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New perspectives for the study of lucid dreaming: From brain stimulation to philosophical theories of self-consciousness

Commentary on “The neurobiology of consciousness: Lucid dreaming wakes up” by J. Allan Hobson

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Summary. The neural mechanisms underlying lucid dreaming have recently been investigated using brain imaging techniques such as electroencephalography and functional magnetic resonance imaging, which produce insightful but merely correlative results. We propose that research on the neurophysiology of lucid dreaming, for instance concerning the exact relationship between the dorsolateral prefrontal cortex and metacognitive insight into the fact that one is dreaming, should be complemented by methods allowing direct causal interference with neural functioning during sleep. To achieve this aim, several stimulation methods are proposed, i.e. transcranial magnetic stimulation, transcranial direct current stimulation, and galvanic vestibular stimulation. Given the broad range of cognitive and metacognitive processing in dreams, which support a continuous view of lucid and nonlucid dreaming, we further propose that certain aspects of dream lucidity and its neural mechanisms can be investigated in so-called ordinary, nonlucid dreams. This would allow for phenomenologically more comprehensive and practically more efficient experiments in this field of dream research. Such experiments would also provide a solid ground for understanding self-consciousness in lucid and non-lucid dreams, as well as for integrating dream research into more general neurophilosophical theories of consciousness and the self.

Keywords: lucid dreaming, brain stimulation, self-consciousness, sleep

1. The prefrontal hypothesis of lucid dreaming

Dreaming is often described as a state of cognitive deficiency characterized by a loss of self-reflection, orientational instability regarding persons, times, and places, deficient short- and long-term memory, and a lack of control over volition and attention (Hobson, Pace-Schott & Stickgold, 2000). On the neurophysiological level of description, a plausible correlate of such cognitive deficiencies is the hypoactivation of the prefrontal areas during rapid eye movement (REM) sleep, which is the sleep stage in which the most vivid dreams occur (Hobson et al., 2000). Specifically, neuroimaging studies using positron emission tomography (PET) have shown that the dorsolateral prefrontal cortex (DLPFC), which is associated with executive abilities such as expectancy and working memory in wakefulness (Fuster, 2008), is selectively deactivated during REM sleep (Muzur, Pace-Schott, & Hobson, 2002; Maquet et al., 2005). This finding seems to fit in well with the common loss of self-reflective awareness and rational thought in dreams (Kahn, 2007). Nevertheless, even though early studies tended to emphasize the absence of cognition in the dream state (e.g., Rechtschaffen, 1978), it appears that the actual prevalence and quality of cognitive activity varies considerably in dreams (Meier, 1993; Kahn & Hobson, 2005). The most prominent example of wake-like cognition in nocturnal dreams is dream lucidity, which is characterized by heightened levels of cognitive clarity as well as by metacognitive insight into the hallucinatory nature of the dream state.

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Based on the hypothesized correlation between the selective deactivation of the DLPFC in REM sleep and the common attenuation of cognition and self-reflective awareness in the dream state, one would consequently also expect the degree of DLPFC activity to vary in proportion to varying degrees of cognitive and metacognitive activity in dreams. Such a hypothesis has been put forward by Allan Hobson and colleagues who suggested that dream lucidity might be related to a selective reactivation of DLPFC during REM sleep (Hobson et al., 2000; Kahn & Hobson, 2005). Though this suggestion was met with relative enthusiasm in recent years, it has remained highly speculative, as the original PET studies demonstrating DLPFC hypoactivity during REM sleep did not collect or analyze dream reports. Consequently, the correlation between reduced metacognition in nonlucid dreams and prefrontal hypoactivity has not been investigated directly, nor have existing imaging studies tried to relate metacognitive insight in lucid dreams to a selective reactivation of these areas.

In the latest update on lucid dream research, Hobson (2009) referred to several recent studies that do seem to provide evidence for a direct association between dream lucidity and cortical activation patterns. In arguably the most important empirical study on dreaming of the year, Voss, Holzmann, Tuin, and Hobson (2009) were able to demonstrate for the first time that lucid dreaming in trained participants is associated with increasing electroencephalography (EEG) gamma power over frontal regions during REM sleep. Furthermore, Hobson (2009) refers to preliminary functional magnetic resonance imaging (fMRI) data gathered by Dresler et al. (2009) showing that dream lucidity is related to a rather broad cortical network involving not only prefrontal but also temporal and occipital cortices. These findings are invaluable and we do not intend to downplay their cutting-edge importance for the field of lucid dream research; to the contrary, follow-up studies, specifically involving fMRI data from larger numbers of participants, are an important desideratum for future research on lucid dreaming. At the same time, a general problem of EEG, fMRI or PET is that they only allow for correlative statements about the brain regions involved in different kinds of mental processes such as perception, mental imagery and cognition. When a certain pattern of EEG or fMRI signal correlates with a cognitive function, or its retrospective report such as in dream studies, it is always possible that the observed activation is only an indirect correlate or even an epiphenomenon modulated by the actual neural mechanisms that may nonetheless remain undetected. Notably, this problem is not specific to lucid dream research, but is one of the main challenges in research focusing on the neural correlates of consciousness (Metzinger, 2000). In order to exclude such possibilities and go beyond a correlative investigation, we suggest that EEG, fMRI or PET studies of lucid dreaming should be complemented by methods allowing for a direct modulation of the excitability of specific cortical regions. This would potentially reveal the causal contribution of the involved brain areas to cognitive and metacognitive processing in dreams. Furthermore, we will argue that lucid dreaming does not present a state of consciousness or of the brain that is clearly distinguished from nonlucid dreaming. Instead, certain elements of dream lucidity can be investigated through the study of nonlucid dreams. The experiments proposed in the following sections would not only further the understanding of the neural mechanisms of dreaming, but also contribute to a more comprehensive theory of self-consciousness integrating findings from both standard wake states and nocturnal dreaming.

2. New electrophysiological tools for the study of lucid dreaming

In this section, we provide a brief review of several electrophysiological methods that can transiently inhibit or facilitate activity in the stimulated cortical or peripheral area, thus providing evidence for the causal role of specific brain regions in bringing about changes in cognitive processing. Furthermore, we discuss how each of these methods could contribute to neurophysiological research on lucid dreaming.

2.1. Transcranial magnetic stimulation

Barker, Jalinous, and Freeston (1985) introduced transcranial magnetic stimulation (TMS) as a neuroscience research tool able to focally and painlessly stimulate the cortex by creating a time-varying magnetic field. This localized, pulsed magnetic field over the surface of the head depolarizes underlying superficial neurons, thereby inducing electrical currents in the brain. When applied in a repetitive manner, TMS can also be used to modulate the excitability of the targeted cortical regions (Karim et al., 2003). Based on animal data, and depending on the stimulation frequency used, repetitive transcranial magnetic stimulation (rTMS) has been reported to induce long-term potentiation (LTP)-like or long-term depression (LTD)-like mechanisms, which can induce persistent effects on N-methyl-D-aspartate (NMDA) binding sites (Kole, Fuchs, Ziemann, Paulus, & Ebert, 1999). Several studies have convincingly shown that low-frequency rTMS (1 Hz or less) is capable of inhibiting the excitability of the motor cortex (Chen et al., 1997; Muellbacher, Ziemann, Boroojerdi, & Hallett, 2000), whereas high-frequency rTMS (5 Hz and more) is known to facilitate the excitability of the motor cortex (Pascual-Leone, Valls-Solé, Wassermann, & Hallett, 1994). Although the majority of TMS studies in the last decade were concerned with the motor system, there is current interest in TMS studies on higher cognitive functions such as working memory (Grafman & Wassermann, 1999; Sauseng et al., 2009), language (Mottaghy et al., 1999), visual functions (Boorojerdi, Prager, Muellbacher, & Cohen, 2000; Hilgetag, Théoret, & Pascual-Leone, 2001) and operant learning (Karim et al., 2003; Karim, Schüler, Hegner, Friedel, & Godde, 2006).

TMS has also been successfully applied during sleep (Massimini et al., 2005; 2007) as well as in studies assessing the neurophysiological effects of sleep deprivation (Manganotti, Palermo, Patuzzo, Zanette, & Fiaschi, 2001; Badawy, Curatolo, Newton, Berkovic, & Macdonell, 2006). In a combined TMS-EEG study, Massimini et al. (2005) delivered TMS pulses over the premotor area across the sleep-wake cycle and observed the same pattern of spreading EEG waves during wakefulness and REM sleep. In contrast, TMS pulses delivered during NREM sleep did not induce a propagation of response waves beyond the stimulation site. These findings suggest that effective connectivity, i.e. the ability of certain neuronal groups to affect the firing of other neuronal groups within a system, breaks down during NREM sleep, but not during REM sleep, which is typically characterized by long and vivid dreaming. In a follow-up study, Massimini et al. (2007) showed that NREM sleep-specific slow EEG waves and sleep spindles can be artificially evoked and enhanced by repetitive TMS pulses (0.8 Hz). These studies demonstrate the general feasibility of using TMS in sleep research.

Since high-frequency rTMS has been shown to increase cortical excitability, the prefrontal hypothesis of lucid dreaming (Hobson, 2009) could be directly tested by applying high-frequency rTMS over the DLPFC region during REM sleep. Afterwards, post-awakening dream reports following real stimulation (verum condition) and sham stimulation (placebo condition) could be compared, expecting to observe a higher rate of lucid dreams in the verum condition. Alternatively, the prefrontal hypothesis of lucid dreaming could be also tested by applying low-frequency rTMS over the DLPFC, which has been shown to inhibit cortical excitability (Karim et al., 2003; Chen et al., 1997). Participants previously trained to induce lucid dreams would be expected to report significantly reduced rates of lucid dreams after inhibiting the DLPFC compared to sham stimulation. Such results would confirm the direct involvement of the DLPFC in the generation of dream lucidity. Yet, due to the poor reliability of lucid dream induction techniques (for a review, see Price & Cohen, 1988), it is not clear that the latter possibility is feasible with lucid dreaming novices or even experienced lucid dreamers.

One of the main practical complications for the use of repetitive TMS during sleep is the auditory artefact produced by TMS coils, which might awaken the sleeping participant. Even though it is possible to develop auditory stimuli that would mask the sound produced by the TMS coil (Massimini et al., 2005), another artefact - rTMS induced tactile sensations over the scalp - is too difficult to mask, especially at higher stimulation intensities. Moreover, some participants might experience high-frequency rTMS over the prefrontal cortex as aversive or even painful. On the other hand, if the TMS-induced auditory and tactile sensations do not reach the awakening threshold and if low stimulation intensities are sufficient to modulate cortical excitability, the TMS-induced auditory and tactile sensations might be a useful reminder for the experienced participant that she is in a dream and thus may help her to become lucid. The effect may thus be similar to lucid-dream induction devices submitting a red light at the onset of REM sleep in order to remind the participant to become lucid (LaBerge & Levitan, 1995).

2.2. Transcranial direct current stimulation

Unlike TMS, transcranial direct current stimulation (tDCS) does not induce auditory artefacts, and the voltage needed to hold the current constant decreases after approximately 1 min and usually becomes subthreshold for evoking peripheral sensations. tDCS involves continuous administration of weak currents of ~1 mA through a pair of surface electrodes, cathode and anode, attached to the scalp (Nitsche & Paulus, 2000). Animal studies have shown that subthreshold DC stimulation decreases or completely inhibits spontaneous neuronal activity if the cathode is placed above or within the cortex, while anodal stimulation results in increased neuronal activity (Bindmann, Lippold, & Redfearn, 1964; Creutzfeldt, Fromm, & Kapp, 1962). This is caused by a subthreshold membrane hyperpolarisation induced by cathodal and a depolarization induced by anodal stimulation (Purpura & McMurtry, 1965). In human studies, it has been shown that cathodal stimulation reduces cortical excitability, whereas anodal stimulation increases cortical excitability. These effects have been observed in the motor (Nitsche & Paulus, 2000; Liebetanz, Nitsche, Tergau, & Paulus, 2002), visual (Antal et al., 2004), somatosensory (Rogalewski, Breitenstein, Nitsche, Paulus, & Knecht, 2004) and prefrontal cortices (Karim et al., 2010).

Marshall, Mölle, Hallschmid, and Born (2004) were the first to demonstrate that tDCS can also be reliably applied during sleep without waking up participants. The transcranial application of oscillating anodal potentials (0.75 Hz) over frontocortical areas during NREM sleep not only increased slow oscillations and spindle activity, but also improved declarative memory consolidation, which was measured by post-awakening recall of a list of words that had been given to the participants before sleep. In contrast, procedural memory of the mirror tracing task was not enhanced by tDCS during NREM sleep, while there was a significant improvement of mood after tDCS session sleep when compared to sham stimulation (Marshall, Helgadóttir, Mölle, & Born, 2006), showing that tDCS during sleep can be used to modulate not only cognitive but also emotional processing.

Since anodal tDCS has been shown to modulate cortical excitability, the prefrontal hypothesis of lucid dreaming (Hobson, 2009) could be directly tested by applying anodal tDCS over the DLPFC during REM sleep. Afterwards, dream reports collected following verum and placebo stimulation conditions could be contrasted, expecting to observe increased rates of lucidity in the verum condition, at least in experienced and previously trained lucid dreamers. Alternatively, lucid dreaming could be also investigated by applying cathodal tDCS over the DLPFC. In this case, experienced lucid dreamers should report significantly reduced rates of lucidity after inhibiting the DLPFC compared to sham stimulation. Once again, such tDCS induced effects would confirm the direct involvement of the DLPFC in the generation of dream lucidity. If so, given that DLPFC stimulation may have a therapeutic value for clinical populations (Loo, 2008), the modulation of dream cognition by tDCS might be of a special therapeutic relevance in the treatment of neuropsychiatric disorders (for a more elaborated discussion on the psychotherapeutic application of tDCS see the commentary of Karim (2010) in this issue).

Compared to the use of TMS in sleep studies, tDCS has the important advantage of being completely silent and easy to apply practically: the participant can sleep for the whole night in a separate room with tDCS electrodes attached on the scalp. In contrast, TMS requires an experimenter to be near the participant during stimulation, unless the head and the coil are completely immobilized, which might be a too harsh a requirement for prolonged sleep sessions. The main disadvantage of tDCS is its low spatial resolution, which however might be advantageous for stimulating such large areas as the DLPFC. Another possible complication is the relatively long period of time, i.e. 10-20 min, which is usually required to induce observable cognitive effects. During 20 min of stimulation, the participant might awaken spontaneously, causing the loss of data. Another important specificity of tDCS is the concurrent use of two electrodes. To induce lucidity, the anode should hypothetically be placed over the DLPFC, but where to attach the cathode is a more complicated question. Ideally, it should be placed over some large cortical area showing activation patterns negatively correlated with dream lucidity, i.e. the lower the neural activity would be in this region, the more likely it would be that the participant is dreaming lucidly. Yet, no such area has been detected and it is not at all clear if it exists. Alternatively, the cathode could be placed over some body part other than the head, but in these cases, special precautions should be taken to ensure that the electrode montage does not interfere with brainstem or heart functioning (Nitsche et al., 2003).

2.3. Galvanic vestibular stimulation

Galvanic vestibular stimulation (GVS) is an old and very simple stimulation technique (Day, 1999) that is based on similar principles as tDCS. A small current (usually 0.5-5mA) is applied between the mastoid processes in order to artificially change vestibular signalling. It is usually applied in a binaural bipolar configuration by placing a pair of electrodes on the left and right mastoid bones. The current flows between the electrodes increase the firing rate in vestibular afferents on the cathodal side and decrease the firing rate on the anodal side (Goldberg, Smith, & Fernández, 1984). This change is associated with illusory movements of both one's own body (Fitzpatrick, Marsden, Lord, & Day, 2002; Mars, Vercher, & Popov, 2005) and of the visual field (Zink, Bucher, Weiss, Brandt, & Dieterich, 1998) to the left or the right, depending on the electrode polarity. An important advantage of GVS as compared to other vestibular stimulation techniques such as natural or caloric stimulation is a very precise control of intensity and duration of the stimulation as well as the fact that the intensity of the electrical stimulation can be individually adapted for each participant (Lenggenhager, Lopez, & Blanke, 2008).

While early work focused mainly on the ocular and postural effects of GVS, more recent studies investigated its effects on neural processes (Fink et al., 2003) and higher cognition, such as the body schema (Stolbkov & Orlov, 2009), mental imagery (Lenggenhager et al., 2008) or face recognition (Wilkinson, Ko, Kilduff, McGlinchey, & Milberg, 2005). Within the line of this research, an important contribution of the vestibular system to bodily self-consciousness has been suggested (Lenggenhager, Smith, & Blanke, 2006). Patients with vestibular deficits have a high prevalence of depersonalization and derealization symptoms (Jáuregui-Renaud, Ramos-Toledo, Aguilar-Bolaños, Montaño-Velázquez, & Pliego-Maldonado, 2008). Furthermore, vestibular stimulation in healthy participants can induce transient symptoms of depersonalization and derealization (Sang, Jáuregui-Renaud, Green, Bronstein, & Gresty, 2006). Moreover, patients with disturbed bodily self-consciousness often experience vestibular symptoms at the same time (Blanke, Landis, Spinelli, & Seeck, 2004) and artificial vestibular stimulation has been shown to modify these disturbances; for example, body ownership was normalized in a patient with somatoparaphrenia (Bisiach, Rusconi, & Vallar, 1991) and phantom sensations in amputees or paraplegic patients have been altered through stimulation (Le Chapelain, Beis, Paysant, & André, 2001; André, Martinet, Paysant, Beis, & Le Chapelain, 2001). Even experimentally induced abnormal bodily self-consciousness in healthy participants could be altered by GVS (Lopez, Lenggenhager, & Blanke, 2010). This link is further supported and explained by neuroimaging data showing that artificial vestibular stimulation activates the temporo-parietal junction (Eickhoff, Weiss, Amunts, Fink, & Zilles, 2006), a region that has been shown to be importantly involved in multisensory integration and the construction of a stable self- and body representation. Presumably, as the temporo-parieto-occipital junction has also been implicated in dreaming (Solms, 2000), GVS stimulation during sleep might be expected to intensify dream experiences.

Several studies using different approaches have proposed a link between vestibular processes and dream lucidity. Flying dreams – which are presumably related to vestibular signalling – and lucid dreams have been shown to significantly correlate (Hunt, 1989). Gackenbach, Snyder, Rokes, and Sachau (1986) found a relationship between individual sensitivity to vestibular caloric stimulation and lucid dream frequency. A more direct influence of vestibular signalling was shown by Leslie and Ogilvie (1996), who found increased lucid mentation in participants sleeping in a rocking hammock. As fully lucid dreams are not only characterized by changes in cognitive processing as compared to nonlucid dreams, but by a number of other changes related to the consciously experienced dream self (see below), GVS might help investigate these other elements of lucid dreaming. It might thus provide a helpful contrast and comparison condition for stimulation studies of lucid dreaming targeting the prefrontal areas.

Apart from the interesting link between lucid dreaming and vestibular activity, we believe, based on the above-mentioned links, that GVS might also be a promising tool to investigate bodily awareness in dreams. Previous studies on the influence of vestibular processes on dreams have used natural vestibular stimulation such as a rocking hammock (Leslie & Ogilvie, 1996). However, these methods have several disadvantages (e.g. practical feasibility), confounding variables (e.g. somatosensory changes) and lack good control conditions (e.g., Leslie and Ogilvie (1996) compared rocking versus stable hammock). GVS allows to better control for these factors, as it directly stimulates the vestibular organ and sham stimulation on the neck can be applied.

3. Studying lucidity in non-lucid dreams

Lucid dreams are often contrasted with ordinary nonlucid dreams, assuming that these two types of dreaming are categorically distinct states of consciousness. On this view, nonlucid dreams can be described as a uniform state of cognitive deficiency, often also termed the single-mindedness of dreaming (Rechtschaffen, 1978). In contrast, lucid dreams are often held to differ from nonlucid dreams not just because the dreamer realizes that she is currently dreaming, but also because of the high, wake-like level of cognitive and mnemonic functioning. The study by Voss et al. (2009) explicitly assumes such a clear-cut distinction between lucid and nonlucid dreams by claiming that lucid dreaming is an instance of a state-dissociation, combining cognitive elements of waking consciousness with the hallucinatory quality of dreaming. This dissociation between two states of consciousness is matched by the dissociation of brain states, with lucid dreams being characterized by a higher degree of 40 Hz power in frontal regions than nonlucid dreams (see also Hobson, 2009).

This view of lucid and nonlucid dreaming as ultimately different conscious and brain states is questioned by findings that both lucid and nonlucid dreams in fact give rise to a wide range of cognitive and metacognitive activities. Several studies have shown that even in nonlucid dreams, cognitive activities such as speech and thought play a more prominent role than was previously believed (Meier, 1993; Kahan & LaBerge, 1994; Kahn & Hobson, 2005). Also, lucid dreams themselves more often than not provide examples of the erratic reasoning style usually thought to characterize nonlucid dreams. Often, even insight into the fact that one is dreaming is less than complete, and even experienced lucid dreamers often fail to successfully control their dreams with the intended results (Green & McCreery, 1994; Brooks & Vogelsong, 1999; Worsley, 1988; LaBerge & DeGracia, 2000). For this reason, it may be better to describe cognitive activity in dreams along a continuum, with stereotyped views of lucid and nonlucid dreaming occupying the extreme ends of the spectrum. This continuous view is strengthened by the very instability of the phenomenon of lucid dreaming. Insight into the dream state is often fleeting, and lucid dreams are often described as a balancing act between waking up and falling back into a nonlucid dream (LaBerge, 1985). Also, various types of prelucid dreams, in which dreamers wonder whether or not they are dreaming or become aware of the dreamlike, unreal quality of their dream without fully grasping this fact intellectually, support this continuous view. Generally, there is a close relationship between lucid dreams and other types of intense dreaming, including nightmares, dreams involving vestibular sensations such as flying or falling, false awakenings and prelucid dreams (for a detailed description of different types of prelucid dreams, see Brooks & Vogelsong, 1999). Such dreams often turn into lucid dreams, and frequent lucid dreamers also often report experiencing these other types of intense dreaming (Schönhammer, 2004; Gackenbach, 1988). Therefore, describing the fluctuations of cognitive and metacognitive activity across lucid and nonlucid dreams may be more fruitful than presuming these two types of dreaming to be clearly distinct.

Much of this question, of course, hinges on the problem of how to define lucid dreaming. While some authors define lucidity only in terms of the awareness that one is currently dreaming (Green, 1968; LaBerge, 1985; LaBerge & Gackenbach, 2000; Hobson 2009), proponents of strong definitions of lucid dreaming view lucidity as an all-pervading experiential phenomenon additionally characterized by full intellectual clarity, the availability of autobiographical memory sources, the ability to actively control the dream, as well as an overall increase in the intensity of multimodal hallucinatory imagery, which is often described as taking on a hyperreal quality (Tart, 1988; Tholey & Utecht, 1995; Metzinger, 2004, 2009). Such fully lucid dreams as are characterized by the latter type of definition certainly exist, but they may actually be quite rare compared to dreams in which lucid insight arises independently of additional factors and is only marked by the transient realization that one is currently dreaming (for details, see Windt & Metzinger, 2007). In any case, for studies targeting such strong forms of fully lucid dreams, one would also expect a clearer difference in terms of the neural correlates of lucidity, whereas for dreams characterized only by the fleeting realization that one is dreaming one would not expect such a robust deviation from the brain activity characteristic of nonlucid dreams. Thus, the questions of how to define lucid dreaming and of which dream reports to score as reports of lucid dreaming may have direct bearing on research results. For instance, Dresler et al.'s (2009) finding that lucidity involves not only frontal areas but also the bilateral cuneus and occipito-temporal cortices, which seem to overlap with the ventral stream of visual processing, seems to target fully lucid dreams of the former rather than of the latter type. Another point is that for methodological reasons, laboratory studies of lucid dreaming always target stronger forms of lucidity: at least studies focusing on signal-verified lucid dreams (SVLDs; see LaBerge, 1990; Voss et al. 2009; Erlacher & Schredl, 2008) always go beyond weak definitions of lucid dreams only in terms of metacognitive insight, as the ability to signal lucidity to the experimenter, i.e. by making a predetermined pattern of eye movements, already requires a certain degree of lucid dream control. Thus, there exists a confound in most laboratory studies of lucid dreaming between lucid insight and dream control, and such studies are better thought of as targeting a subgroup of lucid control dreams.

In describing the transition from nonlucid via prelucid to fully lucid and lucid control dreams, a number of potentially dissociable elements can be distinguished (see Table 1). To understand these distinctions, it is important to realize that a generalized concept of lucidity has to do with the availability of information concerning the overall representational nature of the system's current model of reality. What is special about the dream state, on the representational level of description, is that dreams arise largely independently of sensory inputs from the sleeping participant's current environment. They are misrepresentational, or simulate presence in a virtual environment. What is crucial, however, is how this information is made available, that is, under which functional form of access - attention or cognition - and under which representational format - subsymbolic or conceptual. According to the concept of lucidity discussed here, this information can become available when introspective attention is directed at the construction process that creates phenomenal representations. This factor can be called "A-lucidity" (for details on the different elements of lucidity introduced in this section, see Windt & Metzinger, 2007). A much stronger concept of lucidity, called "C-lucidity", involves the additional capacity to form mental concepts and engage in abstract thought: If we are C-lucid, we can cognitively ascribe the property of "lucidity" to ourselves, because we are not only introspectively aware of certain aspects of the construction process that brings the phenomenal contents about, but can also form a mental concept of ourselves as currently experiencing a lucid dream. It is empirically plausible to assume that this is something only human beings can do: Only rational creatures capable of self-directed concept formation can become C-lucid.

Weaker forms of lucid and prelucid dreaming arise when A-lucidity occurs in the absence of C-lucidity, or vice versa. In the former case, the dreamer may become aware of the virtual character of her current phenomenal world without actually being able to conceptualize her ongoing experience as a dream or have the thought that she is currently dreaming. In the latter case, the purely cognitive realization that she is currently dreaming occurs independently of or prior to a corresponding shift on the level of phenomenal experience. This type of C-lucidity without concomitant A-lucidity can also occur in wakefulness: whenever you think about what it means that conscious experience as a whole is a simulation created by your brain - just as you may be doing right now, at this very moment - you can become C-lucid. Nonetheless, your perceptual experience of the world does not change or suddenly lose its realistic quality: you cannot think yourself into a state of A-lucidity, at least not in standard wake states.

Other potentially dissociable factors of fully lucid dreams include lucid behaviour and emotional lucidity. The former is the case if the virtual character of the dream is available on the level of behaviour. This involves the ability to engage

Table 1. Dissociable elements of lucid and prelucid dreams

Lucidity types	Functional level of description	Phenomenal level of description
A-lucidity (prelucid; lucid if combined with C-lucidity)	The virtual character of the dream is available to attentional processing.	Imagery related to the dream world and/or the dream self takes on a dreamlike quality; the dream is experienced as a merely virtual simulation of a world and/or a self.
B-lucidity (prelucid; lucid if combined with C-lucidity)	The virtual character of the dream is available to behavioural control.	Dream behaviour no longer conforms to the natural laws of the waking world, but is appropriate to the dream state; if the dreamer is also C-lucid, she is able to engage in deliberate dream control.
E-lucidity (prelucid; lucid if combined with C-lucidity)	The virtual character of the dream is available to emotional processing.	Emotional reactions to dream events differ from the emotions that would be expected if the same events occurred during wakefulness; dream emotions are appropriate to the virtual character of the dream state.
C-lucidity (minimal requirement for scoring a dream report as lucid rather than prelucid)	The virtual character of the dream is available to cognition.	The dreamer knows that she is dreaming and is able to intellectually grasp the consequences of this fact.
Full lucidity: A-, B-, C- and E-lucidity	The virtual character of the dream is available to attention, behaviour, emotion and cognition.	The dreamer not only knows that she is dreaming, but also experiences the dream as unreal; behavioural and emotional reactions are appropriate to the dream state and the dreamer is able to engage in deliberate dream control.

in deliberate dream control - such as changing the setting, objects or other dream characters, or deliberately directing the dream plot. Interestingly, these types of lucid behaviour occasionally occur in otherwise nonlucid dreams, in which the dreamer is not explicitly aware of the fact that she is dreaming. Dreamers may even start carrying out previously planned dream experiments without explicitly remembering that they went to sleep with the intention of doing so (Brooks & Vogelsong, 1999). Such dreams can possibly be described as "B-lucid" dreams, in which lucid behaviour arises independently of metacognitive insight. In the latter case of emotional or "E-lucidity", the virtual character of the dream is available to emotional processing. Here, dream events do not induce the emotional reactions that would be appropriate if the same events occurred during wakefulness; instead, emotions are appropriate to the fact that one is dreaming. An example would be the absence of fear reactions to an attacking dream monster, which might suggest, once more, that the merely virtual nature of the threat was emotionally, though not necessarily cognitively, available.

Such distinctions show that full-fledged lucidity is a complex and graded phenomenon and may be helpful in understanding not only those dreams traditionally regarded as lucid, but also prelucid and nonlucid dreams. It should be pointed out, however, that for methodological reasons, C-lucidity is a minimal condition for dream lucidity: unless the dreamer reports having been cognitively aware of the fact that she was dreaming, it will be impossible to score a given dream report as a lucid dream report. A-, B- and E-lucidity are important elements of full-fledged lucidity, but they are neither necessary nor sufficient for knowing that one is dreaming. In keeping with existing weak and strong definitions of lucidity, which converge on metacognitive insight as a defining feature of lucid dreaming, A-, B- and E-lucidity without C-lucidity are better considered as forms of prelucid dreaming. Moreover, such weaker degrees of lucidity or prelucidity seem to comprise the bulk of lucid dreaming, and fully lucid dreams involving all four of these elements might constitute a "hypothetical maximum" (Malamud, 1988; Brooks & Vogelsong, 1999).

Finally, in view of what is known about the role of the DLPFC in waking cognition, it is plausible that a relatively mild reactivation of the DLPFC during REM sleep, naturally or experimentally induced via brain stimulation techniques, would be associated with cognitive activity in dreams in general and increasing metacognition associated with dream lucidity and prelucidity in particular. Moreover, metacognition, or thinking about one's own mental states and behaviour, is not completely absent in nonlucid dreams. What is missing here is only the particular type of metacognition that allows the dreamer to realize that she is dreaming rather than awake. Consequently, the neurophysiology of the different elements of lucidity can be studied in so-called ordinary and pre-lucid dreams as well. In such experiments, the level of lucidity and metacognition in dreams, but also instances of lucid behaviour, emotional lucidity and changes in the intensity of imagery or their realistic quality (A-lucidity) can be measured in questionnaires assessing the lucidity continuum, such as the Dream Lucidity Questionnaire (Voss et al., in preparation). This would also increase the feasibility of performing such studies, as they could be more easily performed with larger numbers of dreamers. Thus, the difficulty of finding reliable lucid dreamers could be minimized by concentrating on cognitive processes, as well as on other elements contributing to lucidity, in nonlucid dreams as well. This might nonetheless help understand C-lucidity as the crucial factor in mediating the explicit realization that one is currently dreaming. On the other hand, as pointed out above, studies investigating full-fledged, signal-verified lucid dreams should better be regarded as targeting a specific subgroup of lucid control dreams, which are not only C-lucid, but also B-lucid as well as, possibly, A- and E-lucid. Investigating the relationship between these different factors of full-fledged lucidity, such as by manipulating the intensity of TMS, tDCS, and GVS stimulation during sleep, thus gives rise to important perspectives for future lucid dream research and enables a more fine-grained and differentiated analysis of this phenomenon.

4. Lucid dreaming and consciousness research

Beyond their interest for dream research, lucid dreams also offer new perspectives for consciousness research and specifically for understanding self-consciousness. As Hobson (2009) points out, nonlucid dreams show that primary consciousness, including sensory imagery and the experience of a self interacting with the dream world, is not specific to the wake state, but can be decoupled from sensory inputs and motor outputs. Lucid dreams also provide rich examples of secondary consciousness, and specifically of more sophisticated cognitive and metacognitive processes occurring in sleep.

One way of understanding the differences between lucid and nonlucid dreams is by relating them to different levels of self-related processing (for details, see Metzinger, 2004, 2009; Windt & Metzinger, 2007). Most contemporary philosophers working on dreams (see for instance Metzinger, 2004, 2009; Revonsuo, 2006; Ichikawa, 2009) agree that nonlucid dreams are conscious experiences because they are phenomenal states: there is something it is like to dream, and (contra Malcolm 1956, 1959; Dennett, 1976) dreams give rise to consciously experienced imagery during sleep. According to the self-model theory of subjectivity (Metzinger, 2004), however, most nonlucid dreams lack important layers of waking self-consciousness and thus should only be regarded as subjective experiences in a conceptually weak sense. The failure of nonlucid dreamers to realize that they are currently dreaming - the so-called metacognitive deficit - is closely related to the fact that the first-person perspective is highly unstable in nonlucid dreams. Consequently, nonlucid dreamers are unable to form a conscious model of their current relation to the consciously experienced dream world. Without such a stable first-person perspective, they not only fail to realize that they are dreaming, but are also typically unable to direct attention and cognition at their own thoughts, emotions and behaviour. To the extent that even nonlucid dreams occasionally provide instances of cognition and metacognition, this requires, in keeping with the self-model theory of subjectivity, at least a partial stabilization of the first-person perspective. Nonetheless, as nonlucid dreamers by definition fail to realize that they are currently dreaming, this also means that they lack the type of stable first-person perspective that would allow them to cognitively grasp their relation to the dream world and thus become lucid. Moreover, the characteristic disorientation, confabulatory and erratic reasoning style and spontaneous, uncontrolled behaviour of stereotypical nonlucid dreamers is symptomatic of a reduced sense of agency: the stereotypical, cognitively impaired nonlucid dreamer does not deliberately control the direction of attention, her thoughts or even her behaviour in the dream state. While she may nonetheless experience herself as the author of her thoughts and actions, she lacks an important aspect of the phenomenal experience of agency, i.e. the experience of engaging in such deliberate control. At the same time, the property of agency is also not fully instantiated on the functional level of description. Finally, both the common deficiency of short- and long-term memory within the dream state and frequent dream amnesia after awakening also mean that most nonlucid dreams are only weakly integrated with autobiographical and narrative layers of self-related processing. As always, there are exceptions. For instance, false awakenings, or realistic dreams of waking up, are a good counter-example and show a strong degree of coherence with the narrative self experienced in wakefulness (for details, see Windt & Metzinger, 2007). But for the majority of nonlucid dreams, such a strong degree of integration with autobiographical memory sources is lacking. In sum, the theory predicts that at least stereotypical nonlucid dreams are only subjective experiences in a conceptually weak sense related to the first-person perspective, agency and the narrative self. Again, the contrast between lucid and nonlucid dreams should be considered as continuous rather than exclusive, and the degree to which a given nonlucid dream should be considered as a subjective experience will depend on the degree to which the phenomenal-functional properties of agency and the first-person perspective are instantiated and on its integration with the narrative self experienced in standard wakefulness.

Keeping these exceptions in mind, fully lucid dreams nonetheless afford a vastly different interpretation in terms of self-consciousness. Lucid dreamers, especially in lucid control dreams, are attentional, cognitive and behavioural agents in a much stronger sense, related both to the phenomenology of agency and its functional profile. Again, this is related to a stable first-person perspective and the ability to form a conscious cognitive model of one's current relation to the dream world, enabling both the insight that one is currently dreaming and the ability to engage in dream control. At least in fully lucid dreams, mnemonic processing is also enhanced: fully lucid dreamers can typically remember facts about their waking lives and also report being able to remember their lucid dreams more easily than their nonlucid ones. All of these factors support the view that fully lucid dreams are subjective experiences in a stronger sense than most nonlucid ones, in some cases even approaching the type of self-consciousness characteristic of standard wakefulness.

For consciousness research, this suggests that lucid dreams and their comparison with nonlucid dreams afford a unique opportunity for the study of self-consciousness. Conceptual analysis of these phenomena can afford rich theoretical insights and prove informative for theories of self-consciousness, for instances by revealing the degree to which these different layers of self-consciousness are dissociable. By investigating the transition from nonlucid to lucid dreams, for instance through the analysis of dream reports or the Dream Lucidity Questionnaire (Voss et al., in preparation), one can chart the changes in self-related processing that enable this transition as well as, in neuroimaging experiments, their neural correlates. In addition, the perspective of experimentally manipulating and inducing lucid dreams means that the neurofunctional profile of certain aspects of self-consciousness can be made experimentally tractable. This is not just true for cognitive and mnemonic processes, but also, for instance, for bodily experiences. As Hobson (2009) and Erlacher and Schredl (2008) suggest, lucid dreams may help discern the neural correlates of dream behaviour and answer the question of whether bodily experiences and dream behaviour are similar to their waking counterparts not only phenomenally, but also in terms of underlying brain activation. Finally, the experimental manipulation of dream content and induction of lucid dreams may also help investigate the neural correlates of the sense of agency, the first-person perspective and the narrative or autobiographical self-model and thus may help operationalize such theoretical concepts in the laboratory.

5. A concluding call for a network of lucid dream researchers

In this section, we would like to draw attention to the rather symptomatic and worrying pattern that most existing research on lucid dreaming suffers from various methodological problems. Due to the practical difficulties involved in finding and training participants who would frequently reach lucidity in the unfamiliar, uncomfortable and relatively hostile sleep laboratory environment, most published studies do not go beyond case or case-series reports, preventing more complex statistical analyses that require larger participant samples. Consequently, it is often very difficult to estimate whether certain results can be replicated and whether they can be generalized to the general population. Another common problem is that lucid dream researchers themselves often take part in their own experiments as research participants. Such a practice is welcomed and helpful during pilot stages of research projects, but it brings unnecessary confounding variables and biases during actual experiments, especially when the number of participants is very low.

Arguably, most of these problems could be avoided by simply increasing study samples. However, as such a simple solution is practically very difficult to implement, we believe that for the successful development of this exciting branch of research, a closer collaboration between researchers is essential, which would help organize multicentre-studies with shared participant groups. Ideally, each participating centre would develop and pilot some new laboratory tasks and paradigms, which could later be provided to participants of ongoing lucid dreaming studies in other collaborating centres. If well organized, such a network could boost the quality and impact of research on lucid dreaming, as well as its integration with consciousness research. We hope that through the ongoing discussions in the International Journal of Dream Research and other well-guided initiatives, the formation of such a network will be made possible in the near future.

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