Theories of dreaming and lucid dreaming: An integrative review towards sleep, dreaming and consciousness

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Summary. The present review gives an overview on common theories of dreaming with a specific emphasis on how they are able to explain lucid dreaming. The theories are grouped either to such that describe structural or biological processes of dreams or to such that describe evolutionary and adaptive functions of dreams. This overview shows that none of the theories outlined is fully capable of explaining neither non-lucid dreaming nor lucid dreaming. With respect to the first group, the concept of "protoconsciousness" is the theory that at best explains lucid dreaming. With respect to theories with an evolutionary and adaptive function of dreams, those theories, that stress the problem solving or simulation functions of dreams are more suited to explain lucid dreaming. Further, aspects that induce or amplify lucidity and the neural mechanisms that may be involved in lucid dreaming are described.

Keywords: Lucid dreaming, lucidity, evolutionary functions, dreaming, consciousness, dream theories, protoconsciousness

1. Introduction

Over the last several decades an effort has been made to shed light on the phenomenon of lucid dreaming and the factors associated with this ability. The phenomenon of lucid dreams in REM sleep was verified in the late 1970s (Hearne, 1978; LaBerge, 1980a). It is defined as the fact that a dreamer is aware that he is dreaming while dreaming (e.g., LaBerge, 1980a, Spoormaker & van den Bout, 2006). Although some authors defined lucid dreams as a hybrid state of consciousness that has definable and measurable differences from both waking and REM sleep (e.g., Voss, Holzmann, Tuin, & Hobson, 2009), others argue that lucid dreaming is not a dissociative hybrid mixture of waking and dreaming and that REM sleep is capable of supporting reflective consciousness (e.g., LaBerge, 2010). Nevertheless many questions regarding the prevalence of lucid dreams (LD), as well as the trait and state personality factors related to them remain open. Several proposals have been made for integrating dreaming into broader theories of consciousness (Hobson, Pace-Schott, & Stickgold, 2000; Revonsuo, 2006; Windt & Noreika, 2011). In order to integrate data on LD into present dream theories we subdivided them into theories that explain structural and biological processes and theories proposing evolutionary and adaptive functions for dreaming. In other words: theories that explain how dreaming works and theories that explain why the dreaming process evolved in our ancestors. We thus put an emphasis on lucid dream research and its compatibility with current dream theories.

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2. The epidemiology of lucid dreaming

Lucid dreaming is defined as the fact that a dreamer is aware that he is dreaming while dreaming (e.g., LaBerge, 1987; Spoormaker & van den Bout, 2006). Tholey and Utecht (1987) added more criteria to this phenomenon, such as awareness of freedom of decision, memory of the waking state, and full intellectual abilities. However, only very few of all lucid dreams seem to fulfill all of Tholey and Utecht´s criteria (Barret, 1992). In a representative German sample Schredl and Erlacher (2011) found that 51% of all participants had experienced a lucid dream at least once in their life. An Austrian representative survey by Stepansky et al. (1998) showed that 26% of the sample had experienced the phenomenon of LD. In another unselected student sample, 82% reported having experience with becoming aware that they were in a dream (Schredl & Erlacher, 2004). Still, the proportion of lucidity among all recalled dreams is small, according to some studies only 0.3% to 0.7% of all recalled dreams are related to this specific state of mind (Barret, 1992; Zadra, Donderi, & Phil, 1992). Schredl and Erlacher (2011) found a higher rate (7.5%) of all dreams to be lucid, whereas Erlacher, Stumbrys and Schredl (2011) found the percentage of lucid dreams compared to all dreams in German athletes to be twice as high as in the general population (14.5% vs. 7.5%; Schredl & Erlacher, 2011). Nevertheless, the exact proportion of lucid dream remains uncertain.

Regarding gender differences, Schredl and Erlacher (2011) found that lucid dream recall was significantly higher in women. However, this gender difference might be explained by the fact that women report a higher dream recall frequency (DRF) rate than men (Borbely, 1984; Giambra, Jung & Grodsky, 1996; Pagel, Vann, & Altomare, 1995; Schredl, Bozzer & Morlock, 1997; Schredl & Piel, 2003, 2005; Wyneandts-Francken, 1907; Zink & Pietrowsky, 2013). This conclusion is supported by a correlation coefficient of .57 between DRF and lucid dream frequency (Schredl & Erlacher, 2011). In a study by Schädlich and Erlacher (2012) nearly twice as many women as men used LD for problem solving. These authors argued that the difference between men and women could be explained by the generally higher frequency of nightmares in women (e.g., Schredl, 2003) which was associated to be accompanied by a higher lucid dream prevalence, which may act as a treatment for nightmares.

Schredl and Erlacher (2011) also found that lucid dream recall is negatively correlated with age. Thus, the same problem with DRF as a possible mediator variable occurs. Large-scale studies showed that DRF diminishes with age (Giambra et al., 1996; Schredl ,1998; Stepansky et al., 1998), whereas Borbely (1984) found a higher DRF in the group of 60-74 years compared to 15-19 years. In a large sample of school children and young adults, Voss, Frenzel, Koppehele-Gossel and Hobsen (2012) found LD to be quite pronounced in young children, while incidence drops at about 16 years. It thus remains a task to establish the prevalence and differences of lucid dream frequency by partialling out other correlating factors such as DRF.

In the following, an overview on theories of dreaming and their compatibility to lucid dreaming is made. The theories are grouped to either structural and biological theories of dreaming or evolutionary and adaptive functions of dreams. Table 1 and 2 summarizes the theories and their possible predictive value for lucid dreaming.

3. Structural and biological theories of dreams

3.1. Random Activation Theories

The random activation theories (RAT) state that dreaming is a synthesis of random cerebral image activation. Hobson and McCarley (1977) proposed an activation-synthesis hypothesis, whereby dreaming is nothing but a nonfunctional epiphenomenon constructed by erratically activated memories during REM sleep. The neurophysiological and neurochemical processes occurring during REM sleep determine the activation pattern of dreaming, which is seen as a functionless side effect of sleep-related brain activation. The main problem of RAT is that they cannot explain why the form of dreams is so well organized (Valli & Revonsuo, 2009). Why and how does the brain create a coherent and detailed simulation of the world? Even though random activation could lead to more organized dream content, it does not explain consciousness during dreams, for example lucidity and interindividual differences in certain dream structures and contents.

3.2. Reverse Learning Theory

The reverse learning theory introduces the notion that the process of dreaming resembles to an ‚off-line' computer mode during dreaming (Crick & Mitchison, 1983). During REM sleep and dreaming, information gathered during waking life activities is shifted and unwanted material is thrown out, since the cortex must cope with this vast amount of information in order to maintain the efficient organization of memory. So, the aim of the dream process is to eliminate and forget unnecessary information and to regulate unwanted modes of acquired neural network interaction as a ‚reverse learning' or ‚unlearning' function. This would explain why dreams tend to be easily forgotten. However, the reverse learning theory cannot explain why dreams are often organized in a systematic way with clear narratives, since they are supposed to be disposable, unwanted material.

Kinouchi and Kinouchi (2002) developed a computational model to test the hypothesis that the reverse learning process could regulate excessive plasticity and weakens over stable brain activation patterns during the dream or REM sleep. In their model they produced a pool of weak and strong or dominant memories. They showed that equalizing the strength of all memory clusters in their model by weakening the stronger ones revealed that the downgrade of strong and dominant emotional memories produces a better recovery of memories and can also produce a clear dream narrative.

Thus, it may be possible to have memory consolidation with a 'forward' learning process as well as a reverse learning mechanism. The emotional unlearning process has functions that might extend the general memory integration process during REM sleep (Stickgold, 2005; Walker & Stickgold, 2004) and could also help to explain aspects of the psychological healing theory and the affective network dysfunction model (see below). In line with the psychological healing theory emotional unlearning results in an impaired strength of traumatic memories after REM sleep which may lead to a better psychological balance. Regarding the affective network dysfunction model, failure of emotional unlearning may be associated with chronic posttraumatic nightmares.

As far as LD is concerned the role of reverse learning for awareness and cognitive control in dreams remains unclear. In a pilot study, Erlacher and Schredl (2010) compared a lucid dream practice group, a physical practice group, and a control group, who were asked to practice a simple motor task. Lucid dreamers, who were able to practice a motor task in a lucid dream, showed a significant improvement in performance, whereas the other lucid dreamer showed no improvement. The physical practice group had the highest enhancement in performance followed by the successful lucid dream practice group. Thus, if a reverse learning mechanism underlies dreams, it might be assumed that lucid dreams would counteract the equalization of memory strength by means of a controlling action in the experienced dream.

3.3. AIM Model

Hobson, Stickgold and Pace-Schott (1998) revised the activation-synthesis hypothesis and developed a cognitive model of sleep (Hobson & Pace-Schott, 2002). According to this model, dream content is specific for individuals, but a neuropsychological model can help to explain formal differences between dream activity and wake state: The AIM Model proposes that on a neurophysiological level all conscious states (including dreaming) are determined by three interdependent processes:, which are the level of brain activation (A), the origin of inputs (I) to the activated areas, and the mode (M), that means the levels of activation of aminergic and cholinergic neuromodulators (Hobson et al., 2000). All conscious states can be described as a point in a three-

Table 1. Overview on the structural and biological theories of dreaming and their compatibility with lucid dreaming.

	Structural & Biological Theories	Compatibility with Lucid Dreaming
Random Activation Theory	Dreaming is a synthesis of random cerebral activation and a nonfunctional epiphenomenon constructed by erratically activated memories during REM-sleep.	Low as with non-lucid dreaming.
Reverse Learning Theory	Aim of the dream process is to eliminate and forget unnecessary information. REM-sleep regulates brain activation patterns to optimize emotional responses, fear learning, and anxiety level.	The role of reverse learning for awareness and cognitive control in dreams remains unclear. Lucid dreams would counteract the equalization of memory strength by means of a controlling action in the dream.
AIM-Model	On a neurophysiological level, all conscious states can be described as a point in a three-dimensional space: the level of brain activation (A), the origin of inputs (I) to the activated areas, and the mode (M), that means the levels of activation of aminergic and cholinergic neuromodulators.	Lucid dreaming is a hybrid state lying across the wake REM interface. It can be explained as a dissociation along the A-axis of the AIM-model.
Continuity Hypothesis	Dreams are assumed to reflect previous waking life experiences.	Lucidity in dreams exists in all dreams and there is a continuum with “lucidity” and “non-lucidity” representing the two ends of the dimension. There is a relative continuity of consciously accessible memory linking lucid dreams and waking experience.
Protoconsciousness	Waking and dreaming states cooperate and have a functional interplay that is necessary for the optimal functioning of both. It is a gradual, time-consuming and lifelong process that constantly builds on and maintains consciousness and develops along with brain development.	Lucidity in dreams may occur when the REM sleep state overlaps with components of secondary consciousness in the wake state. Thus, different features of dream state are combined into a hybrid state of consciousness.

dimensional space spanned by the axes A, I and M. Thus, the AIM Model represents the mind state as a sequence of points with time as a fourth dimension. Hobson et al. (2000) explain the phenomenon of LD as dissociation along the “A” axis of the AIM Model. If the dorsolateral prefrontal cortex (DLPFC), normally deactivated in sleep, is reactivated but not so strongly as to suppress signals to it from pontolimbic systems (Voss et al. 2009), lucidity — a combination of waking insight combined with dream hallucinosis — occurs. This dissociation is represented in the AIM model by splitting AIM, so the portion representing the DLPFC can take a position dissociated from that of the rest of the brain. During this partial reactivation of the DLPFC during dreaming, internally generated dreams are seen for what they are and are not misinterpreted as coming from the outside world. Hobson et al. (2000) state that the fact that lucidity can arise when the DLPFC is deactivated can also be explained using AIM. LD occurs spontaneously or can be induced by several methods (see below; e.g., Stumbrys et al., 2012). Spontaneous lucidity indicates that the reduced amount of reflective self-awareness during dreaming is sometimes enhanced enough for the subject to recognize the dream state for what it is. Autosuggestion may increase the probability of this process by priming the brain circuitry in prefrontal areas that subserves self-reflective awareness. In both cases, the phenomenon of lucidity clearly illustrates the dissociable quality of brain-mind states.

Several studies have reported an association of lucid dreams with false awakenings (FAs; Buzzi, 2011; Green, 1968; Green & McCreery, 1994; Hearne, 1983a; La Berge & DeGracia, 2000) - sleep-related experiences in which the subjects erroneously believe that they have woken up, only to discover subsequently that the apparent awakening was part of a dream. Buzzi (2011) have argued that like lucid dreams, FAs are also a hybrid state of consciousness with definable differences from waking and from REM sleep, and that the onset of FAs is connected to activation levels of some frontal brain areas along the “A”-axis of the AIM model. Thus, the AIM model accommodates these features by proposing that both LD and FAs are hybrid states lying across the wake-REM interface. Stumbrys (2011) points out that the assumption of Hobson that lucid dreaming is a dissociative state and a hybrid mixture of waking and REM sleep (Voss et al., 2009) rather helps to maintain consistency between the model and the lucid dreaming phenomenon and is not supported by empirical evidence. It was argued that there is some evidence against Hobsons assumption about lucid dreaming (Brylowski, Levitan, and LaBerge, 1989; LaBerge, 2004; Yuschak, 2006), which make it more plausible to classify lucid dreaming in the AIM model in the same place as non-lucid REM sleep.

Table 2. Overview on the evolutionary and adaptive function theories of dreaming and their compatibility with LD.

	Evolutionary & Adaptive Function Theories	Compatibility with Lucid Dreaming
Psychoanalytic Theories	Freud: Latent dream content of the subconscious in order to protect the sleeper from disturbing sexual or aggressive wishes until it can pass a censorship instance and become a manifest dream. If this dream content cannot be modified appropriately the dream will be suppressed and cannot be transferred into the wake state. Jung: Dreams try to communicate with the dreamer via images and symbols. The unconscious communicates to the dreamer in a compensatory function in order to become more complete and have more meaning in life. Behavior, cognitions, and feelings occur in dreams, that have previously been neglected by the waking consciousness.	Do not have as substantial predictive value for a possible function of lucid dreaming.
Costly signaling function	REM features influence dream content, mood, and emotional displays for the next wake episode, whether or not dream content is recalled. Dreams are an emotional burden, greatest if a negative dream was recalled. If the individual is able to display appropriate and functional behavior in the face of the emotional burden, the emotional signals are honest and hard to fake.	Cannot explain why lucid dreaming evolved, as it does not specify how behavior is influenced by REM sleep and dreaming, how they interact and how other persons can monitor and evaluate external behavioral cues that are modulated by previous REM sleep and dreaming.
Sentinel Function	Dreams have a predictive and preparatory function for the situation in which the individual awakes. REM-sleep increases the level of brain activity and prepares for brief awakenings and immediate fight or flight reactions if danger is detected while awakening. Dreams prepare the individual for fight and flight if information from the environment leads to that conclusion.	Triggers of lucid dreaming such as light cues or physiological arousal are associated with a preparatory function, although no direct evidence has yet been observed.
Problem Solving & Creativity Function	Psychological problem solving function has a creative and psychotherapeutic effect, in particular for traumatic incidents. Broader connections during dreaming help linking information in new ways that were evolutionarily useful, which have a creative and problem solving function.	Some lucid dreamers use lucid dreams for creative purposes and to solve problems. An evolutionary basis that makes all dreams potentially lucid and that there is a strong connection between LD, creativity, and problem solving, is assumed.
Psychological Healing Theories	Dreaming maintains psychological balance and is necessary to adjust in current waking life. It promotes coping capabilities, psychological well-being, and recovery from traumatic experiences.	Lucidity in dreams promotes psychological healing or vice versa. However, there is no evidence that dreaming about a trauma somehow contributes to psychological recovery from that trauma.
Simulation Functions	General: Dream experience is functionally constructed for simulating waking life experience. Play Function: Dream experience resembles play behavior in mammals. Social Stimulation Function: Dreaming about the intentions of others prepares us for social encounters when awake. So practicing how to manage complex human social life interactions may have an important adaptive value. Threat Simulation: Dream consciousness is specialized in the simulation of various threatening events to which our ancestors were exposed to and improves survival success of the individual.	Does not explain LD in addition to non-lucid dreaming. Does not explain LD in addition to non-lucid dreaming. Does not explain LD in addition to non-lucid dreaming. There is some evidence for threat to be associated with lucidity in dreams. There is also preliminary evidence that anxiety-triggered dreams become less frequent with more experience in LD.

3.4. Continuity Hypothesis

The continuity hypothesis (CH; e.g., Domhoff , 1996) describes a continuum between waking experiences and dream experiences, with dreams reflecting nothing more nor less than previous waking life experiences. This hypothesis receives support from several studies (Bell & Hall, 1971; Domhoff, 1996; 2001; 2002; Hall & Lind, 1970; Hall & Nordby, 1972, Schredl & Piel, 2005). It has been derived from that hypothesis that there is continuity between the waking and dreaming personality (Domhoff, 1999; Patrick & Durndell, 2004). Likewise, a continuity of dream content with waking mentation of children in the laboratory has been found (Foulkes, 1967; Foulkes, Larson, Swanson, & Rardin, 1969; Foulkes, Pivik, Steadman, Spear, & Symonds, 1967). Although Schredl (1999) argued that direct effects of incorporations are rather small and have methodological issues, Strauch and Meier (1992) showed that more than 50% of dream elements can be linked to waking experiences of the previous wake state. While many activities of our daily lives such as highly focused cognitive processes like writing, reading and calculating are underrepresented in our dreams – probably due to the cholinergic activation or other alterations of brain physiology like down-regulation of the DLPFC during dreaming (Hartmann, 2000, Schredl & Hofmann, 2003) - other elements like negative emotions and events are overrepresented (Domhoff & Schneider, 2008; Valli & Revonsuo, 2009). Similarly, Foulkes (1982; 1999) found that children between ages 5 and 15 dreamed very little of their two most time-consuming daytime activities, going to school and watching television. Instead, they dreamed about recreational activities.

Such findings seem to contradict most important prediction of the CH: That frequency and type of any real events are correlated with the frequency and type of subsequent dream events. Thus, the CH is not the most reliable explanation for form and content of dreams, because it does not have the potential to clarify more about the possible function of dreaming-waking continuity and why some elements of wake-state experiences are more likely to be incorporated into dreams than others.

In the context of LD, La Berge and DeGracia (2000) showed that lucidity in dreams is not a discrete phenomenon, but that reflective consciousness exists in all dreams and can be measured on a continuum with 'lucidity' and 'non-lucidity' representing two ends of the spectrum within dreams. They also presume that there is a relative continuity of consciously accessible memory linking lucid dreams and waking experience. This is reflected by the effectiveness of certain cognitive techniques (see Stumbrys et al. (2012) for a review), which show that habits developed in wakefulness are subsequently transferred to dreams. Moreover,, and – probably more convincing – the continuity between LD and wakefulness is reflected by the effect of practicing motor tasks within LD and their subsequent improved performance in wakefulness (Erlacher & Schredl, 2010).

As in LD, where there is an attentional skill of having metacognition about the dreamer's state of consciousness at the same time as being engaged in the dream scenario, the Stroop color naming task also involves a combination of two levels of cognition, because in the incongruent condition there is interference between the attentional demands of a relatively difficult task (color naming) and an easy one (reading). Blagrove, Bell and Wilkinson (2010) proposed continuity in attentional ability between waking and dreaming cognition, based on their observation that frequent lucid dreamers to be significantly faster in the incongruent condition of the Stroop task than occasional and non-lucid dreamers. Reconsidering these results, it can be assumed that the CH applies better to some dream features than others. As Schredl and Hofmann (2003) pointed out, it will be necessary to specify the continuity hypothesis more fully and to include factors (e.g., type of waking-life experience, emotional involvement), which modulate the incorporation rate of waking-life experiences into dreams.

3.5. Protoconsciousness

Allan Hobson's (2009b) theory of protoconsciousness suggests that waking and dreaming states cooperate and have a functional interplay that is necessary for the optimal functioning of both and is seen as a lifelong process. Protoconsciousness, a primordial state of brain organization, is a building block for consciousness, which is proposed to develop along with brain development, in REM sleep in utero and in early life as a state that preludes consciousness and further develops and maintains higher order consciousness (Hobson, 2009b). The development of consciousness is seen as a gradual, time-consuming and lifelong process that constantly builds on. Hobson suggests that waking and dreaming states in humans cooperate and that their functional interplay is crucial to the optimal functioning of both. Thus, REM sleep has integrative functions and is the basis on which the brain prepares for secondary consciousness, the subjective awareness including perception and emotion that is enriched by abstract analysis and metacognitive components of consciousness. In the waking state the brain has access to information about external space and time. These external inputs are not available in sleep and must therefore be simulated in dreaming. Hobson states that because intrinsic activation of the forebrain during REM sleep arises early in development, a ‚protoself' is established to take responsibility for what begin as entirely automatic acts, but commanding our dreamed motor acts is as much an illusion as our wake-state sense of conscious will (Libet, Gleason, Wright, & Pearl, 1983; Wegner, 2004). Taking into account that REM sleep provides a virtual model of the world and that this state is not at first associated with awareness (Kihlstrom, 1987), Hobson (2009b) proposes that it is only in the course of childhood that we become able to integrate this experience and become aware of it, as also discussed by Domhoff (2001). For attributes of secondary consciousness like self-reflection, insight, judgment or abstract thought to be present, activity in the requisite cortical structures must be modulated appropriately as we wake up or dream lucidly. Analyzing the phenomenology of false awakenings, Buzzi (2011) found that false awakenings are consistent with Hobson's hypothesis of dream protoconsciousness, as dream content feeds itself from innate schemes, enacted on the basis of subjective experiental memories.

Foulkes, Hollifield, Sullivan, Bradley, and Terry (1990) studied the development of conscious mental processes and representations in children by analyzing dream reports from laboratory awakenings in REM sleep and cognitive skill tests of 80 participants from 5 to 8 years. They confirmed the earlier findings of a longitudinal study by Foulkes (1982): Dreams were reported relatively seldom and dream experience depends upon representational intelligence. Until age 7, the imagery reported by the children was more static than dynamic, by age 8 a passive-observer role for their self was most common and dream activity evidenced very simple forms of narrative structure. These findings emphasize the hypothesis of a developing process of dreaming skills in childhood that is associated with general cognitive development. It has been proposed that general cognitive development is a lifelong process, with the quality of cognition continuing to develop to higher stages, not ending at an abstract verbal level (Hunt, 1995), implying that dreaming in adulthood may continue to develop as well.

As protoconsciousness is seen as a functional interplay between dream and wake state, a continuum between waking experiences and dream experiences according to the continuity hypothesis (Domhoff, 1996) and incorporation of wake state events seem plausible. De Koninck and Brunette (1991), Weingarden (1972) and Cohen (1972) demonstrated that inducing stress had an influence on dream content. Cipolli, Fagioli, Maccolini and Salzarulo (1983) reported significant incorporations of sentences they present to participants before sleeping. Goodenough, Witkin, Koulak, & Cohen (1975) and Lauer, Riemann, Lund, & Berger (1987) showed indirect incorporations (negative emotions) of stimuli presented in the previous wake state. On the other hand, Foulkes and Rechtschaffen (1964) and De Koninck and Koulak (1975) found no increased negative emotions in dreams after aversive movies. According to the protoconsciousness theory (Hobson, 2009b) REM sleep has integrative functions and is necessary to prepare for such metacognitive components of secondary consciousness as subjective awareness. This suggests that lucidity in dreams may occur when the REM sleep state 'overlaps' with components of secondary consciousness in the wake state. Thus, different features of dream state and wake state are combined into a hybrid state of consciousness. Voss et al. (2009) showed that LD has definable and measurable differences from waking and from REM sleep that can be explained by the three interdependent processes of the AIM model (Hobson et al., 1998). From the biological perspective the onset of spontaneous lucidity may arise from the actual impetus to wake us up or to change a nightmare or bad dream into a more pleasant experience (Schädlich & Erlacher, 2012), but – as the reactivation of the DLPFC and other brain networks in REM sleep state is rather weak (Voss et al., 2009) – lucidity occurs in such a way that without waking there is metacognition about the dreamer's state of consciousness at the same time as the actual dream scenario unfolds.

In sum, the theory of protoconsciousness seems to be compatible with most of the findings in dream research. It incorporates other common structural dream theories such as the CH and AIM models (Hobson et al., 1998) to a considerable extent and is also capable of explaining LD in terms of "normal" dreaming.

4. Evolutionary and adaptive functions of dreams

As REM sleep has been found to be unique to mammals and birds, it is presumed to have some selective advantage (Snyder, 1966), with benefits over reptiles at the time when mammals evolved. Some evolutionary biological approaches have been suggested to explain the function of sleeping and dreaming. Reviewing the proposed functions of dream raises the question whether the phenomenon of LD also derived as a biological function and whether it is as old as dreaming itself. Engel (1997) noted that LD has a long tradition in eastern culture, for example the Tibetan practice of dream yoga (Norbu, 1992; Wangyal, 1998).

4.1. Psychoanalytic Theories

A number of dream theories have been proposed to explain dreaming, its structure and content. In his psychoanalytic theory, Freud (1900) presented the idea that latent dream content of the subconscious is modulated in order to protect the sleeper from disturbing sexual or aggressive wishes until it can pass a 'censorship instance' and become a manifest recalled dream. If this dream content cannot be modified appropriately the dream will be suppressed and cannot be transferred into the wake state. If the sleeper were to become aware of his subconscious wishes, the anxiety they provoked would awaken them. Thus, the only way to access the true content of a dream is to use interpretation techniques. With regard to LD it can be argued that dreaming has a role as the 'guardian of sleep' and that becoming aware that one is dreaming while dreaming might avert the initial impetus to wake up. Empirical tests of this notion are difficult, since there is no way to access the suppressed dream content in order to compare it with the recalled dreams. Jung (1974) proposed that dreams try to communicate with the dreaming person via images and symbols, so the messages of dreams are difficult to understand. His idea was that the unconscious communicates to the dreamer in a compensatory function in order to become more complete and have more meaning in life (Jung, 1974). The complementary hypothesis of dreaming was derived from Jung's compensatory function (Jacobi, 1971). It states that behavior, cognition and feelings occur in dreams that have previously been neglected by the waking consciousness. Many studies have shown that movies presented to participants the night before can manipulate the recalled dream content although the direct effect on dream content is rather small (Cartwright, Bernick, Borowitz, & Kling, 1969; Goodenough et al., 1975; Lauer et al., 1987). Considering personality traits and states biasing dream recall makes it even more difficult to get further support for this hypothesis. As Valli and Revonsuo (2009) pointed out, the psychoanalytic theories of Freud and Jung were influential in personality psychology but cannot be considered valid explanations for dreaming, because their ideas were based on small samples collected unsystematically from only a few individuals. Nor do they have a substantial predictive value for a possible evolutionary function of dreams and LD.

4.2. Costly signaling theory

One evolutionary theory is known as Costly Signaling Theory (CST; Bliege Bird & Smith, 2005; Bradbury & Vehrencamp, 1998; Grafen 1990; Maynard-Smith & Harper, 2003; Zahavi, 1975; Zahavi, Zahavi-Ely, & Ely, 1997). It is based on the concept of sexual selection theory (Trivers, 1972) and was put forward by McNamara (2004) to understand dream phenomenology and dream function.

It was proposed that some animal traits evolve because they indicate that their possessor has good genes, enabling him to invest in courtship and allocate resources to their reproduction. Individuals who display costly and hard-to-fake signals are more likely to be selected by the opposite sex because they improve their fitness. The CST states that REM features influence dream content, mood and emotional displays for the next wake episode, whether or not dream content is recalled. Dreams are seen as an emotional burden, greatest if a negative dream was recalled. Recalling such a negative dream puts the dreamer in a 'handicapped' position (Valli & Revonsuo, 2009). If the individual is able to display appropriate and functional behavior in the face of the emotional burden carried into waking, the emotional signals from this individual are honest and hard to fake. This ability makes her or him more likely to be favored by other group members, especially for selecting an individual as a mate or being preferred over others in cooperative alliances (Valli & Revonsuo, 2009). With regard to LD, the CST cannot explain why LD evolved, as it does not provide a signal of fitness. The problem with the CST is its lack of concreteness. It does not specify how behavior is influenced by REM sleep and dreaming, or how they interact, nor does it clarify how other group members can monitor and evaluate external behavioral cues that are modulated by previous REM sleep and dreaming. Furthermore, there is no plausible evidence that the costly features of REM sleep and the emotional burden of dreaming are directly observable. If there are indirectly observable features, reliable cues that are highly correlated with REM sleep and dreaming have to be discovered and linked to being favored by other group members that find these cues desirable.

4.3. Sentinel function theory

The sentinel function theory (SFT), proposed by Snyder (1966), states that REM sleep increases the level of brain activity and prepares for brief awakenings and immediate fight or flight reactions if danger is detected while awakening (Valli & Revonsuo, 2009). Snyder proposes that dreams prepare the animal for fight and flight if information from the environment leads to that conclusion. If not, continuity of sleep with pleasant dreams ensues. Dreams in REM sleep have a predictive and preparatory function for the situation in which the animal awakes. It has proved difficult to test this theory, as the dreams of ancient and modern mammals cannot be measured. Although external stimuli such as sounds, smells and tactile experiences can be detected by the sleeping brain and lead to increased activity in humans, incorporation of presented stimuli into dream content while dreaming is rather indirect (Schredl, 1999). Moreover, external stimuli are often incorporated into dreams in such a way that dreaming and sleeping are maintained (e.g., the sound of an alarm clock misinterpreted as church bells). Tactile stimuli like pressure, water-jets and electro shocks (Dement & Wolpert, 1958; Nielsen, 1993), or salient stimuli like the dreamer's name (Berger, 1963) or key words associated with problems in waking life (Hoelscher et al., 1981) have a higher incorporation rate. This puts emphasis on a sentinel function of sleep in so far as such stimuli might preserve the sleeping organism from threats.

In the context of LD, LaBerge and Levitan (1995) found that external light cues applied during REM sleep can remind dreamers that they are dreaming, if the cues are incorporated into a dream. Subjects reported seeing in their dreams what they believed to be light cues significantly more often in light cue nights compared to nights without light cues. These authors conclude that the sensory stimuli of the dreamlight appears to increase a subject's probability of having lucid dreams, and that most of the resulting lucid dreams are due to the specific effect of light cues rather than general 'placebo' factors. It was shown that heightened physiological arousal is a lucidity trigger (LaBerge,1992; LaBerge, Levitan, & Dement, 1986) and also triggers nightmares (Schredl, 2000). Schredl and Erlacher (2004) found that lucid dreamers have thinner boundaries according to the boundary concept of Hartmann (1989). These findings highlight the role of REM sleep and the incorporation of evolutionarily important sensory input, and its possible preparatory function. They suggest that triggers of lucid dream such as light cues or physiological arousal are associated with a preparatory function, although no direct evidence supporting the SFT has yet been observed.

4.4. Problem Solving and Creativity Function

Hartmann (1998) proposed two evolutionary functions for the capacity of dreaming to form new connections within the neural networks of the brain: The first is a problem solving function, with a psychotherapeutic effect, in particular for traumatic incidents; this had an advantage in the early development of the human brain when traumatic experiences were presumably an everyday reality. The second function is the creative and problem-solving function of dreams. Broader connections during dreaming help linking information in new ways that were useful to our ancestors in waking life, implying that dreaming was the earliest form of human creativity (Barret & McNamara, 2007). This accords with the findings of Schredl (1995), who showed that persons with visual and verbal creative skills recalled more dreams.

It can be claimed that lucidity in dreams is a possible outcome in line with these evolutionary functions. The psychological problem solving function has many similarities with Psychological Healing Theories, which are discussed below and which seem to be related to LD. With regard to the creative problem solving function, Stumbrys and Daniels (2010) argue that lucid dreams can contribute to problemsolving when dealing with tasks that are more creative than logical, and that dream characters can provide plausible creative advice to the dreamer.

In a group of lucid dreamers, more than a quarter used lucid dreams for creative purposes and to solve problems (Schädlich & Erlacher, 2012). Another study reported that LD has a problemsolving effect in therapy (Zadra & Pihl, 1997). Furthermore, lucid dreamers are more creative (Blagrove, & Hartnell, 2000; Gackenbach, Heilman, Boyt, & LaBerge, 1985; Gruber, Steffen, & Vonderhaar, 1995; Zink & Pietrowsky, 2013), and there is some evidence that LD is a learnable skill (LaBerge, 1980b). Also, as mentioned above, LaBerge and DeGracia (2000) argue that lucidity in dreams is not a dichotomous variable, but rather a continuum between lucidity and non-lucidity in all recalled dreams. Thus, it seems reasonable, that there is an evolutionary basis that makes all dreams potentially lucid and that there is a strong connection between LD, creativity and problem solving.

4.5. Psychological Healing Theories (PHT)

Several authors assert that dreaming maintains psychological balance (Cartwright, 1991; Hartmann, 1995; Kramer, 1993). The idea is that dreaming is necessary to adjust to stressors in current waking life. It promotes coping capabilities, psychological well-being and recovery from traumatic experiences (Garfield, 1991). It is also seen as functional, since the divergent dreaming process makes wider associative memory connections than the convergent waking cognition, as discussed by Hartmann (1996). Therefore, negative emotional memory traces in long-term memory representing situations of psychological imbalance can be broadly integrated into memory networks in order to neutralize them and quell emotional concern. Barrett (1993) found that at least one third of dreams by college students who were trying to "incubate" a problem included at least a partial solution to the problem, as rated by the dreamers and by a group of judges. Nielsen and Levin (2007; 2009) suggested an affective network dysfunction model (AND), according to which chronic posttraumatic nightmares represent a failure of dream function in terms of a psychological healing. Traumatic experience, as the dominant emotional concern for the dreamer, is stored into long-term episodic memory. In posttraumatic nightmares the traumatic event is repeated over and over until the trauma is integrated into memory networks, thus resolving the trauma. If the integration process fails, posttraumatic dreams will persist longer. Thus, this model suggests that sleep-specific mechanisms underlie the neurobiology of posttraumatic stress disorder.

LD has been associated with psychological growth (Green & McCreery, 1994), resilience to traumatic experiences (Soffer-Dudek, Wertheim, & Shahar, 2011), mental health (Doll, Gittler, & Holzinger, 2009), and therapeutic effects (Tholey, 1988; Zadra & Pihl, 1997), which is consistent with findings of practicing dream yoga (Engel, 1997; Norbu, 1992; Wangyal, 1998) and meditation (LaBerge & Gackenbach, 1992). Thus, lucidity in dreams that promote psychological healing or vice versa seems plausible. Even though the PHT is supported by some evidence, there are difficulties in explaining empirical findings. As Valli and Revonsuo (2009) pointed out, while a strong correlation between first experiencing a traumatic event and later dreaming about it exists, there is no evidence that dreaming about the trauma somehow contributes to psychological recovery. The empirical evidence currently available on the PHT is correlative at best, and although recent findings imply that post-traumatic dreams represent a failure in memory integration, dreaming does not necessarily lead to psychological healing. A general interdependent or independent recovery process can also explain the transition from posttraumatic nightmares to normal dreams.

4.6. Simulation Functions

Theories of simulation functions of dreams are based on the view that dream experience is functionally constructed for simulating waking life experience. The "play" function suggests that dream experience resembles play behavior in mammals (Bulkeley, 2004; Humphrey, 2000). Valli and Revonsuo (2009) pointed out several similarities and dissimilarities between dreaming and play behavior. Both have the ability to simulate reality in order to rehearse situations and interactions in a safe context. Therefore, both are biologically determined behaviors that may provide an evolutionary advantage by being useful in some way. Both display, manipulate, transform, simplify and exaggerate a broad range of behaviors that have their origin outside play. On the other hand, dreaming is perceptually more realistic than play, especially in its visual aspects. Play is motorically more realistic than dreaming, as it involves actual physical exercise and the execution of motor programs that generate movement. Thus, it does not seem appropriate to explain the function of dreaming as being similar to that of play behavior, not least because the adaptive functions of play are still not entirely clear either (Valli & Revonsuo, 2009). These authors point out that dreaming and play might have complementary functions in the rehearsal of behaviors and that playing has multiple functions, some of which seem to overlap with dream simulation functions. They argue that some forms of mammalian play display rehearsals of hunting behavior, aggressive encounters, or predator avoidance (Valli & Revonsuo, 2009), which can be related to a threat simulation function (Revonsuo, 2000).

The threat simulation function (TST), proposed by Revonsuo (2000), is based on evidence that negative elements such as negative emotions and aggression are prominent characteristics of dream content (Domhoff & Schneider, 2008). In the ancestral environment a threat simulation system may have evolved to recall life-threatening events from long-term memory and construct various threat simulations based on them. These threat simulation events in dreams might have provided a selective advantage for our ancestors by practicing threat detection and avoidance skills without actually facing such deadly threats in real life situations. In sum, the TST asserts that dream consciousness evolved as an offline model of the world, specialized in the simulation of various threatening events to which our ancestors were exposed. A threat simulation function was therefore selected because it improved survival and reproductive success of its individual (Barret & McNamara, 2007; Valli & Revonsuo, 2009). The TST takes such selection pressures into account and there is a certain amount of support for it. Although it offers a plausible explanation for how dreaming about negative and threatening events might have provided a slight advantage to our ancestors in maintaining and enhancing special skills, the TST and the genetic determination of threat simulation in dreams remain controversial (Nielsen & Levin, 2009).

LaBerge, Levitan and Dement (1986) argued that heightened physiological arousal is a lucidity trigger. Although generally lucidity in dreams is associated with higher positive emotions and lower fear-related emotions (Thomas, Claudatos, & Kahan, 2013), LaBerge (1985) states that there is an evolutionary basis for anxiety stimulating reflective consciousness in dreams. Schredl and Erlacher (2004) showed that nightmare frequency was moderately associated with LD frequency. Thus, there is some evidence for threat to be associated with lucidity in dreams. There is also preliminary evidence that anxiety-triggered dreams become less frequent with more experience in LD. For example, LaBerge (1985) reports percentages of anxiety-triggered lucid dreams in year 1-3 after practicing LD of respectively 36%, 19% and 5%, probably due to the psychotherapeutic techniques applied. Other intense emotions such as embarrassment or delight can also initiate lucidity (LaBerge & DeGracia, 2000). In a study by Schädlich and Erlacher (2012), 81.4% of a sample of lucid dreamers reported having fun in lucid dreams, and 68.8% reported changing a bad dream or nightmare into a pleasant one. It can be argued that the onset of lucidity after feeling intense emotions, especially negative ones, in a dream is a reaction that helps the subject to deal with them, either to resolve problems related to these emotions or to find an avoiding strategy. In inexperienced lucid dreamers, the onset of lucidity in a negative dream is sometimes followed by waking. It can be argued that nightmares trigger the onset of lucidity (Schredl & Erlacher, 2004) as part of the threat simulation function in so far as consciousness in dreams aids the management of a challenging dream containing negative elements. It is also possible that sleep disordered breathing (SDB) like sleep apnea or hypopnea syndrome, a phenomenon that is associated with PTSD, nightmares and insomnia, has a mediating impact on the onset of lucidity in nightmares. SDB leads to physiological arousal during sleep, which increases the probability and frequency of awakenings and fragmented REM sleep. From a biological perspective, the findings of Hobson et al. (2000) imply that lucidity occurs if the dorsolateral prefrontal cortex (DLPFC) is reactivated during negative dreams, but not so strongly as to suppress the pontolimbic systems signals to it. Threat simulation in dreams might be functional if it enhances psychological stability and preparedness in real life events, in agreement with a psychological healing effect as postulated by the PHT.

Another suggested dream function is a social simulation function. The idea here is that interacting with other members of the group had an important selection pressure in the ancestral environment. Dreaming about the intentions of others could prepare us for social encounters when awake, so practicing how to manage complex human social life in order to gain the best access to the resources available to the group had a robust adaptive value. Finding a mate, building coalitions and avoiding conflicts would have been useful skills. Furthermore, strong family and group cohesion would have improved the chances of survival and health of group members by organizing defenses against predators and enemies. Brereton (2000) suggests in his social mapping hypothesis that dreaming allows simulation of self, location, and awareness of others, including awareness of their internal mental state. Kahn and Hobson (2005) argue that a social species like man has a state-independent need for a theory of mind. Thus, the awareness of what others are thinking and the ability to attribute feelings to others in waking consciousness continue into dreaming. Valli and Revonsuo (2009) maintain that an awareness of the minds of others during dreaming might have contributed to the ability to anticipate their intentions while awake, and afforded an opportunity to rehearse the perceptual and emotional features required for successful social mapping.

Indeed, dreams often represent familiar human characters identified by their feelings, behavior and appearance, who most often evoke affection or joy in the dreamer (Kahn, Pace-Schott & Hobson, 2002; Kahn, Stickgold, Pace-Schott & Hobson, 2000). Although the social simulation hypothesis is consistent with the fact that dreams often represent multiple social interactions with familiar characters, which afford the opportunity to practice social interaction in dreams, the hypothesis has some problems in explaining an evolutionary function of dreams. As Valli and Revonsuo (2009) pointed out, it remains unclear whether the costs of practicing social interaction during wakefulness are higher than in dreaming. If this were not the case, a selective advantage for social simulation in dreams is questionable. Second, since there is a lack of studies on the nature of social interactions in dreams, one cannot be sure that the interaction with other dream characters is really a useful simulation that enables practicing and learning for real-life social interaction. Further studies should examine cost-benefit analysis to consider if dream simulation is useful for human development, at least for our ancestors.

Another approach to a simulation function was presented by Tholey (1990), who suggested that LD can also be used for practicing mental movements, making sensory-motor learning easier. LD might be used for learning and refining sensory-motor skills and for improving the organization of the phenomenal field with respect to the execution of sports movements. Erlacher & Schredl (2010) showed that LD practice in sports has beneficial effects. In a subsequent study by Erlacher et al. (2011), the majority of their sample of athletes had the impression that rehearsal within the lucid dream improved their performance in wakefulness; the percentage of LD compared to all dreams was twice as high as in the general population. Future research has to focus on other beneficial effects with reliable techniques for lucid dream induction.

5. Amplifiers of lucidity

5.1. Meditation

Hunt (1995) suggested that the quality of cognition continues to develop to higher stages, and exposure to appropriate amplifiers is necessary in order to move to the next higher level of consciousness (Alexander et al., 1990). To achieve a higher level of consciousness, nonverbal levels like spatial thinking, multimodal speeding of processing, and the integration of self and affect with cognition are thought to be important.

Several studies show that mindfulness meditation training can increase cognitive abilities, such as cognitive flexibility, visual-spatial processing, working memory, executive functioning and meta-awareness (Hargus, Crane, Barnhofer, & Williams, 2010; Moore & Malinowski, 2009; Zeidan, Johnson, Diamond, David, & Goolkasian, 2010). In the same way as one can develop a higher or lower degree of mindfulness in wakefulness, it is also possible to have a higher or lower degree of lucidity in dreams, which seems to be not an on-off phenomenon, but rather a continuum (Moss, 1986). Thus, comparing the degree of lucidity in dreams and mindfulness in wakefulness seems plausible.

Moffitt et al. (1988) suggested the parallels between meditation and lucid dreaming to be on a continuum of self-reflection with a positive relationship between the frequency of meditation and lucid dream frequency. In addition, some connections were drawn between lucid dreams and meditation and meditators have been found to have very high levels of lucidity in sleep (Gackenbach, 1992; Gackenbach, & Bosveld, 1989; Hunt, 1988; Hunt & Ogilvie, 1989; Mason, Alexander, Travis, Gackenbach, & Orme-Johnson, 1995). In sum, there seems to be a strong connection between lucidity in dreams and meditation practice. Whether meditation in wakefulness and lucid dreaming in sleep reflects the same phenomenon and only differs in the state of consciousness it occurs, has still not been tested empirically.

5.2. Electronic Media

In addition to traditional amplifiers for higher consciousness such as meditation, prayer, recall of dreams and self-reflection, video-game-play seems also to be related to dream qualities such as dream bizarreness (Gackenbach, 2009a; Gackenbach, Kuruvilla, & Dopko, 2009) and creativity (Gackenbach & Dopko, 2012).

Gackenbach (1991) proposed that a naturally occurring “virtual” reality such as LD might bridge the gap to the experience of higher states of consciousness. Gackenbach and Karpen (2007) argued that today’s home media ecology, which essentially offers continuous access to virtual worlds, is having effects on consciousness. As in the case of meditation, focused attention is a prerequisite for serious game play (Maynard, Subrahmanyam, & Greenfield, 2005). Gackenbach (2009b) argued that video game play may also be one of the amplifiers for LD and consciousness. LD frequency as well as other potential indicators of consciousness development were examined especially as a function of the frequency of video game play (Gackenbach, 2006; 2009a; 2009b). Frequent video game players were more likely to report lucid dreams, observer dreams, and dream control when dream recall frequency and motion disorientation during play were controlled (Gackenbach, 2006). Gackenbach and Kuruvilla (2013) suggested that gaming may be associated with a metacognitive dimension to the lucid dream, for example focused problem solving. Other variables that can be associated with video game play and LD are visuospatial information processing (Sternberg & Preiss, 2005), a lack of susceptibility to motion sickness in lucid dreamers (Gackenbach, Snyder, Rokes, & Sachau, 1986) and gamers (Preston, 1998), improved spatial skills like spatial orientation and imagination (Gackenbach, & Bosveld, 1989), and spatial-analytic skills for lucid dreamers compared to nightmare and non-lucid dreamers (Spandafora, & Hunt, 1990). Especially field independence, the ability to use body references to place oneself in a visual field, has been repeatedly associated with the ability of LD (Gackenbach, Heilman, Boyt, & LaBerge, 1985; Galvin, 1990; Patrick, & Durndell, 2004; Stepansky et al., 1998; Wolpin, Marston, Randolph, & Clothies, 1992). On the other hand, two recent studies downplay the relationship between video game play and LD, showing miscellaneous results comparing the felt sense of presence in games versus dreams (Gackenbach & Rosie, 2011) and no association between gaming, dream bizarreness and dream lucidity (Gackenbach, Kuruvilla, Ferguson, Mathewson, & Darlington, 2014). In conclusion, some studies support Gackenbach's (2006) hypothesis that daytime exposure to virtual reality through electronic media is associated with nonverbal dream structure variables such as spatial skills and lucidity, whereas other studies have found no relationship. More effort is required to identify the exact effects of extensive video game playing on dream characteristics and LD.

6. Inducing lucidity

For inducing LD we have to differentiate between cognitive techniques, external stimuli, and other techniques like the intake of specific substances. Levitan (1990; 1991) and Levitan, LaBerge and Dole (1992) found two ways to start a lucid dream. First and most likely was the "dream-initiated lucid dream" (DILD), in which the dreamer acquires awareness of being in a dream while fully involved in it. In the second case, the "wake initiated lucid dreams" (WILD), the dreamer awakes from a dream and then returns to the dream state with unbroken awareness. Stumbrys, Erlacher, Schädlich, and Schredl (2012) revised the methodological quality of studies using cognitive techniques like mnemonic induced lucid dreams (MILD), reflection/reality testing, intention, autosuggestion, Tholey´s combined techniques, post-hypnotic suggestion, alpha feedback, dream re-entry and other eclectic approaches to induce LD. They showed that none of these induction techniques had been shown to induce lucid dreams reliably and consistently, although some like MILD, reflection/reality testing, intention, and Tholey´s combined techniques look promising. For external stimuli Stumbrys, Erlacher, Schädlich, and Schredl (2012) showed that studies using light stimuli were methodologically successful in several empirical studies to induce LD (LaBerge et. al. 1988; LaBerge & Levitan, 1995; Levitan & LaBerge, 1994; Paul, Schädlich, & Erlacher, 2014), whereas methods such as acoustic stimuli (Kueny, 1985; LaBerge et al. 1981; Ogilvie et al. 1983; Reis, 1989), vibro-tactile (Paul, Schädlich, & Erlacher, 2014; Reis, 1989), electro-tactile (Hearne, 1983b) and vestibular stimulation (Leslie & Ogilvie, 1996) showed some success, but the findings have not been replicated or are ambiguous, while a water stimulus was not successful at all (Hearne, 1983b). Other techniques like the application of Donepezil showed preliminary, but clear results (LaBerge, 2004) that have yet not been replicated. The Wake-up-Back-To-Bed method (WBTB; Erlacher, 2010), in which the subject goes back to bed and takes a nap after a certain period of awakening (e.g. 30–120 min) in the early morning hours, was used successfully in some studies to induce lucid dreams (Edelstein & LaBerge, 1992; LaBerge et al., 1994; Levitan, 1990, 1991; Levitan et al., 1992). Although WBTB was tested empirically in combination with MILD only, Stumbrys et al. (2012) argue that WBTB is a method for facilitating lucidity on its own, and may be successfully applied in combination with other induction techniques. Voss et al. (2014) recently found that transcranial direct current stimulation in the lower gamma band during REM sleep influences ongoing brain activity and induces lucidity in dreams. In a retrospective, single-case study Schredl (2013) analyzed a series of 8,420 dream reports of a young male over a span of twenty-three years and found increased LD frequency after a LD workshop and reality-check training, with LD frequency returning to baseline level after training was discontinued. More effort has to be made to investigate the long-term effects of different techniques for inducing lucid dreams.

7. Neural mechanisms involved in lucid dreaming

Recent studies on LD put LD in a position that „could move from its marginal and tenuous place at the fringe of psychophysiology to center stage in the emerging science of consciousness" (Hobson, 2009a). Using magnetic resonance imaging (MRI), Dresler et al. (2012) found markedly different regional activation patterns between LD and non-LD, with activation particularly increased in brain regions that distinguish humans from macaque monkeys. Thus, Hobson (2009a) concluded that this may reflect the activation pattern of the frontoparietal region that Vincent et al. (2007, 2008) suggested is the substrate of consciousness, because the brain activation pattern that underlies lucidity (Dresler et al., 2012) was found not only in frontal cortical areas, but also in parietal and temporal brain structures.

Two studies (Fosse, Fosse, Hobson, & Stickgold 2003; Stickgold, Malia, Maguire, Roddenberry, & O'Connor, 2000) suggest that episodic memories are not reactivated during dreaming as dream construction occurs without activation of hippocampus-mediated episodic memories; instead they show abstracted images of key elements of the waking events. Such an absence of episodic memory replay is supported by Maquet (2000) showing that the dorsolateral prefrontal cortex, normally involved in memory recall, is deactivated during sleep, especially REM sleep, which is also supported by animal studies suggesting that the hippocampus-to-cortex connection is blocked during REM sleep (Buzsáki, 1996).

As especially dorsolateral prefrontal reactivation during lucid drams could parallel activity during waking consciousness (Hobson et al., 2000; Muzur, Pace-Schott, & Hobson, 2002; Voss et al., 2009) it has recently been suggested that electrical brain stimulation of prefrontal areas may be a way to induce lucid dreams and alter the sense of presence and immersion in the dream state (Noreika et al., 2010).

Stumbrys, Erlacher and Schredl (2013) found preliminary evidence for the involvement of the dorsolateral prefrontal cortex (DLPFC) in LD. Transcranial direct current stimulation (tDCS) with 1 mA was applied during REM sleep to manipulate activation of the DLPFC in order to test if this stimulation increased dream lucidity. The participants' self-ratings indeed indicate an increased lucidity in dreams, but the effect was not strong and was only found in frequent lucid dreamers.

Using EEG, Voss et al. (2009) found increased phase synchrony and elevated frequency-specific activity in the gamma frequency band around 40 Hz in lucid dreams, especially in frontal and temporal areas, which are more active in the wake state than in REM sleep (Hobson & Voss, 2011). In an attempt to answer the question whether LD triggers gamma-band activity or vice versa, Voss et al. (2014) applied fronto-temporal transcranial alternating current stimulation (tACS) at various frequencies (2, 6, 12, 25, 40, 70 and 100 Hz) and under sham conditions in REM sleep. Based on subjective ratings, lucid dreams were most prominent during stimulation at 25 (58%) and 40 Hz (77%), providing evidence that tACS causes frequency-specific cortical oscillations in humans and altered conscious awareness during sleep as a direct consequence of these induced gamma-band oscillations. Gamma-band oscillations are normally assumed to be mediated by the activation of fast-spiking interneurons known to generate gamma oscillations in cortical networks (Brown et al., 2012, Cardin et al., 2009; Crick & Koch, 2003). Since lower gamma-band power was also present in the absence of LD, Voss et al. (2014) hypothesized that lower gamma-band stimulation enhances neuronal synchronization, thus settting the stage for lucidity in dreams.

Neider, Pace-Schott, Forselius, Pittman, & Morgan (2011) have argued that the ability to achieve lucidity during adolescence may be related to the degree to which frontal systems have become integrated and are able to receive coherent input from a variety of sources, including emotional information. Thus REM sleep, which is linked to normal emotional memory (Brown et al., 2012; Hu et al., 2006; Wagner et al., 2002) and is disrupted in emotional disorders (Mellman, 2006; Peterson & Benca, 2006), may contribute to the normal development of emotionally guided decision making during adolescence. Neider et al. (2011) found an association between performance on the Iowa Gambling Task and lucidity, which suggests that a connection between LD and ventromedial prefrontal function is potentially relevant to differences in the experience of metaawareness.

By measuring the correlation between frontal and occipital EEG patterns, Voss et al. (2009) demonstrated that subjects have more EEG coherence in the lucid dream state than in non-lucid dreaming, but less than in full waking. Hobson (2009a) concluded that dreaming results from posterior brain activation, whereas waking requires frontal activation as well. This puts lucidity in dreams in a position between these two states. Wake-initiated lucid dreams and the Wake-up-Back-To-Bed method for increasing lucid dream frequency (Erlacher, 2010), and increased LD in laboratory awakenings may thus lend support to the hypothesis that LD is usually “on the cusp of two states which are programmed to be all-or-none, winner take all, with ties improbable” (Hobson, 2009a). The likelihood of LD can only be increased by training in order to maintain this unstable and evanescent state. Neider et al. (2011) hypothesized that during sleep a generally greater intensity of activation in anterior paralimbic REM activation areas, such as the ventromedial prefrontal cortex (Nofzinger et al. 1997, 2004), may spread within densely interconnected prefrontal areas (Petrides & Pandya, 2002) to an extent sufficient to trigger awareness without exceeding waking thresholds.

8. Methodological concerns in lucid dream research

The first concern in assessing methodological issues in lucid dream research is that all the instruments used to assess lucid dreams (as for dreams in general) are more or less retrospective and based on subjective experiences that are difficult to control for incorrect recall. As Schredl (2002) pointed out, there are methodological issues to consider for backdating dream elements. Unlike some items on dream questionnaires, dream diaries or laboratory awakenings minimize biases due to inadequate memory. Bernstein and Belicki (1995) argued that questionnaire items are more valid measures for trait aspects of dream life than the content analysis of dream diaries or dreams from laboratory awakenings. Nevertheless, the intercorrelation between questionnaire items and diary data is often high (Baekeland, 1970; Belcher, Bone & Montgomery, 1972; Bernstein & Belicki, 1995; Schredl, 1998).

The second concern is that the measurement technique can affect the results. Several studies indicate that keeping a dream diary or laboratory awakenings can increase dream recall frequency (DRF) significantly (Cohen, 1969; Cohen & MacNeilage, 1974; Goodenough, Shapiro, Holden, & Steinschriber, 1959; Moffitt et al., 1982; Reed, 1978). Cohen (1969) maintained that low dream recallers tend to increase their DRF as a result of focusing on dreams, while high recallers cannot increase their DRF owing to a ceiling effect. If laboratory awakenings and keeping a dream diary increase the DRF for some participants, they may increase lucid dream frequencies as well, especially in a sample of lucid dreamers.

The third concern is to control the influence of mediator variables like DRF. Many studies have shown a strong correlation between LD and DRF (Doll, Gittler & Holzinger, 2009; Erlacher et al., 2008; Watson, 2001, Wolpin, Marston, Randolph & Clothier, 1992; Zink & Pietrowsky, 2013). Schredl and Erlacher (2004) found that DRF mediates between LD frequency and personality, since the correlation between LD and personality is reduced significantly once DRF is partialled out.

The definition of lucidity in dreams is the fourth concern. Whether to call a dream “lucid” or not in the analysis of dream diary content depends on how lucidity in dreams is defined. Definitions vary from simply becoming aware in a dream while dreaming (LaBerge, 1987) to additional criteria such as awareness of freedom of decision, memory of the waking state, and full intellectual abilities (Tholey & Utecht, 1997). As LaBerge and DeGracia (2000) pointed out, lucidity in dreams is not a dichotomous variable but rather a continuum from lucidity to non-lucidity. Different underlying definitions of LD might explain differing prevalence rates of lucid dreams, as discussed earlier.

9. Discussion

The present review served to present an overview of how LD might be explained on the basis of a number of theories of dreaming. Since none of the theories outlined is fully capable of explaining normal dreaming, none can explain LD. While dreaming is a specific form of consciousness, different from waking consciousness but without awareness of dreaming, LD differs in that it is associated with the knowledge of dreaming, and thus may be seen as an interplay between dreaming and waking, comparable to the hypnagogic state.

As far as the structural and biological processes of dreaming are concerned, the random activation theories are not suitable for explaining LD. In the context of reverse learning theory, which states that dreaming is a process to delete unwanted or unnecessary information from waking life, LD can be regarded as a specific form of this mechanism, in which this deletion process is under the partial control of consciousness. The AIM model (Hobson & Pace-Schott, 2002), which explains the different forms of consciousness (and thus also of dreaming) on the basis of the differential activation on three dimensions ((i) brain activation, (ii) origin of input to the activated area and (iii) the mode of activation of aminergic and cholinergic neuronal activity) can accommodate LD as one of the several patterns of possible states according to this model. LD thus is characterized by a brain activation related to wakefulness, with the inputs of this activation originating from the same sources as during dreaming and a mode of activation comparable to REM sleep. However, strictly speaking, this model is nothing more than a description of LD in terms of neurophysiological correlates. According to the continuity hypothesis of dreaming, lucidity reflects the ability of a person to easily access memory information stored during waking (La Berge & DeGracia, 2000). LD thus may be the result of easily accessible memory during waking and dreaming with the impression of conscious processing of memories while dreaming . The concept of "protoconsciousness" (Hobson, 2009b), a state supposed to develop early in ontogeny and to reflect an interplay between the dream and wake states, is the theory that best explains LD. It asserts that LD occurs if the integrative function of REM sleep does not fully operate and overlaps with components of secondary consciousness in the wake state. Thus, different features of dream state and wake state are combined into a hybrid state of consciousness. This assumption is also supported by recent neurophysiological findings, which suggest that there is a definable and measurable difference between LD, waking and REM sleep (Dresler et al., 2012).

With regard to the evolutionary and adaptive functions of dreams, LD can hardly be explained by the psychoanalytic theories. However, it may be assumed that in terms of Freud's theory of the dream as the guardian of sleep, LD may fulfill this role in anxiety provoking dreams in which the censorship function does not fully work and which would lead to awakening, so that lucidity may signal that it is a dream, thus to calm the sleeper and keep him asleep. Likewise, the costly signaling theory does not provide an explanation for LD during evolution. LD in terms of the sentinel function theory of dreams seems to be controversial. On the one hand, the awareness of dreaming appropriate adaptive reactions to dangerous situations may help the sleeper to cope with these situations when awakened. But on the other hand, the incorporation of (harmful) external signals into lucid dreams may prevent awakening and an adequate fight or flight reaction on the part of the sleeper.

The group of theories which suppose an adaptive function of dreaming with respect to problem solving, such as Hartmann's (1998) theory, the psychological healing theories, and the theory of simulation functions, while not proven, are more suited to explain the function of dreaming and lucid dreaming. In terms of Hartmann's theory, dreaming should help to establish new associative connections between stored memory nodes and thus aid awareness of these modes of problem solving and creativity. Likewise, the psychological healing theories, which assume that dreaming helps to adjust to current waking life stressors, can provide a convincing model of LD: Since, according to these theories, dreaming may help to adjust to stressful life events and psychological growth, the awareness of such mechanisms that may help to find these adjustments, and coping with such events in a dream may help to transfer these solutions to consciousness and waking life. The same holds for the theory of simulation functions, in particular the threat simulation function (Revonsuo, 2000), which assumes that dream experience is taken by the individual for simulating waking life experience with the aim of finding new or better solutions for real problems. This simulation function is comparable to playing, in which an experimental trial of possible coping strategies can be applied without appraisal or censorship. According to the theory of simulation functions, LD may – as for the psychological healing theories – enhance the adjusting effect of dreaming to cope with threatening situations, since the awareness of possible adjustments to these situations in dreams may help to transfer them to consciousness and thus to real life. In a similar vein, the assumption of Tholey (1990) that LD can be used to practice mental movements and facilitate sensory-motor learning, means that LD can be seen as an adaptive mechanism to learn new or complex sensory-motor sequences. Accordingly, procedural learning and memory, which is consolidated during REM sleep (Plihal & Born, 1997), should also be enhanced by LD. For example Erlacher et al. (2011) showed that 9% of an athlete sample, who reported having lucid dreams, used this dream state to practice sport skills and that that LD practice in sports has beneficial effects (Erlacher & Schredl, 2010).

New and promising insight into the nature of LD comes from recent neurophysiological research. First, patterns of cranial activation have been observed to differ between lucid and non-lucid dreaming, indicating that different psychophysiological processes are underlying lucid dreaming (Dresler et al., 2012). Second, transcranial electrical stimulation during REM sleep was shown to induce lucidity (Stumbrys et al., 2013; Voss et al. 2014). The later results indicate that LD can be induced in the future, with all the promising effects of this mode of consciousness. Based on these findings and current theories, it appears that dreaming (and protoconsciousness as an interplay between dreaming and waking) evolved because of three major selection pressures that are closely interrelated: preparedness (sentinel function and threat simulation function), adaptation (problem solving, creativity, social simulation, play function), and integration (psychological healing, resilience, learning; Figure 1). It can be argued that the adaptation functions like problem solving and creativity in dreams are evolutionary tools to prevent or alleviate stress, if they work adequately. Memory consolidation and integration in sleep is crucial for the ability to solve

Figure 1. Illustration of the closely interrelated processes that affected the development of dreaming by evolutionary selection pressures: preparedness (sentinel function and threat simulation function), adaptation (problem solving, creativity, social simulation, play function), and integration (psychological healing, resilience, learning).

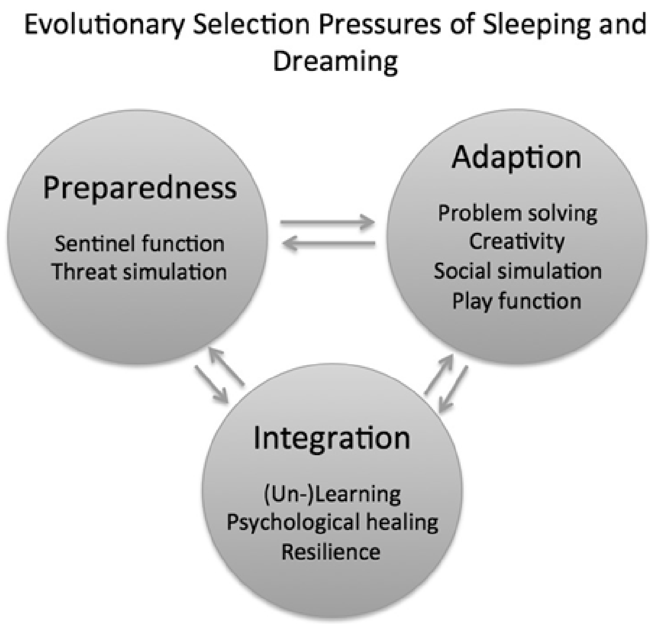
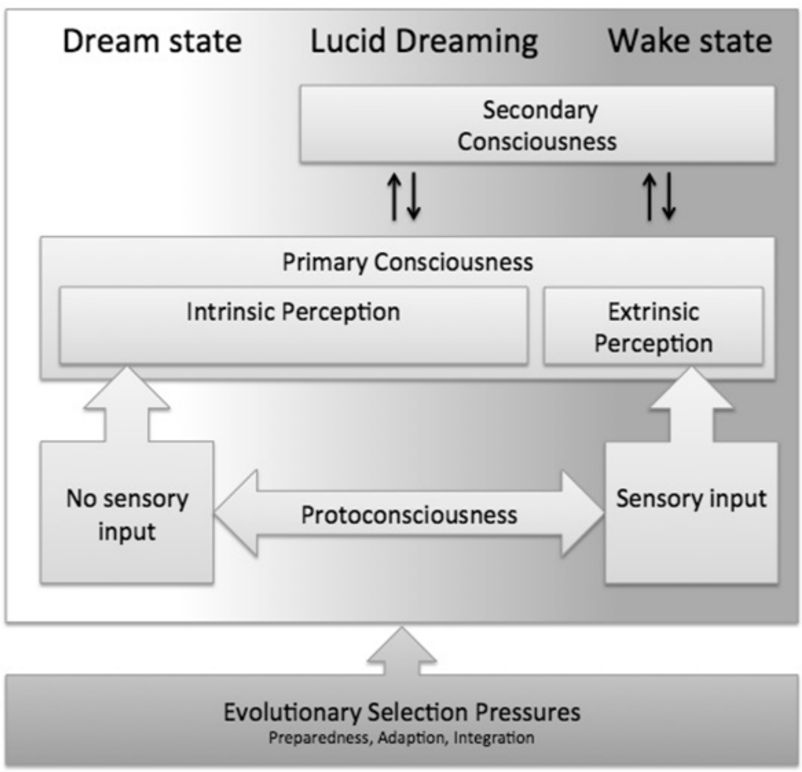


Figure 2. Schematic presentation of the supposed evolutionary selection pressures on the development of different forms of consciousness and different subsequent forms of dream and wake states. Protoconsciousness can be seen as a functional interplay between sleep and wake and precedes primary consciousness. In the wake state, primary consciousness is built predominantly extrinsically by external sensory input. In the dream state, where external sensory input is missing, primary consciousness is generated intrinsically by intrinsic perception (activation and synthesis of stored memories). In lucid dreams there is secondary consciousness like in the wake state but also intrinsic perception like in dream state.



problems, simulate interactions and find creative solutions in both sleep and dream states, which may also influence psychological healing and resilience. Integrating traumatic experiences into other memory networks while dreaming by simulating threats may also have a preparatory function, reminding the brain to avoid such situations.

Regardless, the question why people dream or whether dreams serve any function remains open. We state that protoconsciousness as a functional interplay between sleep and wake states precedes the development of primary consciousness which evolves first and is based primarily on perception and emotion, and expands until adulthood towards a secondary consciousness which contains self-reflective awareness of others (theory of mind), abstract thinking, volition and (inhibitory) control and metacognition (Flavell & Wellman, 1977). The main difference between dream state and wake state is that in the wake state primary consciousness is built extrinsically by perception via sensory input, whereas there is no sensory input in the dream state, therefore sensory input in dreaming has to be generated intrinsically. This difference in the perceptional properties of dreaming and waking puts lucidity in dreams between those states in so far, as there is secondary consciousness like in the wake state but also intrinsic perception, which is mostly self-generated (Figure 2).

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