aggressive interactions are somewhat more common, and occur in about 45% of dreams in a normative sample (Domhoff 1996). Strauch and Meier, however, point out that in their sample, neutral interactions were also common, and only about half of the social interactions in their sample could be classified as particularly friendly or aggressive. The third category of social interactions that has typically been quantified in dream reports is sexual interactions, but they occur at a very low frequency—in Strauch & Meier's (1996) laboratory data, in less than 1% of REM dreams, and in the normative Hall and Van de Castle (Domhoff 1996) data, in 4% of women's and in 12% of men's dreams collected in a home setting.

In sum, the simulation of dream characters occurs very frequently, the characters are perceived and recognized by the Dream Self, and the Dream Self actively participates in communication, social interaction, and joint actions with the characters. The simulated characters are also for the most part realistic, stable, and represent a variety of different kinds of people. Their behaviours, however, may sometimes be unusual or inappropriate, and not exactly what we would have expected from their counterparts in real life. The tone of the interactions may be neutral, friendly, or aggressive.

When this evidence is taken together, we may conclude that dreaming simulates a rich, variable, realistic, and concrete, but somewhat unpredictable social reality, inhabited by a mixture of familiar, unfamiliar, and undefined people. Therefore, we have solid grounds to state that dreaming *is*, among other things, definitely a social simulation. If this is a universal and ubiquitous feature of dreaming, what kind of theory could explain it? *Why* does dreaming simulate social reality at all? It is by no means self-evident that this should be the case. Dreaming could as well be only a simulation of some basic features of the physical world: space, time, objects, events, and the perception of and bodily interaction with the physical world. Or it could be a simulation of thought processes, a thinking-through of our problems, or of our emotional states and concerns. Moreover, simulation of physical objects and their behaviour, or a replay of thinking and emotions, would probably be a simpler task for the brain than the simulation of a complex social world. Simulation of human bodies and faces and interactive behaviours such as conversations seems to require a lot of energy and computing power—these are very complex phenomena to simulate realistically. Thus, *why* does the sleeping brain simulate social situations in such an intense and invariant manner? Is there any convincing theoretical answer to be found to this question?

5 The continuity hypothesis and social simulation theories of dreaming

There are, of course, countless theories of dreaming. Some have explicitly considered the role of social interactions in dreams, while others make more general statements about dream content. One of the latter is the Continuity Hypothesis (CH), which states that dreams *reflect* waking life experiences (Schredl & Hofmann 2003) or, more specifically, that our waking concerns, thoughts, and experiences have a *causal influence* on subsequent dream content. Thus, if certain types of social contacts or interactions become more frequent (or less frequent) in waking life, their simulation in dreams becomes correspondingly more (or less) frequent.

This general principle seems to hold in many cases. For example, in hunter-gatherer societies, where people perceive and interact with wild animals on a daily basis, the proportion of animal characters remains high (as it is in children's dreams across cultures), whereas in highly industrialized societies, the animal percentage decreases dramatically from childhood to adulthood. But the CH merely restates this empirical relationship; it cannot answer the theoretical question of *why* in young children's dreams the proportion of animal characters *is high to begin with*. TST (Revonsuo 2000) has attempted to answer this question by referring not to personal experiences in waking life, but to a universal bias that is built into the default

values of dream content during human evolutionary history.

The CH, even if on the right track in many cases, is too vague and general as a theoretical explanation of the details of dream content. It does not predict in any detail how and why the causal relationship between waking and dreaming works. It also does not specify in any detail what counts as a "continuity" and what would count as a "discontinuity" between waking life experiences and dream simulations of the same. If something happens in waking life *how closely similar* will the dream simulation be to its waking origin, *when* will the same (or a similar) content appear in dreams, *how frequently and for how long* will it be incorporated into dreams, and so on? These questions have been studied under the concepts of day residue (Freud 1950) and the dream lag effect (Nielsen & Powell 1989). The CH takes almost any similarity between waking life and dream life as a confirmation of the continuity hypothesis. But "similarity" as a relationship between two phenomena is undefined, ambiguous, and vague. Something that in one respect is similar to its waking counterpart is in another respect dissimilar from it; thus it can be interpreted as either continuous or as discontinuous with waking life. Obviously, if the very same evidence could be counted as either supporting or disconfirming a theory, there is something wrong with how the theory is formulated.[2]

As long as the CH remains vaguely formulated, almost anything can be counted as its support. If the hypothesis does not specify in any detail the potential empirical observations after which its predictions would be falsified, it is not an empirically testable theory. Unless it is formulated in a much more specific manner, so that risky, exact predictions can be derived from it, its explanatory power remains correspondingly weak. In one study where more precise predictions from CH were derived, the CH was found not to be valid as a general rule concerning how often different everyday activities are reflected in dreams (Schredl & Hofmann 2003).

2 For a recent exchange, see Hobson & Schredl (2011) and related commentaries in the International Journal of Dream Research (2011, vol. 4).

Perhaps a more precise prediction that could be derived from CH can be formulated in the following way: according to CH, dreams represent a random sample of recent waking experiences (or a random sample of their memory representations). The quantities of different types of contents in dreams will therefore passively reflect the proportion of their occurrence in waking life in the recent past (or the memory representations of waking life). If CH is formulated in this manner, as a prediction of random sampling and passive mirroring of recent waking life, then any systematic deviation from a random sample of waking contents (or memories thereof) would count as evidence against the CH. A deviation from passive mirroring of waking life would suggest that some kind of *selective* mechanism is at work. An *active selection* bias of particular contents to be either included in dreams or to be left out would be expected to result in a disproportionately exaggerated or diminished frequency of that content in dreams as compared with waking life. This kind of formulation of the predictions of CH makes it a testable theory.

Some more specific suggestions about dreaming as social simulation have been put forward in the literature. Brereton's (2000) Social Mapping Hypothesis suggests that dreaming simulates, among other things, the awareness of other persons (social perception) and their internal mental states (mentalizing or theory of mind-abilities). This theory proceeds from an evolutionary standpoint, and considers dreaming as a rehearsal ground for emotional and perceptual abilities related to the mapping of the body image of the self into an emotionally-salient social space. Others have also hypothesized that our mindreading abilities could potentially be a target of simulated social perception in dreams (Kahn & Hobson 2005; McNamara et al. 2007). Moreover, Nielsen & Germain (2000) have suggested that dreaming might simulate attachment relationships and interpersonal bonds in ways that would maintain their adaptive significance even today, and Humphrey (2000) has compared the social functions of dreaming to those of play. The possibility that dreaming simulates pro-social and ag-

gressive social interactions in distinct sleep stages, and that these simulations might exert a regulatory influence on our waking social lives, was put forward by McNamara et al. (2005). Last, Franklin & Zyphur (2005) have considered how the simulation function of dreams might be expanded to cover social cognition and complex socio-cultural situations.[3]

The problem with the above social simulation theories of dreaming is that either they are not detailed enough to be testable, or that few, if any, have ever been directly tested against competing theories. They are interesting general ideas, but not strictly formulated theories that could be directly tested, or from which detailed predictions and potential explanations for the social contents of dreaming could be derived. Thus, these theoretical ideas have not led to a strong empirical, hypothesis-driven research program that would be able to systematically test the plausibility of these theories.

Whenever we formulate theories of dreaming, or of the functions of dreaming, they should be formulated in such detail that *empirically testable predictions* can be derived from them. Statements that are too vague or too general (e.g., "dreams are continuous with waking life"; "dreams are social simulations") are difficult to test as such. The predictions derived from general statements are too unspecific. Thus, the theories remain uninformative but of course consistent with almost anything we might realistically expect to find in dream content. If a theory makes no detailed, risky predictions about what should or should not be found in dream content (under some specific circumstances or in specific populations) it doesn't have much explanatory power, either. So far there is no detailed, convincing, testable theory

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[3] Another popular theory of dreaming postulates that the realistic simulation of character–self interactions serves the function of *emotion regulation* during dreaming (Nielsen & Lara-Carrasco 2007). In this group of theories, the function of dreaming is proposed to be the calming down of emotional surges, such as we see in psychotherapy (Hartmann 1995, 1996, 1998), or as reflecting the extinguishing of fear memories (Nielsen & Levin 2007). It is increasingly apparent that sleep plays a role in the consolidation of emotional memories, but whether sleep also *regulates* the emotional charge and valence of memories is not yet entirely clear (for a recent review, see Deliens et al. 2014). Thus, whether the emotional regulation theory has specific implications or predictions for social simulations in dreaming is not evident.

of the nature and the function(s) of social simulations during dreaming. There is also a lack of data on the detailed quantity and quality of simulated social interactions in dreams, and how they relate to real social interactions in the waking life of the same person. In the rest of this paper, we will try to outline ideas for the theoretical basis of a social simulation theory of dreaming and to formulate some empirically-testable hypotheses directly derived from the theory.

6 Towards a testable social simulation theory of dreaming

The relatively loose idea or the general observation that dreams are social simulations needs to be turned into a theory from which testable predictions can be derived. There are several ways in which this could be done. In the rest of this paper, we will formulate some suggestions towards that end. The basic assumptions that we adopt are based on the earlier work on the definition of dreaming (and consciousness) as an internal world-simulation in general (Revonsuo 2006). Any plausible theory of social simulation should also take into consideration, and draw from, concepts and advances in the fields of social psychology and evolutionary biology, in order to create a credible theoretical context into which social simulations in dreams can be placed. We will therefore connect the idea that dreaming may function as a platform for simulating social perception and interactions to some influential evolutionary biological and social psychological theories, as well as to the earlier simulation theory of the original evolutionary function of dreaming, the TST (Revonsuo 2000).

The two generally-accepted theories in evolutionary biology that seem to be relevant for the formulation of an evolutionary SST of dreaming are the Inclusive Fitness and Kin Selection Theory (Hamilton 1964) and Reciprocal Altruism Theory (Trivers 1971). Both are general evolutionary biological theories that apply not only to humans, but to multiple other species as well. Further, both have received ample empirical support from animal and human stud-

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ies, and could thus serve as solid ground in guiding our thinking about social behaviours in evolutionary biological terms.

The Inclusive Fitness Theory (Hamilton 1964) postulates that an individual's genetic reproductive success is the sum of that individual's direct reproduction and the reproduction of the individuals carrying identical gene alleles. An individual can improve its overall genetic success by engaging in altruistic social behaviour that is directed towards individuals carrying identical alleles. The Kin Selection Theory is a more specific form of the inclusive fitness theory, which requires that the shared alleles are identical by descent. Thus, Kin Selection Theory postulates that an individual can increase its inclusive fitness by directing acts of altruism specifically towards genetic relatives, whereas inclusive fitness as such is not limited only to cases where kin are involved. Both, however, predict that acts of altruism should more often be directed towards individuals who share identical alleles.

Reciprocal Altruism (Trivers 1971) is defined as behaviour whereby an individual acts in such a way that temporarily reduces its fitness while increasing another individual's fitness. However, individuals engage in altruistic behaviour with the expectation that the recipient of the altruistic act will act in a similar manner at a later time. A strategy of mutual cooperation may be favoured when there are repeated encounters between the same individuals. Although cheating might be more beneficial for the individual in terms of immediate rewards, co-operation might provide net gain compared to short-term benefits.

Since selection pressures act on the typical conditions present in the history of any species, consideration of the demographics of the typical evolutionary environment of humans is crucial for understanding the evolution of social behaviours in our species. Recently, Hill et al. (2011) analyzed co-residence patterns among thirty-two present-day foraging societies, assuming that these might reflect an ancestral human group structure. They found that primary and distant kin of an adult individual accounted for approximately 25% of the co-resident adult

members of a band, i.e., about 25% of adult members in the group were directly genetically related, whereas about half of the adults were related through spouse or siblings' spouses, and the other 25% of adults were genetically unrelated.

If we accept the assumption that this observed distribution of relatedness approximates the degree of relatedness in ancestral human bands, there have been ample opportunities for ancestral humans to be subjected to selection pressures that could be explained using strategies postulated by the inclusive fitness and Kin Selection Theory, as well as Reciprocal Altruism Theory. There is ample evidence that people are more likely to help their relatives than genetically unrelated individuals (e.g., Burnstein et al. 1994), and that lethal violence is more frequently directed towards genetically-unrelated individuals than relatives (Daly & Wilson 1988). People also tend to be more altruistic towards other people in single round prisoner's dilemma game than could be expected (Frank et al. 1993) in order to protect their reputations. This seems to be a reasonable course of action, given that the faces of individuals labelled as untrustworthy cheaters are better recalled than those labelled as cooperative (Mealey et al. 1996). There are also rather large interindividual differences in altruistic behaviour, depending on factors such as age, sex, tendency to empathize, and circumstantial conditions.

The social environment has afflicted strong selection pressures on human cognitive faculties, and there are several theories that consider our essentially social nature. Dunbar (1992, 2008) has forwarded the Social Brain Hypothesis, which states that the main factor in the increase of our neocortical volume has been the cognitive demand bestowed on us by the increase in hominid group size. Sutcliffe et al. (2012) propose the idea that the costs and benefits of social interactions have been a critical driver for cognitive evolution. While our most intimate relationships are a source of social support, they are also the most costly as the quality of these relationships is dependent on the time invested in creating and maintaining them

over time. Forming weaker and less time-consuming ties with acquaintances can provide benefits such as information exchange and access to resources without exhausting an individual's resources that are allocated for social interaction. Our individual social worlds thus consist of hierarchically-layered sets of relationships defined by relationship intimacy, and different relationship types are designed to have different kinds of functions.

Turning our attention to the potentially relevant literature in social psychology, some further concepts and measures might be considered useful for dream theory. When it comes to the simulation of social interaction, one of the most relevant concepts is the social "Need to Belong" (Baumeister & Leary 1995). This fundamental motive towards interpersonal attachment and close, supportive social bonds pervades and influences our actions, emotions, and cognitions, and is fulfilled only by social affiliation and acceptance. To help us navigate the complex social world, and attune us to socially relevant information, two further advancements have been hypothesized in the form of the Sociometer Theory (Leary et al. 1995) and the social monitoring system (Gardner et al. 2000). Sociometer Theory proposes an internal monitoring device that feeds forward information about our level of social inclusion in the form of self-esteem or self-worth (Leary et al. 1998), whereas the social monitoring system is purported to guide the processing of social information whenever people's needs to belong are not being met (Pickett et al. 2004). In sum, the concept of "Need to Belong" in general, and the suggested social monitoring systems in particular, might prove useful in postulating testable hypotheses for the functions of social simulation in dreams. The Sociometer, for example, might act in a similar fashion to the threat cues postulated in TST, and prompt dreams to simulate relevant social skills or interactions.

An interesting developmental suggestion about the interplay between simulation mechanisms and social deficits has recently been put forward by Oberman & Ramachandran (2007), who propose that in typically developing individuals the abilities of Theory-of-Mind (ToM), empathy, perceptual recognition, and motor mimicry might be mediated by an internal simulation mechanism or mechanisms. By taking into consideration a condition—autism—where all these abilities appear to be impaired, they make the case for a possible link between deficient simulation mechanisms and behavioural and social deficits. The exact implications of this idea for the hypothesis that dreams serve a social simulation function requires further consideration. One possibility is to test whether individuals with Autism Spectrum Disorders (ASD) dream less of social interactions, or whether their dreams of social interactions are different in content from those of other people. Thus far this line of research has not been explored in depth. Daoust et al. (2008) have looked into the dream contents of people with ASD, and found that they report significantly less dream-characters and social interactions than the control group. They note, however, possible error sources in the testing procedure, such as, for example, how the reporting of dreams itself might be affected by ASD.

There has been some research linking the effects of attachment relationships to dreaming. If, as attachment theory proposes, we use our early experiences with primary caregivers and other attachment figures as model states for future social interactions and the way we view and attune to our social world, it could be assumed that this would also affect our simulations of this world. Early attachment and bonding are, after all, quintessential for our species, and according to Fonagy & Target (1997) might also work as the basis for our abilities to mentalize or to create a ToM. McNamara (1996) has developed the idea that REM sleep is the mechanism that activates and maintains early attachment relations, as well as pair-bonding in later life. Selterman & Drigotas (2009) have found that attachment style is correlated to dream emotions when dreaming about romantic partners, so that those with anxious or avoidant attachment styles reported more stress, conflict, and negative emotions.

In an exploratory study on the dream contents of those suffering from Complicated Grief

(CG) after the loss of an attachment figure, Germain et al. (2013) found the dreams containing family members to become significantly more frequent, while there was no marked increase in the occurrence of deceased characters. Males suffering from CG also reported more familiar persons in their dreams than the control group. Both male and female CG patients also exhibited fewer negative emotions and fewer instances of aggression in their dreams, and females also had decreased amounts of positive emotions and friendliness.

We can thus conclude that the inherently social nature of our species is deeply ingrained, and has likely been as important for our survival in the ancestral environment as threat perception and avoidance skills. SST can therefore be formulated in an analogous manner to TST, but in addition to the evolutionary background theory, also taking into consideration important social functions such as the need to belong, social bonding, social networking, and social support as essential ingredients.

TST (Revonsuo 2000) places the contents and the function of dreaming in an evolutionary-psychological context and proposes that dreams were selected for their ability and propensity to simulate threatening events in a safe way, thus preparing the individual to survive real-life dangers. The hypotheses and predictions of the TST, especially concerning the inclusion of threat simulations in dream content, have gained support from several independent sources, such as studies on the content of nightmares and bad dreams (e.g., Robert & Zadra 2014), recurrent dreams (Valli & Revonsuo 2006; Zadra et al. 2006), post-traumatic dreams in children and adults (Bulkeley & Kahan 2008; Valli et al. 2006), dreams anticipating a stressful experience (Arnulf et al. 2014), children's earliest dreams (Bulkeley et al. 2005), dreams and mental contents in parasomnias (Uguccioni et al. 2013), the dreams and nightmares of new mothers (which mostly depict the infant in peril and trigger protective behaviours, Lara-Carrasco et al. 2013, 2014; Nielsen & Lara-Carrasco 2007), as well as dreams of the general population (for a review, Valli & Revonsuo 2009).

Thus, when it comes to emotionally negatively-charged dream contents that simulate some sort of dangerous situation or unfortunate event, the TST seems able to quite well predict and explain many features of the quantity and the quality of the threat simulations found in the data. Therefore, a similar theoretical approach might also prove fruitful in the case of social simulation theory. The SST, however, needs to be formulated in such a manner that its predictions can be clearly distinguished from those of the TST.

As negative and threatening events commonly occur in dreams, the TST alone already covers a fairly large proportion of dream content. But it also ignores a relatively large proportion of dream content, as it does not offer any explanation of non-threatening dreams or for the simulation of neutral and positive events in dreams. This raises the question: do types of dream events other than those that are threatening have some evolutionarily-based simulation function, independent of the threat-simulation function of dreaming? Are there events that are equally important targets for simulation as the negative, threatening situations simulated in threat simulation dreams?

TST covers threatening events in dreams, whether social in nature or not. Many threatening events of course do involve social interaction (such as verbal or physical aggression), but are explained by the TST as primarily simulations of specific types of threat, and therefore as rehearsals of threat perception and threat-avoidance behaviours, rather than as simulations of social interactions as such. A social simulation theory that explains dreams that TST does not cover should thus focus on social simulations that are largely independent of the threat-simulation function. In some dreams these two types of simulation may, however, be difficult to tease apart. For example, a social simulation theory might account for some social interactions that happen during a threatening event in a dream, such as how the Dream Self interacts with others and collaborates with them during a threatening situation. Furthermore, these two simulation theories may not be mutually exclusive but instead complement each other. Some specific

types of simulations of negative social interactions are better accounted for by the TST while other, positively toned simulations can be explained by the SST. For example, from an evolutionary perspective it might make sense to simulate different kinds of interactions, friendly or aggressive, with people belonging to different layers of our social hierarchy.

We are open to the possibility that social simulation is an original evolutionary function of dreams alongside the threat-simulation function of dreaming. We believe that social simulation theories hold much promise. But before this belief can be empirically justified, a testable version of the social simulation theory needs to be formulated. Such a theory should independently cover the social simulations in dreams that fall outside the scope of the TST.

Furthermore, also the predictions of the CH must be distinguished and separated from those of the SST. Therefore, the question becomes: What aspects of human social reality might dreams be specialized in simulating in such a way that these social simulations have significant consequences for cognition and behaviour during the waking state, and in virtue of which social simulations during dreaming have fulfilled important functions in the evolutionary history of the human species? What kind of social-cognitive processes and behavioural social skills might have been both critical enough both for an individual's survival and successful reproduction, as well as occurring frequently and universally enough in the human ancestral environment, to be selected for as a universal feature of human dreaming? Moreover, those processes and skills would have to be something that in fact *can* be regularly simulated by the dreaming brain, and they have to be contents that actually *are* being simulated frequently and universally in human dreaming, according to the evidence from content analysis studies of dreaming.

To sum up, a credible version of the SST should have predictions and explanations that are clearly different from both the TST and the CH. To be different from TST, the SST should predict and explain the social simulations that happen outside threatening events in dreams, and to be different from the CH, the SST

should predict that some types of social stimuli, social cognition, or social behaviours are simulated actively and selectively, so that they are overrepresented in dreams as compared to waking life.

We will first consider some basic cognitive processes that might fulfil these roles and will then proceed to more complex social behaviours and interactions. We admit that many of these ideas are at this stage speculative. But if it is possible to formulate them in an empirically testable manner, then we can figure out later on which ideas remain mere empirically unsupported speculations, and which ones might actually predict and explain central aspects of our dream content.

6.1 The simulation of social perception as a function of dreaming

Overall, there are good reasons to support the view that fast and errorless social perception abilities were universally important skills for humans during their evolutionary history, and, therefore, rehearsing them through dream simulations would have served to maintain and enhance their speed and accuracy during wakefulness. In the ancestral environment, fast and efficient social perception and recognition mechanisms were essential for telling friends and allies apart from potential enemies. Thus, detecting the presence of other human beings in the same spatiotemporal context where oneself is located, immediately classifying them in terms of familiarity, identity, and history of past interactions with them, and predicting the nature of future encounters with them must have been an important survival skill. Perhaps it was important enough that rehearsal of these social-cognitive functions through social simulations during dreaming would have increased an individual's inclusive fitness.

The social perception system needs to quickly estimate answers to the following questions: *am I alone in here or are there other humans present? Are the other humans around me familiar to me or are they strangers?* Thus, the first stage of social perception is to detect other humans in the vicinity and to classify them in

terms of unfamiliar people (strangers) vs. familiar people. As Diamond (2012) explains in "The World Until Yesterday", in most traditional societies during human evolutionary history, to encounter strangers was unusual and typically considered potentially dangerous, because the social interaction that followed might not necessarily have been peaceful in nature.

The second stage of social perception deals in more detail with the familiar people that are detected. If the people in my presence are familiar to me, who exactly are they? What is my relationship with them? What have my past interactions with them been like? What should I expect the interaction between us to be like this time around? To answer these questions, familiar people need to be quickly identified. Based on semantic and autobiographical memory information that we have about people familiar to us, we quickly activate expectations and strategies as to how we should interact with the people around us in the most constructive way.

But so far this idea is mere speculation. What kind of *testable hypotheses and predictions* could be derived from this theory? How could we derive predictions that clearly distinguish the SST from the CH? The CH does not attribute any evolutionary simulation functions to dream content; according to CH, dreaming simply and passively *mirrors* whatever experiences have recently been encountered in the dreamer's waking life (and thus impressed on long-term memory). Obviously, therefore, it would not lend sufficient (or specific) support to the SST to predict that social perception should be found in dreams in the same proportions as in waking life, because the CH predicts and explains exactly the same observation and, moreover, does it more parsimoniously, without postulating any just-so-story of evolutionary *functions* to social dream content.

The SST must thus go beyond the CH and make the risky prediction that, if social perception is the original evolutionary function of dreaming and it is therefore still expressed in our dream contents, then dreams are *specialized* in simulating social perception. If dreams are specialized in simulating social perception, then perceptual contents, cognitive processes, and

behaviours relating to social perception skills should occur (as simulations) in a selective or *exaggerated* form in our dreams. The testable prediction derived from this is that during dreaming, social perception occurs *more frequently* than in waking life (shows quantitatively an increased frequency) and/or qualitatively in a more difficult or challenging form than in waking life.

Quantitatively, dream simulations could exaggerate the proportion of the types of stimuli that were most important to recognize quickly and accurately during evolutionary history (e.g., strangers vs. familiar people; enemies vs. friends). It is important to process this information quickly because the information had high survival value in ancestral environments. Furthermore, dream simulations could present qualitatively challenging stimuli for the social perception system; for example, more variety of different kinds of stimuli (different kinds of familiar and unfamiliar simulated people), or ambiguous stimuli that are more difficult to perceive or interpret than real life stimuli (vague or unstable simulations of people).

Conversely, if the social stimuli in dreams simply mirror the social stimuli during wakefulness (and memory representations of them), quantitatively and qualitatively, then the CH gains support: dream experiences merely *copy* the patterns and rates of social stimulation encountered during wakefulness, but do not *selectively* and *actively* simulate them in ways and proportions that would reflect some original evolutionary functions and would therefore have supported important survival skills in ancestral environments.

To test these two opposing theories, SST and CH, against each other empirically, we need detailed information not only about the quantity and quality of social perception in dreams, but also about the quantity and quality of social perception during wakefulness in the same subjects' lives during the same period of their lives. Some studies already exist that provide us with this kind of data, but most of the hypotheses remain to be tested in future studies that should be explicitly designed to test the opposing hypotheses and predictions of the two theories.

McNamara et al. (2005) conducted an interesting study that can be interpreted as testing the SST prediction that social perception is quantitatively exaggerated in dreams as compared to waking life. They conducted experience sampling from fifteen individuals over two weeks across waking, REM sleep, and Non-Rapid Eye-Movement (NREM) sleep states. The participants recorded verbal reports of their perceptual and other experiences when paged at random intervals during sleep or wakefulness.

The results showed that *more characters appeared in dreams than in wake reports*. Unfortunately McNamara et al. (2005) do not report the exact descriptive statistics of this finding, so we do not know how large this difference exactly was. In any case, this finding is better in accordance with the predictions of the SST than CH: Stimuli requiring social perception (human characters) are present at higher frequencies during dreaming than during wakefulness, when experiences from both states are sampled and reported in a similar manner.

This important finding suggests that the basic processes and skills required in social perception are more engaged during dreaming than during an equal stretch of time in wakefulness. This lends support to the hypothesis that *dreaming is specialized in the simulation and rehearsal of social perception*, which may thus be one of the original evolutionary functions of dreaming. It has to be added, however, that McNamara et al. (2005) is the only study so far that provides us with this kind of data, where the frequencies of the social contents of dreaming and waking experiences have been directly compared with each other. Replications are obviously required in different populations and in larger samples of dreams and waking experiences. But so far, so good for SST.

The same study can be taken to test the additional prediction of SST, namely that dream simulations of human characters should exaggerate the proportion of the particular types of stimuli that were, during evolutionary history, most important to recognize quickly. Meeting strangers posed a threat in the original evolutionary context; thus, the SST predicts that *strangers or unfamiliar people should be overrepresented in dreams as compared to waking life*, to simulate and rehearse the type of perceptual categorization (familiar vs. unfamiliar) that was most important in the evolutionary context. McNamara et al. (2005) report that the proportion of strangers (or unfamiliar people) encountered in dreams is indeed significantly higher than in waking life. Only 25% of people present in the waking episodes were unfamiliar, whereas about 50% of the (simulated) people in dreams were unfamiliar. Again, this discrepant pattern is well predicted by and accounted for by the SST, but goes against the predictions of the CH.

The recognition and identification of familiar people as who exactly they are could also potentially be a target of useful simulation in dreams. It might be argued from SST that quick and correct recognition of familiar people enhances the quick selection of the appropriate social strategies and behaviours when we interact with them. As about 50% of simulated people in dreams are familiar, there are still plenty of opportunities to rehearse these recognition skills. There are, however, no studies that would have directly and quantitatively compared the frequency of face recognition during dreaming and wakefulness. But still, there are some studies that question whether face recognition is engaged during dreaming and to what extent.

Kahn et al. (2002) report, in a character recognition study, that about 45% of familiar dream characters were recognized through their appearance (including facial features), and an additional 12% by their observable behaviour. Thus, nearly 60% of dream characters are recognized perceptually. However, about another 12% of dream characters are recognized intuitively, by "just knowing" who they are, which suggests that in those cases, the "recognition" happens in a top-down manner and is therefore independent of the perceptual and facial features of the dream character.

If familiar persons are *not* overrepresented in dreams to begin with (as the McNamara et al. 2005 study suggests), and only well *under 50% of the familiar people simulated in dreams*

are recognized through their facial features, this pattern of data does *not* particularly support the idea that dreams are specialized in rehearsing familiar face recognition. However, we still lack knowledge about the frequency of face recognition in waking vs. dreaming, and only a study directly making that comparison could properly test this idea. So, the case remains open, but the expectations are not particularly high that this prediction of the SST will gain strong support in the future.

6.2 The simulation of mindreading as a function of dreaming

In addition to the processing of familiarity and identity, another aspect of social perception is called Theory-of-Mind (ToM) or "mindreading". This refers to the interpretations we automatically make about the internal mental states of the people around us. We not only categorize the people around us as familiar and unfamiliar, and assign an identity to familiar persons, we also attribute thoughts, beliefs, motives, and emotions to them. As mindreading is crucial for our ability to predict and explain other people's behaviours, our mindreading abilities could potentially have been a target of simulation during simulated social perception in dreams (Kahn & Hobson 2005; McNamara et al. 2007).

The study by Kahn & Hobson (2005) quantifies the frequency of mindreading activities in dreams. In one sample of thirty-five participants and about nine dream reports per participant, about four dream characters per report were observed on average. In over 80% of these dreams, the participants reported having had engaged in mindreading (at least one of) the other dream characters' internal mental states. In another sample, 24 subjects reported on average six dreams per participant. Each dream was divided into separate dream events (on average four events per report were found), and the participants were asked to report, concerning each event, whether or not they were engaged in mindreading the other dream characters. In 50% of the episodes, mindreading was reported to have occurred. Thus, on the basis of these results, we may say that mindreading fre-

quently occurs during dreaming. Kahn & Hobson (2005) in fact suggest that this may be evidence for a specific simulation function being at work:

> The two studies undertaken here support the idea that dreaming may provide a simulation of waking life as suggested by Revonsuo (2000), though not restricted to only threatening events. Instead, the data of these studies suggest that if dreaming is a simulation process, it is a simulation that provides a way of knowing and dealing with the intentions of others, both positive and negative. (p. 56)

The above studies show that mindreading is well represented in dreams, but they cannot tell us whether mindreading is *overrepresented* in dreams, as its frequency of occurrence cannot be directly compared to waking life. However, McNamara et al. (2007) have conducted a direct comparison of the frequency of mindreading between waking experiences, REM dreams, and NREM dreams of the same subjects. This is what they found:

> REM reports were three times as likely to contain instances of mind-reading as were wake reports and 1.3 times as likely as NREM reports. Of 100 reports per state, there were 39 instances of mind-reading in REM reports, 29 in NREM reports, and 12 in wake reports. (McNamara et al. 2007, p. 211)

In conclusion, from looking at these studies, we may say that mindreading activities frequently occur in dreams, and that their frequency of occurrence is significantly greater during dreaming than during wakefulness: Mindreading is overrepresented or exaggerated during dreaming. Thus, this data *supports the* SST *prediction that dreaming specifically simulates mindreading* in order to maintain and rehearse our mindreading abilities, rather than the CH prediction that dreaming simply reflects the amount of mindreading we engage in during wake experiences.

Another finding that might indirectly lend support to the SST-mindreading idea is that the behaviours and communications of dream characters are often bizarre (Kahn et al. 2002; Revonsuo & Salmivalli 1995; Revonsuo & Tarkko 2002); that is, they are unusual, unexpected, and thus unpredictable on the basis of our waking expectations. Studies on intentional social interactions between the Dream Self and other avatars in lucid dreaming suggest that dream characters are largely independent of the dreamer and behave autonomously (Stumbrys et al. 2011; Tholey 1989). Unusual and unpredictable behaviours could be interpreted simply as failures of the dream simulation to produce credible sequences of real-life behaviour. But they could also be interpreted as particularly engaging and activating social stimuli that serve to challenge our mindreading skills. That is, bizarreness in this case could be functional in the sense that it makes the simulation more challenging. Perception of unexpected behaviours may trigger a reconsideration of what is going on in the character's mind in order to produce such unexpected behaviour, and thus present a frequent need to engage in mindreading as we interact with unpredictable characters in our dreams. This idea could be empirically tested by studying whether bizarre behaviours on the part of dream characters tend to trigger mindreading in the Dream Self, and whether this feature of dreams might partially explain the apparently frequent engagement in mindreading in dreams.

6.3 The simulation of social interactions as a function of dreaming

Humans are an essentially social species and an individual's survival in the ancestral environment was most likely entirely dependent on the individual's ability to form long-lasting positive social bonds with close kin and other group members who offered protection, access to nutrition and other crucial resources for survival, collaboration, friendship, social support, mating opportunities, and opportunities to gain a better social status within the group.

Social interaction in dreams is a more complex affair than simple social perception. There need to be some behaviours that link dream characters and the Dream Self, where the intentional behaviour of one character (or the Dream Self) is directed at another character (or at the Dream Self), and the recipient somehow registers it or reacts to it. Traditionally, in the Hall & Van de Castle (1966) content analysis system, social interactions have been classified into three different categories: aggression, friendliness, and sexual interactions. It may be, however, that these three categories are too broad, and do not cover or identify all theoretically-interesting types of social interaction.

When it comes to the simulation of social interactions, the predictions of the SST should, again, be contrasted with the predictions derived from competing theories. In this case the SST needs to be distinguished from two other theories: CH and the TST. The TST is a simulation theory that describes and explains the simulation of aggressive behaviours in dreams, by including them under the category of "threatening events". The function of dreaming, according to TST, is not to specialize in the simulation of social interactions *per se*, but in threatening events; thus, any social interactions are simulated in dreams not because they are social events but because they are threatening events. No independent social simulation theory is required to explain the simulation of social interactions involving a threat; and aggressive behaviours between dream characters are, obviously, social interactions where the wellbeing of the Dream Self or some other dream character is potentially threatened.

Compared to CH or SST, the TST can account for the overrepresentation of threatening events and aggressive interactions in dreams (as compared to waking life, McNamara et al. 2005; Valli et al. 2008). The TST, however, gives no description or functional explanation for neutral and positive types of social interactions (unless they occur as parts of a threatening event). The TST assumes that neutral and positive events in dreams are either parts of a threat simulation (e.g., responding to a threat by helping others who are targets of a threat) or that they repres-

ent some kind of superfluous, non-functional dreaming that simply goes on automatically even if the threat simulation mechanisms are not activated. Thus, when it comes to social interactions, the SST should in particular predict and explain the neutral and friendly types of social interactions, and show that some of them are actively selected as targets of dream simulation. In contrast, the CH predicts that neutral and positive types of social interactions should only occur in the same proportions as they occur in real life, passively reflecting their waking-life frequencies.

If, according to SST, the simulation of neutral and positive social interactions in dreams serve to represent and strengthen important social connections and to rehearse prosocial behaviours in relation to those connections, then these types of interactions should frequently occur in dreams. This would serve the function of maintaining, rehearsing, or strengthening our waking life social bonds and networks, and would satisfy our social need to belong to groups that enhance our survival. After dreaming about prosocial behaviours, our social bonds during wakefulness would automatically be experienced as stronger and we would be more likely to engage in behaviours that further strengthen those bonds. Some tentative steps towards examining how the affects and contents of social dreams predict subsequent waking behaviour have been taken by Selterman et al. (2014). They discovered that an increased frequency of dreams involving significant others was associated with higher levels of intimacy and interaction the following day, whereas dream infidelity predicted less intimacy. Reported arguments in dreams were also found to be correlated with subsequent conflict in waking life. They leave open the question whether this is due to the conscious reflection of the reporting procedure, a more implicit association, or a mixture of the two.

Again, there are no detailed content analysis studies that have investigated the exact nature of social interaction in dreams by taking into account the social context of the interaction; that is, by studying who is engaged in what type of interaction and with whom. From previous studies based on home dream diaries we know that dreamer-involved aggression, adjusted to take into account all social interactions except sexual interactions, is present in 60% of male dreams and half (51%) of female dreams (Domhoff 1996). When male strangers appear in a dream, the likelihood that physical aggression will occur in that dream far exceeds what would be expected on the basis of chance. Basically this means that male strangers signal physical aggression. The dreamer, however, is an aggressor in 40% of male dreams and a third of all female dreams (Domhoff 1996).

Yet, as the Hall and Van de Castle norms indicate, there are friendly interactions in dreams—slightly more often in female (42%) than male (38%) dreams (Domhoff 1996). Females also dream more often of familiar people (58%) than of strangers (42%) while the opposite is true for males (45% vs 55%, respectively); which might suggest that when there are more familiar people in dreams, there is also more friendliness. The dreamer participates in the majority of interactions that involve friendliness (84% for females, 90% for males), and the befriender proportion is 50% for males and 47% for females. Thus, both sexes initiate friendly interactions in their dreams approximately as often as they are befriended. Helping and protecting is the most frequent type of friendly behaviour in both sexes, followed by friendly remarks and compliments, and giving gifts or granting loans. Surprisingly, however, there is very little mutual or reciprocal friendliness, so although friendly interactions are initiated in dreams by the Dream Self or other characters, in less than 10% of friendly interactions the act is reciprocated immediately. This observation goes against any social simulation theory that predicts reciprocal friendliness should be highly represented in dreams: this does not seem to be the case.

McNamara et al. (2005) investigated whether types of social interaction are different in REM than in NREM dreams compared to wakefulness, and noticed that aggressive interactions were more often simulated in REM dreams, whereas friendly interactions were more often simulated in NREM dreams. Furthermore,

dreamer initiated friendliness was more typical for NREM than REM dreams. What is most interesting in this study, however, is that they also found that social interactions in general are more often depicted in both REM and NREM dreams than in wake reports. While aggression was more often simulated in dreams than encountered in waking life, the number of reports with at least one occurrence of friendliness did not differ significantly across sleep–wake states. Thus, these observations imply that dreams do not seem to overrepresent friendly interactions as compared to waking experiences.

In sum, aggressive interactions seem to be more prominent in dreams than neutral or friendly interactions, which would lend more support to the TST than to SST, and friendly interactions are not more prominent in dreams than in waking life, which would lend support to CH and the TST. Nevertheless, if simulations are biologically functional, and if these two types of simulation functions are not mutually exclusive, might there be enough room in the dream content for simulation of neutral and positive interactions, in such a way that it could have contributed to the inclusive fitness of our dreaming ancestors?

6.4 Some testable ideas derived from SST

Let us see how this general approach to social simulation in dreams could be translated into some directly testable hypotheses. Now, a general thesis derived from the SST could be formulated as follows:

Dreams are *specialized* in simulating *the most important social connections and networks* of the dreamer to give an additional selective advantage and to enhance the survival of the dreamer in waking life. The simulations of particular people (the frequency of their presence in a person's dream life), and the simulations of positive interactions with particular people, should focus on the people closest to us in waking life and on the social bonds most important for our inclusive fitness in the real world.

This thesis could be directly tested by deriving some empirical predictions from it, telling us what kind of simulations of social interactions and to what extent they should appear in dreams. If dreams are specialized in the way predicted by SST, then the most important social networks and the people in them *should appear more frequently in dream life than in a corresponding stretch of waking life*. That is, their frequency of occurrence should be targets of active selection and inclusion into dreams, and hence over-represented and exaggerated in dreams.

This empirical prediction could be tested by identifying a person's most important social networks in waking life, and by quantifying the frequency of interactions of the dreamer with those people during dreaming vs. during wakefulness. In the already existing literature, there are some data relevant to the hypothesis, but data that directly compares waking social life and dream life in the manner required to test the hypothesis seems to be lacking.

The data scattered in the literature describes the relative frequency of dreams in which a certain type of close person appears on average in the dreams of the general (or the student) population. For example, romantic partners occur in 20% of dreams and this frequency correlates with the time spent together in wakefulness (Schredl 2011; Schredl & Hofmann 2003). Core family members occur in 10%–30% of dreams; parents in about 8%–20% of dreams, and siblings from 2%–7.5% of dreams (see Schredl 2013). Friends occur in about 20% of dreams (Roll & Millen 1979), but during long-term isolation from social contacts with friends in one case (Merei 1994) this declined to 10%. In studies of long dream series from a single person, a close family member or spouse has been found to be the person most often dreamed about. In a sample of over two hundred dream reports, reported by a married woman (Arlie) with four grown-up children, the most frequently occurring character is her husband; whereas in a sample of over three hundred dreams from an unmarried woman in her thirties (Merri), the most frequently occurring character is her sister, who was no longer alive at the time when the dream reports were collected (Schweickert 2007).

In Schredl's studies, interesting analyses of a long dream series from a single dreamer were conducted, revealing the proportions of schoolmates (2012) and family members (2013) simulated in dreams across a period stretching over twenty years. Old school mates continued to appear in about 5% of dreams over the years when the dreamer had nothing to do with them any more in real life. Similarly, family members, even when the participant was not living with them anymore, still retained a strong if somewhat reduced presence in the same dream series, being present in approximately 15–20% of the dreams over a twenty-year period.

These results show that the probability of occurrence of a character in dreams is to some extent related to the amount of real life contact with that person and to the closeness of the relationship in real life, thus supporting the CH. However, people who have at some point in life been close and important *do not seem to disappear totally* from the dream simulations even though they have long ago totally disappeared from the real life of the dreamer. This feature of the already-existing data suggests that simulations of social contact might serve the function of maintaining or strengthening close relationships over time. When the frequency of a previously close and important social contact falls to zero in waking life, and the person is no longer encountered in waking life (like old school mates after leaving school, or after the death of a family member), the simulation of such a person seems never to totally disappear from dream life, even if the frequency of dream simulations of that person to some extent diminishes. Social simulations in dreams thus seem to maintain an active storage and rehearsal of the most important and closest social relationships of our entire lives, even when those relationships are broken or discontinued for good, or are temporarily on hold in our waking lives.

What happens if a relationship that has disappeared from waking life is reactivated after years of disconnection? In Schredl's (2012) study, old schoolmates met for a reunion twenty years after going their separate ways. Interestingly, when the same relationships are re-activated in real life for just one day, the dream sim-

ulation of those social relationships is increased significantly and for a long period of time (compared to the time of actually meeting). The mechanism that reactivates old targets of simulation might be analogous to that proposed in TST for the re-activation of old threats. The frequency with which the most important real threats are simulated (e.g., in post-traumatic nightmares) increases when, during wakefulness, new cues are encountered that are associated with the old threat possibly reoccurring in real life.

These considerations suggest a more precise function of social dream simulations that could be formulated along the following lines. We may call it the Strengthening Hypothesis: *the function of social simulations in dreams is to maintain and strengthen the dreamer's most important social bonds from waking life.* Consequently, a prediction derived from the Strengthening Hypothesis can be formulated as follows: if strengthening important social bonds is a function of social dream simulations, then dreaming should include with high frequency social interactions in which the (current or past) most important social bonds are strengthened through various types of simulated positive social interactions and prosocial behaviours. Thus, the frequency of prosocial, positive interactions (bond-strengthening) with the most important persons should clearly surpass the frequency of negative (bond-weakening) interactions within dreams, and also be more frequent in dreams than in a corresponding stretch of waking life.

Schredl's (2012, 2013) findings are to some extent consistent with both the CH and the SST, but do not allow any firm conclusions about which theory better predicts the occurrence of the most important social connections in dreams. Studies that collect data from both waking life and dream life during the same period of life from the same people, as well as from the life history of these individuals, are necessarily required to test whether the representation of the most important connections is exaggerated in dreams, or if they just reflect the waking frequency. In practice, this prediction could be tested by identifying all the interactions between the dreamer and the people in his

or her most important social networks, in both dream and waking reports. Then the interactions could be classified according to whether they tend to strengthen or weaken the relationship with that particular person. If the frequency with which dreaming simulates positive interactions surpasses the frequency of those interactions in real life, then the SST would gain credence over the CH.

Another potential simulation function to consider can be called the Practise and Preparation Hypothesis. According to this hypothesis, the function of social simulations in dreams is to force the dreamer *to practise important social bonding skills*, such as how to give social support to others. The prediction derived from this hypothesis states that if practising social bonding skills is a function of dreaming, then the dreamer should frequently offer various types of social support to other dream characters, for example emotional, instrumental, or informational support. Furthermore, the types of social support offered should be dependent on the degree of relationship intimacy, i.e., the distance between the self and the recipient in the hierarchy of the social world of the individual. If the Practise and Preparation Hypothesis is correct, then the frequency of simulating social support should be higher than comparable behaviours in real life.

These ideas are testable, but dream content studies are to be carefully designed with the specific aim of testing them. In the literature already published, friendliness percentages in different dream samples and descriptive statistics concerning who initiates friendliness in dreams might shed some light on these questions. However, without any data about the frequency of occurrence of these same behaviours in the waking state of the same person, the purely descriptive findings from dreaming alone will not be able to separate CH predictions from SST predictions. The comparable waking data is crucial as a baseline against which the dream data can be evaluated and in relation to which the CH predictions can be contrasted with the SST predictions.

In an ideal setting the hypotheses for the SST and its proposed functions would also be tested cross-culturally and in particular, as the theory makes bold evolutionary claims, in traditional small-scale human societies. As Henrich et al. (2010) have pointed out, the concentration of behavioural research into the so-called Western, Educated, Industrialized, Rich, and Democratic (WEIRD) societies are highly unrepresentative of the species, and might pose problems for the generalizability of the results. Furthermore, by contrasting, for example, the differences between the social simulations of small-scale and Western societies, we might uncover useful information about the plasticity and ontogenetic mechanisms of the social simulation function.

7 Conclusions

The concept of "simulation" is a useful theoretical concept for dream research. It unifies definitions and descriptions of the basic nature of dreaming, and helps to formulate testable theories of the function of dreaming. Applying this concept to the social reality of dreams means that we start to describe the persons and social interactions in dreams as simulations of their counterparts in real life. Consequently, we can ask: How does the simulated social reality relate to the actual social reality in the same person's waking life? Is it plausible to hypothesize that the avatars in the dreaming brain might in fact be there in order to force us to maintain and practise various evolutionarily important functions of social perception and social bonding?

In this paper we made an attempt to clarify what it means to put forward the theoretical statement that "dreaming is a social simulation", especially when this claim is offered as an expression of a theory of the *function* of dreaming. The SST can be formulated in a testable manner, and a number of testable predictions can be derived from it. Some of those predictions, concerning basic social perception and mindreading abilities, already receive rather strong support from the published literature. Many more hypotheses remain to be tested. To achieve theoretically-informative results and to directly contrast the predictions of different theories, future studies have to be designed in a

strictly theory-driven and hypothesis driven manner—which, unfortunately, is not a common approach in dream research.

If the SST, or some parts of it, prove successful, we have to be able to show that the SST predicts the nature and the occurrence of social simulations in dreams more accurately than its main competitors, the CH and the TST. To fare better than the CH, the data would have to show that the most important social contents are actively selected for incorporation in dreams as social simulations, and therefore rehearsed in an exaggerated quantity or form in dreams. To show that the CH is on the right track, the data would have to show that dream simulations merely reflect, both quantitatively and qualitatively, whatever experiences waking life has recently presented to the same person. To go beyond what the TST predicts and explains, the data supporting the SST would have to show that dreaming over-represents and actively runs positive or neutral social simulations in dreams that strengthen the skills of social perception and bonding, but that have nothing specifically to do with threat-perception and avoidance.

At this point, we are not yet sure how strong the empirical case for SST is going to be, and whether the evidence will mostly turn out to be for or against it. We shall wait for the kind of studies that directly test SST and set it against other theories' predictions. However, what we are confident about is that SST *is* an empirically testable theory, and that dream research would in general gain much if dream content studies were rigorously designed to test the predictions derived from opposing theories, and if dream data were in general collected and analysed in a manner that provides us with strong tests of different theoretical hypotheses rather than just producing more and more purely descriptive data of dream content (and then presenting vague, post-hoc theoretical interpretations of them). In that way, dream research would be able to find and test new, promising theoretical ideas, perhaps derived from cognitive and social neuroscience and from evolutionary psychological considerations. New theoretically-guided studies would help leave behind old ideas if they did not generate any clear and testable predictions or if such predictions did not gain sufficient empirical support.

Even if we will at some point be able to explain some of the functions of social simulation in our dreams, we might not be able to explain the *underlying mechanisms that generate* the simulations. The fundamental metaphysical nature of the simulated persons inhabiting our dreaming brain might after all be almost equally mysterious as the immaterial nature of a Cartesian ghost, because, like everything we experience in our dreams, the avatars in our dreams are built out of features that have no objective, physically observable, or measurable substance. Instead, they consist of subjectively-experienced phenomenal features, and at least at the present state of consciousness science, the only way for us to get any empirically-based data about them is through the introspective reports carefully collected from the dreamers. How the sleeping brain produces vivid, dynamic, complex phenomenality and organizes it into subjective spatiotemporal hallucinations, inhabited by avatars and social simulations, still remains beyond any current theoretical explanations of dreaming and consciousness. Any plausible explanation of the actual brain mechanisms that do the trick would have to solve the hard problem of consciousness (Chalmers 1996) and cross the explanatory gap (Levine 1983) between the objective neural mechanisms in the brain and the subjective experiential realities going on in subjective consciousness. We are not quite there yet.

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The Multifunctionality of Dreaming and the Oblivious Avatar

A Commentary on Revonsuo & Colleagues

Martin Dresler

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

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1 Introduction

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

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

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

In this commentary, I shall review several widely propagated functions of sleep and dreaming. I shall then compare these functions with the social and threat simulation functions of dreaming, and finally discuss why and in which regard these two functions might be special. I shall argue that the merit of TST and

SST is not the conclusive explanation of the function of dreaming—which I consider a multifunctional state—, but that they are the only candidates among the variety of dream functions that are capable of explaining a striking feature of most dreams: obliviousness towards the current state of mind.

2 Sleep physiology and the function of dreaming

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

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

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

3 Dream function 1: Memory consolidation and integration

In recent years, the most widely discussed function of sleep and dreaming concerns the consolidation of declarative memory, including semantic, episodic, and autobiographical information; and procedural memory including perceptual and motor skills (Rasch & Born 2013). In particular the role of REM sleep in memory consolidation has been studied for several decades. While many studies from the 1970s have been criticized for being heavily confounded by too stressful REM sleep deprivation procedures (Horne & McGrath 1984), research in the 1990s raised interest in the role of REM sleep for memory consolidation: Karni (1994) demonstrated that a basic visual discrimination task improved after a normal night's sleep, but not after selective REM sleep deprivation. Following this, a leading research aim in the field has been to identify which memory systems benefit from which sleep stages: it was demonstrated that

early deep sleep benefits declarative memories, while late REM-rich sleep supports procedural skills (Plihal & Born 1997). Further support for the role of REM sleep in procedural memory consolidation came from studies showing that REM sleep intensity (total number of REMs and REM densities) increased following procedural-task acquisition (Smith et al. 2004) and improvements in procedural memory performance after a night of sleep were proportional to time spent in REM sleep (Fischer et al. 2002). Moreover, brain areas activated during a procedural learning task were more active during REM sleep in subjects who were trained at the task (Maquet et al. 2000; Peigneux et al. 2003).

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

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

dreams (Baylor & Cavallero 2001), it has been suggested that particularly engaging learning experiences have a more robust influence on dream content relative to more passive experiences (Wamsley 2014).

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

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

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

4 Dream function 2: Emotion regulation

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

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

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

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

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

5 Dream function 3: Creativity and problem solving

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

According to the classical stage model of creativity, creative insights may be described by a process consisting of several stages, of which the incubation phase appears to be most intimately associated with sleep and dreaming (Dresler 2011, 2012; Ritter & Dijksterhuis 2014). The most common psychological approaches support this view: psychoanalytical models of creativity emphasize the primary process concept, which denotes free-associative and dream-like thinking, compared to the more rational and analytical secondary-process thinking (Kris 1952). Cognitive models propose that a state of defocused attention facilitates creativity (Mendelsohn 1976)—creative individuals seem to have less narrowly-focused attention than uncreative ones, which leads to unorthodox connections of remote ideas that might eventually lead to creative cognitions. In a similar vein, creative individuals are thought to have relatively flat association hierarchies (i.e., more, yet weaker associations between cognitive elements), which accounts for the ability to make remote associations; whereas uncreative individuals are thought to have relatively steep association hierarchies (Mednick 1962). Physiological models emphasize the level of cortical arousal as an important variable influencing cre-

ativity: both a lower level of cortical arousal—particularly in the prefrontal cortex—and a higher variability in cortical arousal levels are expected in creative compared to uncreative individuals, depending on specific phases of the creative process (Martindale 1999). In addition, low levels of norepinephrine are thought to facilitate creativity, shifting the brain toward intrinsic neuronal activation with an increase in the size of distributed concept representations and co-activation across modular networks (Heilman et al. 2003). The prefrontal cortex seems to be of particular importance for creative processes; however there is evidence that both prefrontal activation and prefrontal deactivation facilitate creativity—maybe depending on the specific phase of the creative process. Brain areas showing selective activation for insight events are—besides the prefrontal cortex—the visual cortices, the hippocampus, and in particular the anterior cingulated cortex, which is thought to be involved in breaking the impasse that marks the critical step of insight into a problem (Dietrich & Kanso 2010).

Both theoretical models and empirical neuroscience of creativity suggest that sleep and dreaming provide an ideal environment for creative incubation: primary-process thinking is explicitly conceptualized as dream-like, and the hyper-associative nature of dreams can be considered a prime example of a flat associative hierarchy. Defocused attention is a phenomenal feature of most dreams, physiologically probably caused by prefrontal cortex deactivation. And daydreaming has the potential to increase creativity (Lewin 1989), while the level of engagement in such mind-wandering in contrast to explicitly directed thoughts is associated with creative performance (Baird et al. 2012). The sleep cycle provides the brain with highly alternating arousal levels, and the chaotic activation of the cortex in REM sleep through brain stem regions in absence of external sense data leads to a much more radical renunciation of unsuccessful problem solving attempts, leading to co-activations of cognitive data that are highly remote in waking life (Kahn et al. 2002a). These co-activations, woven into a dream narrative in a self-organizing manner, repeatedly receive further

innervations by the brainstem, leading to bizarre sequences of loosely associated dream topics that might eventually activate particular problem-relevant cognitions or creative cognitions in general (Hobson & Wohl 2005). In addition, in REM sleep, which is characterized by low levels of norepinephrine, visual cortices, the hippocampus, and the anterior cingulate cortex have all been shown to be strongly activated, potentially facilitating insight events. In conclusion, the phenomenological and neural correlates of sleeping and dreaming provide ideal conditions for the genesis of creative ideas and insights.

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

6 Dream function 4: Preparation and simulation of waking life

Consolidation, integration, regulation, and re-evaluation of acquired information during sleep prepare the organism for its waking life. However, such processes do not necessarily need to be purely reactive, depending solely on the experiences of the preceding day: several authors propose that a major function of sleep and dreaming might include primarily preparational mechanisms. Since REM sleep dominates sleep more during early developmental periods in comparison to later in life, some researchers have argued that REM sleep plays a role in early brain maturation (Roffwarg et al. 1966; Marks et al. 1995; Mirmiran 1995); however, also a life-long preparational function of REM sleep has been proposed. One of the first approaches in this direction was offered by Jouvet (1979), who combined the brain maturation hypothesis with a metaphor offered by Dewan (1970), in which he claims that the brain is a computer that is programmed during REM sleep—suggesting that innate behaviors are rehearsed during REM-sleep dreaming in order to prepare the organism for their application in waking life. Jouvet later revised his approach, assuming that REM sleep constitutes an iterative genetic programming that helps to maintain

the process of psychological individuation (Jouvet 1998). In a similar vein, Hobson (2009) proposed that REM sleep may constitute a "protoconscious" state, preparing the organism for waking conscious experiences. The development of consciousness during ontogenetic development in this view is a gradual and lifelong process, building on the more primitive innate virtual reality generator, which is phenomenally experienced as dreaming. With the recent integration of Friston's (2010) predictive coding approach into this theory, the brain is thought to run a virtual world model (see also Revonsuo 1995, 2006; Metzinger 2003) that is continuously updated by processing prediction errors during wakefulness. Freed from external sensory constraints, processing of prediction errors in the dreaming brain actively refines intermediate hierarchy levels of the virtual world model. Dreaming thereby minimizes internal model complexity in order to generate more efficient predictions during subsequent wakefulness (Hobson & Friston 2012; Hobson et al. 2014).

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

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

In summary, a fourth important function of sleep and dreaming is preparation for waking life. This includes proposals of REM sleep as an iterative genetic programming system, dreaming

as a state of protoconsciousness and virtual world model optimization, and dreaming as a simulation of threats (TST) and social interactions (SST).

7   The multifunctionality of dreaming

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

The concept of evolutionary function has been one of the main topics in the philosophy of biology (Mahner & Bunge 2000) and philosophy of mind (Millikan 1984; Neander 1991). Several notions of biological functions exist (Wouters 2003); however a general idea is that the biological function of a trait is determined by its contribution to evolutionary fitness (Walsh & Ariew 1996). Darwin (1871) differentiated between selection occurring as a consequence of ecological factors that directly threaten the organism's survival, such as predators or other potentially life-threatening dangers of nature, and interactions with members of the same species in order to compete for mating partners.

Both principles, dubbed natural and sexual selection respectively, eventually determine reproductive success as the ultimate decision points for selection. In contemporary accounts, sexual selection was generalized to the concept of social selection, of which the former is considered a subtype (Lyon & Montgomerie 2012; West-Eberhard 2014). The concept of runaway selection, famously illustrated by the evolution of the peacock's tail, was thought to also be applicable to the evolution of social skills in higher animals, eventually leading to the development of theory of mind, language, dance, or artistic creativity in humans (Flinn & Alexander 2007). This process of an arms race of social skills would require increasing cognitive capacity—and in fact, at least in primates, relative brain size has been related to social group size (Dunbar 1992; Dunbar & Shultz 2007).

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

tool; refinement of the discriminative skills regarding recently perceived pattern, etc.—all these potential benefits of sleep and dreaming increase inclusive fitness of the individual, but do not directly refer to the simulation of threats or social interactions.

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

Segmentation of reality (including dream reality) is possible along numerous lines. In a sense, TST and SST could be interpreted as expressing two orthogonal dimensions of dream space: a security dimension with the directions threat vs. safety, and a sociality dimension with the directions social vs. individual. Dreamed accidents or natural disasters would be characterized by low security and sociality, dreamed experience of bullying by high sociality and low security, and dreamed bonding by high sociality and security, etc. Threat and social interactions in a narrow sense are important aspects both of waking and dreaming life, however they are not the only aspects. Other segmentations are also possible, e.g., by a dimension of motor activity vs. inactivity, or emotional vs. neutral dream content, or a novelty dimension. In the broad sense of natural and social selection, threat and

social interaction would be the two main drivers of evolution, however to the cost that the answer to the question of the function of dreaming becomes a trivial "to support reproductive success". Of note is that also the other discussed functions might be interpreted within a simulation framework: e.g., simulation visuomotor activity after learning a respective task in the memory function, simulating affective experiences in the emotion regulation function, and simulating problem solving attempts in the creativity function. These different functions are neither mutually exclusive nor strictly independent from each other. In particular the emotion-processing function largely overlaps with both TST an SST—all threats and at least the most important social interactions induce strong emotions, and successful coping with these emotions would be of considerable help when facing threats or social situations. Also other functions of dreaming overlap with TST and SST: consolidation of threat-related information or social gossip improves threat avoidance or social skills, as does creative incubation on threat-related or social problems. On a more abstract level, all these simulations serve the integration of recently experienced information into the behavioral repertoire in order to adapt it to the current waking environment (Hobson et al. 2014).

Identifying the original function of a given trait has proven to be a notoriously difficult issue in the philosophy of biology (Wouters 2013). Dreaming might have originally developed as an epiphenomenon of rather basal neurophysiological sleep functions, and this phenomenological level might eventually have acquired additional functions. Such exaptations (Gould & Vrba 1982) might have been further adapted and in turn developed further neurophysiological exaptations without phenomenological correlates, etc. The original function of dreaming might be unimportant today compared to subsequently evolved functions. Instead of singling out one or two functions of dreaming as original, dreaming might be best seen as a multifunctional general reality simulator, including the simulation of motor skills, emotional processing, problem solving attempts, threats, and social interactions. To follow specific research questions, of

course certain functions still could be highlighted and followed as research heuristics with a given purpose. All functions of sleep and dreaming serve reproductive success ultimately, even though some might be more important than others from a selection point of view. For all dream functions discussed in this chapter, there are convincing supporting but also inconsistent data. The fact that dreaming is not an unselective simulation of the waking world as, e.g., the continuity hypothesis suggests (Schredl & Hofmann 2003), is a sign that some simulation functions might be more important than others. We should note, however, that quantitative overrepresentation of a specific function does not necessarily prove the primacy of this function: different functions might rely on different processes with different timescales, with a highly important function potentially requiring only seconds to be processed, while an unimportant function might take hours. In times of sufficient sleep, dream content related to the relatively unimportant function might thus be overrepresented. The relative importance of one function over another might be tested in cases of scarcity of sleep, e.g., under sleep deprivation, when different functions would have to compete for restricted simulation time. Also of interest in this regard is a comparative approach: it has been demonstrated that sleep propensity, and particularly REM sleep, negatively correlates with predatory risk across species (Lima et al. 2005), which would rather speak against TST. Concerning SST, the tendency to sleep in groups has been reported to negatively correlate with sleep time, which, however, has been interpreted either in terms of social sleep being more efficient due to reduced predatory risk, or as more social species sacrificing sleep to service social relationships during wakefulness (Capellini et al. 2008). Against this background, sleep and dreaming pose an optimization problem: how much time is best spent asleep, spent in specific sleep stages, and spent engaging in specific dream mentation in order to optimize the interplay between the different functions of sleep and dreaming? Dreaming as a general reality simulator might dynamically change its functional priorities, favoring one over the other of its several functions, depending on the current requirements and constraints of the environment.

8 The oblivious avatar

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

There is no obvious reason why obliviousness about the dream state would be necessary for the memory function of sleep and dreaming. For procedural memory consolidation, lucid dreaming has even been suggested as a state that allows for a hyper-realistic mental training of recently learned motor skills (Erlacher & Chapin 2010). Several studies support this idea: lucidly dreamed training of coin tossing (Erlacher & Schredl 2010) or a finger tapping task (Stumbrys et al. 2015) has been demonstrated to be effective, and a considerable number of professional athletes use lucid dreams to practice sports skills, with most of them having the impression that their performance is thereby improved (Erlacher et al. 2011). For the creativity and insight function of sleep and dreaming, obliviousness regarding the current state of mind is no prerequisite, and lucid dreaming has explicitly been suggested and shown to be used as a tool to increase creative processes (Stumbrys & Daniels 2010; Schädlich & Erlacher 2012; Stumbrys et al. 2014). As with non-lucid dreaming, lucid dreaming is associated with defocussed attention and flat association hierarchies—lucid dreams have been reported to include

even more uncommon and bizarre elements than non-lucid dreams (McCarley & Hoffman 1981). At the same time, regained reflective capabilities enable the creative dreamer to evaluate new associations and ideas, a step in the phase model of creativity that for non-lucid dreams is reserved for subsequent wakefulness. This mechanism is illustrated by two interesting case studies: Barrett (2001) describes the case of a painter who in his lucid dreams visited galleries, and then searching for interesting motifs to be painted soon after awakening from the lucid dream. A comparable strategy was used by one of our own study participants (Dresler et al. 2011, 2012), a music composer: when he aimed to compose a new piece of music, he turned on a radio in his lucid dreams and changed radio stations until he heard a composition that he considered interesting. He then woke himself up and wrote the new composition down. In line with these data, questionnaire studies reported that frequent lucid dreamers might be more creative than less-frequent lucid dreamers (Blagrove & Hartnell 2000).

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

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

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

In summary, in contrast to other functions of sleep and dreaming, TST and SST essentially

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

9 Conclusion

Sleep and dreaming do not serve a single biological function, but are multifunctional states. Their functions include memory consolidation and integration, emotion regulation, creativity and problem solving, and preparation for waking life. One promising description level is that of dreaming as a general reality simulator. TST and SST describe two important purposes of simulation, namely successful coping with threats and social interactions. The merit of TST and SST is not so much that they conclusively explain the function of dreaming—although they represent the two classical principles of evolution, natural and social selection, there are also several other sleep and dream functions. TST and SST might be the only candidates among the multiple functions of sleep and dreaming that explain a particularly striking feature of dream phenomenology: dreaming is a remarkably realistic simulation of waking life, with the exception of a complete failure to successfully reflect on the current state of consciousness. Veridical insight into the dream state is biologically possible, as the phenomenon of lucid dreaming demonstrates. The fact that state reflectiveness is nevertheless generally ab-

sent in dreaming—dream lucidity is a rare phenomenon (Schredl & Erlacher 2011), and even during lucid dreams, lucidity lapses are common (Barrett 1992)—, suggests that state obliviousness during dreaming has an important function. As demonstrated here, among the different candidates for explaining the function of dreaming, TST and SST are the only ones that are capable of elucidating this specific function: state obliviousness is necessary for the effective simulation of threats and social interactions.

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

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The Simulation Theories of Dreaming: How to Make Theoretical Progress in Dream Science

A Reply to Martin Dresler

Antti Revonsuo, Jarno Tuominen & Katja Valli

Among the most pressing challenges for dream science is the difficulty of establishing theoretical unification between the various theories, ideas, and findings that have been presented in the literature to answer the question of how it is possible to construct a solid scientific theory with predictive and explanatory power in dream science. We suggest that the concept of "world-simulation" serves as the core concept for a theoretically unified paradigm to describe and explain dreaming. From this general concept, more specific theories of the function of dreaming can be derived, such as the Threat Simulation Theory (TST) and the Social Simulation Theory (SST), as we argued in our target article. We agree with Dresler that these two functions may not be the only functions of dreaming, but we still have grounds to believe that they are the strongest contenders. In our reply we first clarify why the functions of sleep should be considered separately from the functions of dreaming. Second, we outline what a good scientific theory of dreaming should be like and what it should be capable of. Furthermore, we evaluate the current state of simulation theories within this context. To conclude, we propose that instead of a general multifunctional theory of sleep and dreaming, where no hypothesis is excluded, the future progress of dream science will benefit more from opposing, competing and mutually exclusive theories about the specific functions of dreaming. This, however, demands that the opposing theories and their predictions must be risky, clearly formulated, and empirically testable.

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1 Introduction

We are grateful to Martin Dresler (this collection) for his thorough and insightful commentary on our target article (Revonsuo et al. this collection). Dresler's commentary places the proposed simulation functions of dreaming into the wider context of other functions for sleep and dreaming, demonstrating that these phenomena may have multiple different and partly overlapping functions. He also suggests the threat simulation and social simulation functions are unique. They can neatly be connected to evolutionary theory and only they explain why the suppression of reality testing and the lack of lucidity are necessary features of these simulation functions of dreaming (i.e., they require an "oblivious avatar"). While we agree with many of the points presented in Dresler's analysis, we believe that it is possible to regard the different proposed functions of dreaming as representing different (preliminary) scientific theories of dreaming. When viewed from this theory-driven perspective, it is also possible to present more definitive evaluations as to which of them are more plausible theoretical explanations than others.

2 Function of sleep vs. function of dreaming

Many of the findings Dresler (this collection) mentions in his commentary are not about dreaming, but rather about sleep, its different stages, and their potential correlates, effects, and functions. While it is encouraging that there is much evidence about the functions of sleep that relates to memory and learning, and that emotionally significant information seems to hold a special place, most of those studies have very little or nothing to do with dreaming as a subjective experience. In most of the sleep studies, whether or not the sleeping participants have been dreaming or not, and what their dream contents have been, is irrelevant for the hypotheses being tested (e.g., whether a certain stage of sleep enhances memory consolidation of particular types of stimuli) and usually remains unknown. In sleep studies purely objective neurophysiological and behavioural phenomena are investigated with objective measures. In contrast, in dream studies purely subjective phenomena are explored by collecting subjective introspective reports describing the contents of phenomenal consciousness. Modern theories of the functions of sleep are undoubtedly quite strong as scientific theories of sleep and its relationship to some neurocognitive mechanisms of memory and learning, but they are not in any direct sense theories of dreaming. Of course, any proposed theory of dreaming should be at the very least *consistent* with the leading theories of sleep, because the phenomenal level of organization supervenes on the lower, neurophysiological level. However, the opposite is not necessarily true. As Dresler (this collection) points out, lower-level functions can be carried out independently of the higher, phenomenal level of organization. Thus, we would like to strongly emphasize that the merits and the predictions of theories of dreaming primarily have to be tested by using data that reflects subjective dream contents, not the objective features of sleep.

3 What is it like to be a strong scientific theory of dreaming?

Any theory of a phenomenon should include a precise definition and description of its target phenomenon (or *explanandum*), as well as clear demarcation of conceptually and empirically different phenomena. Theories of dreaming should clearly state i) in what way dreaming is a different type of phenomenon from sleep (or any particular stage of sleep), and ii) in what way dreaming is a special form of mental activity occurring during sleep. In our approach the starting points are that while sleep and its different stages can be defined by objective behavioural and neurophysiological criteria, dreaming is a subjective phenomenon; a special, complex altered state of consciousness that can be differentiated from simple sleep mentation. Quite independently from any functional considerations, the general, universal *form* of dreaming, as most dream researchers currently agree, is a complex,

multi-modal *simulation* of the sensory perceptual world, inhabited by a simulated self or a self-model (Hobson 2009; Metzinger 2003, 2013; Nielsen 2010; Windt 2010). A fruitful idea in biology is that *form suggests function*; thus the form that dreaming takes, a world-simulation, most likely suggests that the major functions of dreaming have something to do with world-simulation. The most frequent dream contents are therefore the most likely candidates for reflecting the specific function(s) of dreaming: how, when, under what circumstances, and what contents to simulate. Thus, to state that dreaming is an internal world-simulation is to describe the general form that this phenomenon universally takes, but not necessarily its function. The function(s) of the simulation, according to our view, are mainly related to the specific contents selected for simulation.[1]

Furthermore, a proper theory of dreaming should be *simple yet covering*, so that the same general principles apply to many types of dreams, including the pathologies of dreaming, animal dreaming, and other special cases; the theory should be *fruitful*, so that it leads to new ideas, hypotheses, and new directions for active research; it should be *empirically testable*, so that it leads to risky predictions whose accuracy can be objectively checked. It should have both predictive and explanatory power.

Of course, these virtues are desirable in any scientific theory of any phenomenon. When there are rival theories of the same phenomenon, they should be compared with regard to their overall strengths and weaknesses as scientific theories. If they are consistent with each other, perhaps they can be combined into a single, more covering theory. If they are inconsistent with each other, their differing predictions should be empirically tested. After their relative strengths and weaknesses are compared, it should be possible to say which ones are stronger than others.

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1 Further, Dresler (this collection) raises the question of whether the frequency of specific dream contents can be regarded as evidence for the importance of its underlying functions. If we consider the function of dreaming more broadly to be that of a training ground for essential and adaptive behaviors, it becomes rather clear that the observed frequency of these behaviors can be viewed as a valid measure of their importance. This, however, is evident only when comparing the contents within the phenomenal level of explanation.

4 Simulation theories of dreaming

According to the simulation view, dreaming is a special case of phenomenal consciousness, or the phenomenal level of organization being activated in the brain. Waking consciousness and dreaming are manifestations of the same natural biological phenomenon in the brain, but they occur in different contexts and under different conditions. The simulation theory of dreaming is anchored to a more general theory of consciousness, which in turn is anchored philosophically to weak emergent materialism and multi-level explanation (Bechtel 2008, 2011; Craver 2007; Revonsuo 2006, 2010). In a multi-level explanation of a mental phenomenon, several different explanatory dimensions surround the target phenomenon: the *downward-looking* explanation specifies its neural correlates and mechanisms; the *backward-looking* mechanisms specify what has causally brought about or modulated the phenomenon (e.g., day residues or traumatic experiences that directly influenced specific contents of dreaming; the ontogeny of dreaming—how dreaming came about during individual development; phylogeny—how dreaming emerged and might have been selected for during evolutionary history[2]); and the *upward-looking* (functional) explanation—how does dreaming guide or change consequent mental states or external behaviours? Only after all these explanatory dimensions can be accounted for may we be said to have a comprehensive theory of dreaming, including its function(s) (see also Revonsuo 2006, 2010; Valli 2011).

So far, one general and three separate, more specific simulation theories have been proposed. From a more general perspective, some versions of the Continuity Hypothesis (CH) can be regarded as a simulation theory, as some proponents of it consider the world-simulation itself to be a functional *form* of dreaming (e.g., Foulkes 1985, pp. 201–202). Three other, more specific simulation theories have been proposed:

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2 We should, however, also keep in mind the option that dreaming does not serve any function at all and was not selected for, but is merely epiphenomenal, as suggested, for example, by Flanagan (2001), and implied by the Continuity Hypothesis (CH). This notion should be the null hypothesis against which the proposed functions of dreaming are to be pitted.
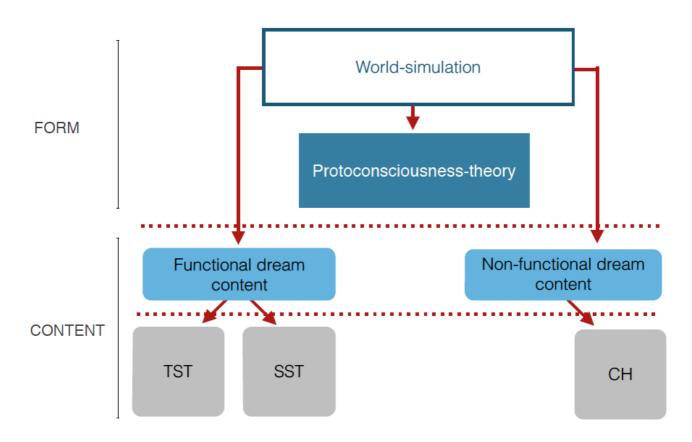
Figure 1: Simulation theories of dreaming. All simulation theories assume that dreaming can be defined as a world-simulation, the form of which is functional. The protoconsciousness-theory is more focused on explaining the form of dreams instead of their specific contents. Threat simulation and Social simulation theories try to explain the content of dreams as having a specific function, while the Continuity Hypothesis assumes the content of the simulation to be evolutionarily non-functional.

the protoconsciousness theory (Hobson 2009), which covers the role of dreaming in ontogeny; the Threat-Simulation Theory (TST), which covers the negative contents of dreaming and provides an evolutionary account for them; and the Social Simulation Theory (SST), which covers the social contents of dreaming, including the positively charged ones. Taken together, these theories are at the same time both covering and economical: the simple principle of "internally activated world-simulation" underlies all of them (see figure 1). The proto-conscious-ness theory accounts for how and why the basic form of the virtual-reality generator comes about in the developing brain, and how during early brain maturation both dreaming and waking consciousness emerge together in interaction. It is, however, the most speculative of the three simulation theories, as we cannot hope to

test it with data about subjective experiences describing the postulated fetal dream experience: what is it like to be a proto-conscious dreaming fetus? Thus, its weakness is that dream reports or any other direct evidence of the existence of subjective dream-like states cannot conceivably be empirically collected to test the validity of the theory.

The TST and SST, as we have explicated in our target article (Revonsuo et al. this collection) and in earlier publications elsewhere (Revonsuo 2000, 2006; Valli & Revonsuo 2009) are testable as they issue specific predictions concerning the frequency and quality of dream contents under different circumstances. They are also covering, TST potentially accounts for normal dreaming as well as several special types of dreams, where negative dream contents are particularly abundant and dominate (bad

dreams, recurrent dreams, nightmares, post-traumatic dreams, children's earliest dreams, dreams in parasomnias such as RBD, night terrors, and so on). Together TST and SST potentially cover a very large proportion of the statistically most frequent dream contents, and the predictions derived from these theories have specific empirically testable consequences as to the quantity and quality of these types of dream contents. As Dresler (this collection) points out, simulation theories also have the advantage of being highly consistent with the peculiar behavioural, neurophysiological, and phenomenal features of dreaming such as isolation from sensory input, motor activity, cognitive reflection, and reality testing. These features are necessary preconditions for running powerful, phenomenologically realistic but behaviorally isolated virtual reality simulations in the sleeping brain. The simulation theories thus have a lot of explanatory power. The concept of world-simulation unifies numerous separate phenomena related to dreaming and makes sense of them under a single concept. In this the simulation theories of dreaming fulfil the requirements of simplicity, coverage, and economy as well as having predictive and explanatory power. Compared to some of the other ideas Dresler presents in his commentary, it appears that currently the simulation theories are amongst the strongest frameworks for the form and function of dreaming.

5 Rival paradigms in dream science

Of the theories that are directly applicable to dreaming, we have already addressed the Continuity Hypothesis (CH) in our target article (Revonsuo et al. this collection). As we say there, it has never been formulated in a sufficiently precise manner such that risky, testable predictions can be derived from it. The CH, largely because of its vagueness, might actually be consistent with simulation theories. The particular contents of dreams are neither selected through an active process, nor do they reflect any function(s); they are selected through a passive and more or less random mirroring of the experiences that have been lived through. Further, CH does not consider how to deal with

potential anomalies for the theory: the relatively frequent cases where either something very alien to our waking world (and thus entirely discontinuous with it) appears, or where something very common in our waking life fails to appear in our dream contents. Can the theory be regarded as falsified when evidence of such blatantly discontinuous dream contents appear over and over again in dream data? One version of the CH, presented by Foulkes (1985) states that the mnemonic sources of dream contents are random and unpredictable; thus dream contents are unselective random samples of our memories; but the general form of dreams as world simulations as such is highly predictable —thus the function of dreaming would be more related to the general form than to the specific contents of dreams. However, as we have argued, dream contents are *not* random, but selective, and in particular they select threatening and social events into dreams. Thus, the basic assumption behind Foulkes's version of CH has turned out to be empirically false. The CH thus does not look very promising. But, as we argued in our target article (Revonsuo et al. this collection), some testable predictions can and should be derived from CH, to render its predictions as the null hypothesis "no selectivity, no functionality", and thereby directly test its predictions against those derived from TST and SST.

Another major functional theory of dreaming, the Emotion Regulation Theory (ERT; also reviewed by Dresler this collection), also seems relatively weak as a scientific theory. It has been presented by many different authors in many different formulations (e.g., Cartwright et al. 2006; Hartmann 1996; Kramer 1991). There seems to be no standard, detailed, or shared version of this theory among its supporters; thus it also suffers from a vagueness similar to that of CH. The shared core in all of the different versions appears to be the idea that dreaming works with and processes difficult, unpleasant emotions and events, and through this dream processing makes us get over them and feel and function better in our lives. An often-used analogy compares dreaming with psychotherapy (Hartmann 1995; Walker & van der Helm 2009).

Again, when looking at the evidence it is important to separate sleep from dreaming. When it comes to emotional processing during sleep, the analogy to psychotherapy gains some support (Walker & van der Helm 2009). But when applied specifically to dreaming and dream contents, the idea runs into difficulties. Its theoretical roots appear to originate predominantly from the clinical tradition, and more specifically from the idea that the function of dreaming is to protect sleep from strong surges of emotion and to solve emotional problems. The negative contents of dreams originate from interpersonal conflicts and current concerns, thus being consistent with the continuity between dreaming and waking, in fact so much so that the CH coupled with the ERT could perhaps be seen to form one specific paradigm of dream theorizing. Perhaps one of the core differences between the ERT+CH paradigm and the simulation paradigm is their relationship to biological explanations. The ERT+CH favours psychological-level explanations and emphasizes recent individual experiences (learning, nurture) as proximate explanations of dreaming. The simulation paradigm emphasizes biological explanations of the form and contents of dreaming, and links dream consciousness to both the underlying neurophysiological levels as well as the ontogenetic and phylogenetic, ultimate biological history of dreaming as explanations of the form and contents of dreaming. A further core difference between these paradigms is that the psychological paradigm sees the function of dreaming as contributing to our psychological well-being and psychological adaptation to our lives, whereas the biological paradigm sees the origin of dreaming in its ability to increase fitness in all mammals and in humans during their evolutionary history; but dreaming need not *necessarily* contribute to our psychological well-being in order to fulfill its original biological function.

As these approaches represent different paradigms with differing core ideas, it might not be possible to integrate them, in the manner that Dresler (this collection) suggests, into one overall multifunctional theory of dreaming. Some of the core assumptions of ERT are incon-sistent with TST, especially when it comes to the function(s) of dreaming and to the explanation of nightmares and bad dreams. According to TST, post-traumatic dreams, recurrent dreams, nightmares, bad dreams, and the earliest dreams in childhood are the best and strongest manifestations of the function of dreaming, when the function is fully at work and typically activated by ecologically valid threat cues and dangerous events observed in the environment, often displaying universal threat scripts consistent with evolutionarily relevant threats. In parasomnias the threat-simulation system can be overactivated, or activated in an inappropriate context and therefore seen as psychologically dysfunctional, so that it might in actuality either decrease the well-being of the individual or hamper with other functions of sleep and dreaming, even though it at the same time carries out its original biological function perfectly. By contrast, according to ERT, such highly negative dreams are malfunctions and failures of the core function of dreaming itself, because such dreams disturb sleep and make us feel negative emotions. Nightmares cause psychological suffering and sleep disturbances, thus they are like a failed psychotherapy session that increases the individual's psychological distress, instead of calming the individual down. As such, very large and important categories of dreams (and their functionality) are explained in squarely opposing ways by the two paradigms.

6 Concluding remarks

Consequently, it is not only possible but theoretically necessary to separate the basic assumptions, the predictions, and the hypotheses of the simulation theories from those of ERT and others. We can have multiple *theories* of dream functions, but dreaming as a specific phenomenon cannot have multiple *conflicting functions*! If one theory says that recurrent dreams, nightmares, and bad dreams are types of dreams that most strongly carry out the TST functions and thus were selected for in human evolutionary history, and another theory says that such dreams are, from the functional point

of view, total failures of dream function, it becomes impossible to construct from those mutually opposing ingredients a "multifunctional" theory.[3] A theory that combines TST and ERT would have to say that on the one hand the function of dreaming is to have many threatening events in dreams, bad dreams, nightmares, and recurrent negative dreams, in order to rehearse threat perception and avoidance, but on the other hand the function of dreaming is also to calm down or suppress exactly those types of dreams to make the dreamer feel better. What is the dream production system supposed to do: increase or decrease the number and impact of these kinds of dreams? The multifunctional theory cannot derive coherent testable predictions about the quantity and quality of these types of dreams.

This situation, however, is far from a scientific catastrophe; in fact, it is highly *desirable.* The problem is not that there is a lack of different theories, hypotheses, ideas, or suggestions about the nature and functions of dreaming, but rather that there are too many. Consequently, it is not only possible, but theoretically necessary to separate the basic assumptions, predictions, and hypotheses of the simulation theories from those of ERT, CH, and others. We can have multiple independent *theories* of dream functions, but dreaming as a specific phenomenon cannot have multiple *mutually inconsistent functions*. We hope that the simulation theories of dreaming, whether they turn out to be correct or not, will at least push dream science forward. The progress of any science is best served by the directly opposing predictions issued by rival, clearly stated, empirically testable hypotheses. Thus it is, from the scientific point of view, much more desirable to

have many squarely opposing testable hypotheses than one all-inclusive theory that is unfalsifiable or too vague to be tested. When the opposing theories have been well-formulated and put through fair but strict empirical tests several times, we will know which ones to adopt for the time being and which ones to leave behind for good, in order to keep dream science a progressive branch of science.

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3 The multifunctionality of dreaming might be possible in different populations, so that in a population that lives in a very threat-filled environment a strong threat simulation system would be selected for, whereas in a population living in more peaceful conditions the psychotherapeutic function and taming of threat simulations dreams would be more likely candidates for selection. However, one and the same population cannot manifest both functions at the same time. Just as in some species of moths, in one environment individuals are selected for towards being white because white provides the best camouflage, while in another environment the color of individuals in the same moth species is selected for towards being dark gray or black, because in that environment all the white individuals are too easily detected by predators.

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