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Neural Correlates of Lucid Dreams:

The Role of Metacognition and Volition

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Abstract

Dreams play an important role in consciousness studies, because of their ubiquitous presence but ambiguous nature. Dreams can be divided into two categories: non-lucid dreams and lucid dreams (i.e., dreams in which the dreamer knows he is dreaming). Lucid dreams are experiences with features of both waking and dreaming consciousness. In this essay, I review the differences in neural correlates between non-lucid dreams and lucid dreams. While both types of dreams share similar neural substrates, lucid dreams are especially accompanied by more activation in prefrontal areas. These areas are known to be involved in functions of secondary consciousness such as metacognition and volition. These findings are also echoed by verbal reports from lucid dreams. While the relationship metacognition and volition and lucid dreams is not yet fully clear, it seems that increased activation of metacognition and volition cause the dreamer to realize he is dreaming. Based on previous literature, I offer a conceptualization of dreams, in which a continuous variable, lucidity, can measure the degree to which metacognition and volition vary across dream types. I suggest that the transition between non-lucid and lucid dreams is a two-step process. The implications of this are discussed.

Keywords: lucid dreams, non-lucid dreams, metacognition, volition, consciousness

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Neural Correlates of Lucid Dreams: Investigating the Role of Metacognition and Volition in Dreams

The term *lucid dream* (LD) comes from Frederik van Eeden (1913). A LD is a dream in which the dreamer knows that he is awake. Long before LDs got its name in the early 20th century, it was practiced in Tibetan Buddhism as a form of yoga which the monks referred to as dream yoga. The practice of dream yoga in Tibet went back so far as the eighth century (Holzinger, 2009). Dream yoga was used in order to preserve a clear state of consciousness during the dreaming states. The dream yogis thought that if consciousness could be maintained during sleep it could outlive the body and move into the afterlife. The monks thought they could escape Karma in the face of death, by constantly practicing to have mental clarity and focused thoughts both in dreams and during wakefulness. They also saw the possibility to investigate the subjective aspects of the dreaming state, which in turn would reveal much about the waking state. For these reasons dream yoga was highly valued in Tibet and the yogis encouraged everyone to benefit from practicing it. The yogis' understanding of the phenomenon was by no means trivial. They understood that dreams were a creation of the mind and that dreams could be probed and cultivated in a somewhat experimental way. This was a very sophisticated way of looking at dreams considering that it was during the eighth century (Holzinger, 2009).

LDs have in modern research been conceptualized as a mysterious state in between wakefulness and dreaming (Voss, Holzmann, Tuin, & Hobson, 2009). Although many people might not be familiar with the term, studies estimate that about 50% of the population has had at least one LD during their lives and about 20% have at least one LD on a monthly basis (Erlacher, Stumbrys, &Schredl, 2012; Schredl & Erlacher, 2011; Snyder & Gackenbach, 1988). Similar results were found in recent meta-analysis (Saunders, Roe, Smith, & Clegg,

2016) that used instruments which have been shown to have a very high test-retest reliability on the individual level (r = .89) (Stumbrys, Erlacher, & Schredl, 2013a).

After lucid dreams were first measured objectively in a sleep laboratory (Hearne, 1978), they have been utilized in a number of ways. Probably the most characteristic use of LDs is by treating recurring nightmares (Spoormaker & van den Bout, 2006; Zadra & Pihl, 1997). Apart from using LD as a clinical tool, it has also been used as a virtual training room for professional athletes (Erlacher et al., 2012). For example, when asking a group of German athletes about their experiences with LDs, 9% had used LDs in order to practice their sports and reported that their performance had improved.

While the reports of improved athletic performance are anecdotal, other studies have more specifically targeted LDs as a virtual room for practice. Erlacher and Schredl (2010) reported that practicing a coin tossing task in LDs had a significant improvement on subsequent trials during wakefulness, when compared to controls. Recently, similar results of mental practice within LDs were found while using a finger-tapping task (Stumbrys, Erlacher, & Schredl, 2016). Accordingly, researchers have speculated about the potential benefits from LDs for rehabilitation purposes. Stumbrys and Daniels (2010) found that LDs has some potential benefits for solving creative problems, but, when it comes to arithmetic problems, the usability seems to be very poor (Stumbrys & Daniels, 2010; Stumbrys, Erlacher, & Schmidt, 2011).

Today, LD is getting more and more attention in the scientific community, not just in the research on dreams but also in the study of consciousness. Many researchers have stressed the potential in utilizing LDs as a way of investigating the nature of consciousness itself (Hobson, 2009a; Voss et al., 2009). Additionally, Revonsuo writes (2009) that “A complete theory of consciousness should also explain or predict in detail what happens to consciousness under exceptional circumstances, such as different types of brain injury or during dreaming, anesthesia, out-of-body experiences and near-death experiences" (p.176).

The aim of this thesis is to review the neuroscientific literature on LDs, both empirical and theoretical. A second focus are of two higher order cognitive functions, volition and metacognition, that are present during LDs and how they relate to consciousness. First, brief descriptions of core concepts are presented, which includes differentiating between concepts such as non-lucid dreams (NLDs), LDs, and metacognitive concepts relevant for this essay. Second, a review of the literature on NLDs will be presented as research on LDs is derived from research on NLDs. Third, research on LDs is presented. Fourth, three main themes from the reviewed research are discussed and conclusions are drawn about the future of the science of LDs, especially in relation to two recent studies (Voss et al., 2013; 2014).

Background

What are Dreams?

What is a non-lucid dream? There are many definitions of dreams and most of them seem to overlap to a great degree. Thus, a suitable definition for this thesis is that by Revonsuo (2009), who writes that "dreaming involves complex, organized and animated imagery in multiple sensory modalities that shows progression and change through time" (p. 241). Considering that the term "dream" is an umbrella term that includes all sorts of dream experiences, the distinction between NLDs and LDs need explanation. NLDs are dreams in which the subject lacks insight into the fact that the ongoing experience is a dream. LDs are dreams in which the subject has insight into the fact that the ongoing experience is a dream (Voss et al., 2014). Therefore, NLDs and LDs are, on this aspect, considered to be two qualitatively different concepts.

More or less all contemporary theories of dreams acknowledge the subjective experience of the dreamer, and while e.g. Hobson argues that dreaming is just random internal activation with no function, acting merely as an epiphenomenon of sleep (Hobson, 2009b), others consider dreams to have an evolutionary function (Revonsuo, 2000). Regardless of the underlying purpose of dream experiences, this essay acknowledges that subjective dream experiences are real and can be studied using scientific methods (Windt, 2015).

What is a lucid dream? Although there are different opinions on what constitutes a LD (Windt, 2015), a common description is the following. A LD is a dream in which the dreamer achieves conscious awareness of the fact that the dreamer is dreaming, while remaining asleep (Hobson, 2009a; Voss et al., 2009). Before the 1970s, when LD was first objectively measured (Hearne, 1978; LaBerge, Nagel, Dement, & Zarcone Jr., 1981), lucid dreaming was met with skepticism due to the fact that being consciously aware during sleep seemed paradoxical (Windt, 2015).

Although LDs can take place during NREM sleep (Stumbrys & Erlacher, 2012), they have been studied more in relation to rapid eye movement (REM) sleep which is a stage during sleep known for muscle atonia, dreams, and rapid eye movements. Recent research has shown LDs to be something of a hybrid state in-between REM sleep and wakefulness (Voss et al., 2014). This conclusion is drawn from the fact that frontal lobe, which is very active in wakefulness but less so in non-lucid REM sleep, becomes reactivated. In the last couple of years in dream science, several researchers recognized the role that LDs could play in investigating consciousness (Hobson, 2009a, 2009b; Voss et al., 2014; Voss, Schermelleh-Engel, Windt, Frenzel, & Hobson, 2013) and in addition it can be said that no theory of consciousness is complete if lacking an explanation of dreams (Revonsuo, 2009), which necessarily includes an explanation of LDs.

Some researchers use a definition similar to that of van Eeden (1913) – arguing that both insight of the fact that the ongoing experience is a dream and control of the dream are necessary and sufficient conditions (Holzinger, LaBerge, & Levitan, 2006) – while others consider only the former condition to be sufficient (Windt & Metzinger, 2007). Accordingly, scientists are not entirely in agreement about the constituent criteria underlying LDs. Until future research shows which cognitive functions are necessary for LDs, this question will remain open.

Secondary Consciousness

Concepts of human consciousness can be divided and categorized in a number of different ways. The distinction most referred to in LD research is that between primary and secondary consciousness (Edelman, 2005)[1]. Primary consciousness includes simple awareness with emotion and perception while secondary consciousness includes self-reflective awareness, abstract thinking, volition, and metacognition (Hobson, 2009b).

Secondary consciousness is regarded as being dependent upon language which is why most animals are only considered to have primary consciousness (Voss et al., 2014). Although human beings have the capacity for language, it seems that in NLDs this secondary consciousness is to a large degree absent, even though language in itself might still be present (Voss et al., 2013). There seems to be a consensus between the most cited researchers in LD research that three concepts – self-reflective awareness, metacognition, and volition – play a major role in the transition between NLDs to LDs (Voss et al., 2014; Dresler et al., 2012; Noreika, Windt, & Lenggenhager, & Karim, 2010; Hobson, 2009a). Self-reflective awareness (i.e., awareness of one's ongoing thoughts emotions, or actions; Kahan & LaBerge, 2011) seems to be more contemplative in nature while volition (i.e., the ability to produce voluntary actions; Brass & Haggard, 2007; Dresler et al., 2014; Haggard, 2008) and metacognition (i.e., the ability to know, report, or control one's ongoing cognitive performance; Fleming & Dolan, 2012; Kahan & LaBerge, 2011; Shimamura, 2000) are more action-oriented. Although previous LD studies usually feature the three above mentioned concepts, I choose to limit

[1]Apart from primary vs. secondary consciousness (Edelman, 2005), phenomenal consciousness vs. access consciousness (Block, 1996) is a popular conceptual categorization of consciousness.

myself to the more action-oriented concepts volition and metacognition, as they are arguably more easily objectively measured.

What is metacognition? Metacognition has also been defined in many ways. John Flavell (1979) defined metacognition as knowledge and cognition about cognitive phenomena[2]. Metacognition is a widely used term in psychology and neuroscience but there is still some confusion about which functions it refers to. One reason for this is that terms like self-regulation or executive control are often used interchangeably with metacognition. Although there might be discrepancies between these concepts, they all agree that metacognition refers to overseeing and regulating cognitive processes such as e.g. memory, learning etc. (Livingston, 2003; Papleontiou-Louca, 2003). In sum, cognitive functions that are overseeing, regulating, or controlling other ongoing cognitive functions will fall under the term metacognition.

One frequently studied metacognitive function is metacognitive monitoring. Metacognitive monitoring, works in the following way: As a person is learning something he simultaneously evaluates his ongoing progress, that is whether his learning is successful or not. In this example there are two levels of information processing, an object-level and a meta-level. The object-level processes the material to be learnt while the meta-level is processing the success rate of the learning in itself. This example of metacognitive monitoring shows that metacognition is a second order cognitive function superimposed on another cognitive function (Fleming & Dolan, 2012; Nelson, Narens, & Bower, 1990; Shimamura, 2000).

In the example above, metacognition is retrospective since it bases the judgment of learning (JOL) on information flow in the recent past. Metacognition can also be prospective. For example, feelings of knowing (FOK) is a term used for knowing that one has information

[2] While Flavell (1979) is the most frequently used definition in the literature, other, similar conceptualizations of metacognition also exist (e.g., Kahan and LaBerge, 2011; Wells & Cartwright-Hatton, 2004; Shimamura, 2000).

stored about a certain subject while not having access to it at that moment. FOK is in everyday language known as tip-of-the-tongue knowledge, and this knowledge often becomes accessible at some later stage (Fleming & Dolan, 2012). Metacognitive accuracy is how well JOL or FOK are either depicting or predicting one's actual object level performance. In other words, how objective a subjective report of the state of the world is. This metacognitive accuracy is important in relation to LDs for two reasons. First, it indicates how accurate subjects are in depicting their dream experiences. Second, a subject's ability in metacognitive accuracy may also reflect his or her ability to achieve lucidity in dreams. To have a LD one must identify the true nature of the dream. In the transition from NLDs to LDs, being skillful in metacognitive accuracy may give an advantage.

What is volition? Volition, or will, is best defined as deciding to engage oneself in a particular behavior or activity (Dijksterhuis & Aarts, 2010). Volition has been closely linked to consciousness as the ability to act freely upon one's own will is considered to be a trait only humans possess. Further, it is a crucial process in attaining one's future goals and hence an important aspect of how people define themselves as individuals.

As a concept, volition can be divided into three components; whether or not to perform an action, what action to perform, and when to perform it (Haggard, 2008). A good way of distinguishing voluntary actions from non-voluntary actions is by contrasting the former to reflexes (e.g. stretching out one's leg as opposed to a knee jerk reaction). A voluntary action has two subjective components that reflexes lack; intention and agency. Intention can be defined as either planning to execute an act or the feeling just before consciously performing an act. Agency focuses more on the connected feeling between the person and the external events caused by the action. For example, one might intend to flip a light switch and when the room lights up the feeling of having caused the change in external events is termed agency (Haggard, 2008). LDs with control are often described by subjects to have a strong sense of volition as opposed to NLDs where the subjects' actions lack this sort of intention.

As the reader has probably noted, there are many degrees of freedom in the concepts outlined above. This is, in part, because dream research currently does not share a common conceptual framework, although proposals have recently been put forward (Windt, 2015). Please note that the concepts outlined above are not always uniformly used in the research literature.

Non-Lucid Dreams

In this section, research on NLDs will be presented. This includes a brief walkthrough of the history of NLDs, research on phenomenology and finally neural correlates of NLDs. Most of the research on neural correlates of dreams is based on the assumption that awakenings following REM sleep will yield dream reports. Therefore, some of the studies have included timed awakenings from REM sleep followed by dream reports, while others have only investigated REM sleep. The data included in the following section comes from studies of both sorts and assumes what is mentioned above. Further, although dreams have been shown to occur during NREM sleep stages as well (Stumbrys & Erlacher, 2012); this section will only include research on REM sleep, because lucid dreams seem to be almost exclusively a REM phenomenon.

History of Non-Lucid Dreams

Arguably the first person who studied dreams as a naturalistic phenomenon was Aristotle. Aristotle looked at sleep as a way for the body to rest and prepare for wakefulness in a continuous cycle where sleep and wakefulness were mutually exclusive. Aristotle defined sleep roughly by behavioral measures; absent motor output and sensory input. He claimed that the phenomenological aspects of dreams were hallucinatory, coming from residual activity in our sensory organs which during wakefulness mediated information about the outside world (Windt, 2015).

In 1953 using electroencephalography (EEG), which measures electrical brain activity, and electrooculography (EOG), which measures eye movements, researchers discovered instances of rapid eye movements during sleep (Aserinsky & Kleitman, 1953). The researchers speculated about these movements occurring in the presence of dreams and in 1957, further investigations confirmed that hypothesis (Dement & Kleitman, 1957).

The other sleep stage is called non-rapid eye movement (NREM) sleep. This sleep stage is divided into 3 stages; stage 1, 2, and 3. Sleep stage 3 is also identified by slow-waves, thus called slow wave sleep (Pelayo & Guilleminault, 2009)

These 5 different sleep stages began to be measured using EEG, EOG, and electromyography (EMG). EMG measures electricity generated by the body’s muscle movements. When the three aforementioned methods are used together this equipment is called polysomnography (PSG). PSG has for a long time been, and still is the standard method of measuring different sleep stages physiologically (Pelayo & Guilleminault, 2009). It is important to note that the distinction between these stages is not always clear-cut but have some overlap and although people to a large degree share the physiological correlates of sleep and dreaming, there are still individual differences. When investigating the phenomenological aspects of dreams, it is important to not to be too adamant when mapping together phenomenological aspects with behavioral and physiological correlates (Windt, 2015).

Although dreams are known to also be present during non-REM sleep (Foulkes, 1962; LaBerge et al., 1981; Stumbrys & Erlacher, 2012) some sleep and dream researchers claim that dreams in their most prototypical sense occurs overwhelmingly in the REM phases (Hobson, 2009b) but according to Windt (2015), this is far from consensus. Considering that the majority of LDs seem to occur during REM sleep as well (Laberge, 1990) this essay will mostly focus on dreams during REM sleep.

Over the last five decades, there have been several claims about what dreams are and why we have them. Daniel C. Dennett took a strong stand in the 1970s claiming that what could not be objectively studied would be better explained as non-existing (Dennett, 1976). Dennett's cassette theory of dreams states that dreams are mere confabulations of memories inserted at the moment of awakening, hence the cassette-band metaphor. Some years after this, objective measures of predetermined eye movements were signaled to external researchers by subjects from within their dreams once lucid, which made the subjective experience of dreams more difficult to deny.

Phenomenology

NLDs are hallucinatory states present during sleep that are characterized by features of primary consciousness (Hobson, 2009a). Although the body is deprived of nearly all input from the external world and paralyzed from motor output, the subjective dream experience is filled with complex vivid imagery that closely resembles that of the outside world.

Content analysis of NLDs shows that dreams are highly visual, auditory, and often contain movements of the dreaming self (Nir & Tononi, 2010). Smell, taste, touch, pain, and pleasure also take place in NLDs, although to a lesser degree compared to wakefulness. The presence of emotions in NLDs seems to resemble wakefulness, including a wide range of feelings like joy, fear, anxiety, and anger. The fact that emotional dream content seems to fluctuate could be because dream reports are shown to vary a lot between individuals. In general, NLDs seem to contain complex emotions like sadness, guilt, or other depressed states to a lower degree compared to wakefulness, which might be due to primary consciousness lacking self-reflective thoughts (Nir & Tononi, 2010).

The dreaming subject is always unaware of the fact that the experience is a dream which shows impaired cognition and memory (Hobson, 2009b). Sudden and inconsistent changes in scenery, breaking physical laws (e.g., flying), and holding contradictory beliefs are often seen in dream reports which point to a lack of metacognition. This lack of metacognition is thought to be due to reduced activity in the frontal cortex (Hobson, Pace-Schott, & Stickgold, 2000; Maquet et al., 1996; Nir &Tononi, 2010).

Some researchers have speculated about the similarities between dreams and psychotic episodes since both can be considered hallucinatory states (Dresler et al., 2015; Hobson, 1999; Voss et al., 2013). Comparing dreams and psychosis could help researchers understand both phenomena considering the superficial similarities, e.g. hallucinations and lack of insight. To assume that they are more or less the same phenomenon happening during different circumstances would be to rush to conclusions because psychotic hallucinations are usually auditory while dream hallucinations are primarily visual (Windt & Noreika, 2011).

Reduced acts of will or volition are also a prominent feature of NLDs (Dresler et al., 2014; Maquet et al., 2005; Voss et al., 2009). Having problems with pursuing goals or avoiding certain content, like running from a murderer, are often reported and might be a consequence of decreased activity in Brodmann area 40, also known as supramarginal gyrus, which is an area in the parietal cortex known to be involved with visuo-spatial skills (Nir & Tononi, 2010).

Neural Correlates of Non-Lucid Dreams

Polysomnography. LDs and NLDs are to a large degree studied in the same manner. If LDs are studied inside a sleep laboratory, PSG is used. PSG measures sleep physiologically and is standard equipment in research on sleep. PSG consists of three components; EEG, EOG, and EMG (Windt, 2015; Pelayo & Guilleminault, 2009).

With EEG equipment, electrodes are placed on the scalp to pick up electrical signals from the brain of the subject who is sleeping. A computer receives these signals and creates visuals of neural the oscillations, or brain waves, that are more easily interpreted. These brain waves are divided into different strata: Delta (1-4 Hz), Theta, (4-8 Hz), Alpha (8-13 Hz), Beta (13-25 Hz), and Gamma (25-40 Hz) (Müller-Putz, Riedl, & Wriessnegger, 2015). These different strata often seem to correlate with different conscious states.

To pick up eye-movements, EOG electrodes are placed around the subject's eyes to pick up activity from eye muscles (Windt, 2015). NREM sleep is for instance often correlated with slow eye-movements whereas REM sleep is self-evidently correlated with rapid eye movements (Pelayo & Guilleminault, 2009).

EMG is typically placed on the chin, leg, and wrist, and is used for measuring muscle movements (Windt, 2015). In NREM sleep for example, there is diminished muscle movements and in REM sleep there is more or less a total absence of muscle movements, or muscle atonia (Pelayo & Guilleminault, 2009).

From a broad viewpoint, considering global brain metabolism and EEG activity, REM sleep looks very much like brain activity during wakefulness (Maquet et al., 1990). Later studies have targeted more explicitly the differences between dreaming experience (DE) and no experience (NE) across both NREM and REM sleep. This is important because since REM sleep can be dreamless and dreams can occur during NREM sleep as well. Siclari et al. (2017) found that in both NREM and REM sleep, DE correlated with low frequency Delta (1-4 Hz) activity bilaterally in parieto-occipital regions. Further, when contrasting reports of dream experiences without recall, where subjects claimed to have dreamt but could not recollect any content upon awakening, the same results were found.

Brain imaging techniques. Two types of brain imaging techniques have mainly been used to study the neural correlates of dreams. The first technique is called functional magnetic resonance imaging (fMRI). This is the technique that has been used when imaging studies on LDs have been done. The fMRI machine works by contrasting changes in blood flow, which relates to energy use by the brain, i.e. brain activity. As opposed to EEG, this technique has a much better spatial resolution but lower temporal resolution (Cabeza & Nyberg, 2000). There are two major problems with using fMRI in sleep research. The first is that the machine is very noisy which makes it difficult for people to fall asleep inside it. The other is that the technique requires the subjects to lie still which poses a problem to subjects that are prone to move in their sleep (Erlacher & Schredl, 2008; Windt, 2015).

The other technique is called positron emission tomography (PET) and is the imaging technique used the most in studies on NLDs. Many dream researchers moved from using PET to fMRI since this was a more cost-efficient technique with better spatial resolution and temporal resolution (Buxton, 2013). Pet works by introducing a tracer to the human body. This tracer is short-lived radioactive isotope that spreads to the brain and continuously decays. The radioactive emissions from the decay enable the PET machine on the outside to image the brains activity, since the isotope works as an analog to glucose. When it comes to studies on NLDs, this is the main technique that has been used.

Maquet et al. (1996) investigated REM sleep and dream correlates and found increased activity in the following areas: Pontine tegmentum, left thalamus, both amygdaloid complexes, anterior cingulate cortex (AAC), and right parietal operculum. Pontine tegmentum is found in the brain stem and is involved with sensory and motor processes. Thalamus is located in the center of the brain and is often considered a relay station for sensory and motor signals. The amygdaloid complex sits in the temporal lobes and is known for its involvement in memory and emotional responses. ACC sits anterior to the corpus callosum and plays a key role in regulating emotions. Parietal operculum is located laterally in the temporal lobes and is considered to be a secondary somatosensory cortex. The results also found correlations between dreams during REM sleep and decreased activation in the following areas: Dorsolateral prefrontal cortex (DLPFC), supramarginal gyrus (BA 40), posterior cingulate cortex, and precuneus. DLPFC is located in the most anterior part of the brain and is known to be involved with e.g. working memory and metacognition. Precuneus sits in the superior parietal lobe and is involved with self referential processing, episodic memory, and visuo-spatial processing. It is important to note that it is not clear whether these activations reflect REM sleep or dreams.

Lucid Dreams

Here, research on LDs will be presented. First, a walkthrough of the history of LDs will first be presented, to provide context. Second, methods used when studying LDs will be explained in order to easier interpret the research on LDs. Following each research method, studies that have used the respective method will be covered. Third, research on metacognition and volition will be reviewed.

History of Lucid Dreams

One of the earliest documentations of LDs comes from the previously mentioned Aristotle, who described dreams in which it becomes clear that the experience is not real but merely a dream (Windt, 2015; LaBerge et al., 1981). In van Eeden’s book, *A Study of Dreams,* he emphasizes a special kind of dreams which he termed LDs. In these LDs, “psychic functions” as van Eeden describes them, would be restored, revealing the true nature of the dream and making acts of will, or volition, possible. While insight into the fact that one is dreaming is by some researchers considered sufficient for a dream to be termed lucid, others argue that volition is also necessary (Windt, 2015).

LDs were first objectively measured inside a sleep laboratory in the late 1970s (Hearne, 1978). In the study, eye movements were used as a means of communication, since the eyes are not under paralysis during REM sleep. Subjects were instructed to perform iterated sequences of left to right (LR) eye-movements when they became lucid inside a dream. These signals, picked up by EOG, were identified as non-random by external researchers and seemed to coincide with the subjects' reports of LDs. A similar study was later performed by Stephen LaBerge, trying to replicate the findings (LaBerge et al., 1981). The idea was that while the body was paralyzed during dreams, the eyes could still be used as a means of communication, seeing how they can move in REM sleep. In the study, experienced lucid dreamers would try to have LDs while sleeping in a laboratory equipped with PSG equipment. Once lucid, the subjects were to perform a pattern of iterated left-right movements with their eyes which would be picked up by EOG. The subjects' reports of LDs were then found to match the eye movement patterns along with physiological measures of REM sleep (LaBerge et al., 1981).

Methods for Studying Lucid Dreams and Neural Correlates of Lucid Dreams

In the early 1980s, researchers Ogilvie, Hunt, Tyson, Lucescu, and Jeakins (1982) set out to look for a relationship between EEG-alpha activity and lucidity based on a hypothetical link between lucidity and meditative states, which were acknowledged to correlate with heightened levels of alpha activity. The researchers used 10 subjects who remembered more than 5 non-lucid dreams per week and had been screened for high levels of alpha waves either during REM sleep or relaxed wakefulness. The group was further divided into two: one experimental group – receiving biofeedback preceding sleep –and one control group. Biofeedback is simply put a non-invasive technique used to induce more of certain brain waves, in this example alpha waves. The research team awoke subjects following REM sleep during which high levels of alpha waves were present. The subjects were then instructed to answer two questionnaires regarding lucidity. The items on the questionnaires were divided into three categories; non-lucidity, pre-lucidity, and lucidity. Since differences in brain waves measured using EEG can be difficult to find if one does not know what to look for, a band filter for alpha brain waves was used. The results showed that alpha brain waves correlated with pre-lucidity and to a lesser degree lucidity. Further, no difference was found between the experimental group receiving biofeedback and the control group. The researchers related their results of heightened alpha brain waves in correlation with pre-lucidity to the sort of insight that takes place in meditative practice.

In a subsequent study, Holzinger et al. (2006) used approximately the same number of subjects as Ogilvie et al. (1982) (N=11) to further investigate the relationship between lucidity and brainwave frequencies. Interestingly, they found different results. Lucidity mostly correlated with Beta-1 waves (13-19 Hz) in parietal regions. Especially in a region where the P3 electrode is placed (cf. Homan, Herman, & Purdy, 1987) which the researchers said was known to be involved in semantic understanding and self-awareness. The researchers speculated about phrases such as “this is a dream” being related to activity in this area.

In 2009, Voss et al. continued the path investigating EEG frequencies in LDs using experienced lucid dreamers. 20 psychology students were trained to become avid lucid dreamers over a period of 4 months. 6 out of 20 were successful in their training and got to participate in the study. Out of the 6 subjects, 3 had one LD each following autosuggestion preceding sleep. Autosuggestion is a cognitive technique used to induce LDs where a certain phrase is repeated accompanied with the dreamer focusing on becoming lucid (Laberge & Rheingold, 1991). After the subjects LDs had been verified, connecting the predetermined LR-eye signals with subjects’ reports of lucidity, the EEG data were analyzed. For frequencies up to 28 Hz, the activity was similar to REM sleep activity in the subjects. From 28 Hz the frequencies arose with a peak in 40 Hz (gamma band) which were more like the wakeful state (Voss et al., 2009). The effects regarding an increase in gamma band frequencies were found to be prominent in the frontal regions. The researchers speculate about activation in DLPFC in LDs since it is known to be involved in the loss of volition, self-reflective awareness, and insight. Considering the poor spatial resolution of EEG, this hypothesis needs further investigation using imaging techniques according to the researchers (Voss et al., 2009).

Following up on the work of Voss et al. (2009), Dresler et al. (2012) carried out the first fMRI study on the neural correlates of LDs. Four people were recruited using the strict inclusion criteria of being able to have at least one LD per week. On several non-consecutive nights, the subjects were to fall asleep inside an fMRI machine wearing polysomnographic equipment. The researchers' instructions for the study were the following. Once lucidity is fully reached, the subjects were to perform LR eye-signals and then clench their left hand for about 10 seconds. Immediately after this, the same LR eye-movement was to be repeated following a clench of the right hand. This was performed so that the researchers could decipher the lucidity onset and trajectory. After this signaling, a researcher would enter the room, awaken the subject, and gather a dream report to further validate the LD.

Out of the four subjects, one managed to have two LDs on different nights. LDs occurred during REM sleep with clear eye-signals picked up by the EOG. The fMRI analysis showed increased activity in DLPFC which is where Voss et al. (2009) proposed the heightened 40 Hz activity is taking place during LDs. This supports the hypothesis that DLPFC has a metacognitive function that is being reintegrated during LDs in the transition from NLDs. Further, they found increased activity in the parietal lobules which the researchers speculated could play a role in working memory. Increased activity was also found in frontopolar cortex. The research team related this to previous research that has shown this area to be involved in the processing of internal states. An example of this function in a LD could be to think about one’s ongoing thoughts or feelings in the dream, i.e. self-reflective awareness. Bilateral cuneus and occipitotemporal cortices were also activated; they are thought to play a role in conscious awareness in visual perception. Last but not least the strongest increase in activation compared to non-lucid REM periods were observed in the precuneus. The precuneus, the researchers claimed, could have a role in self-referential processing. This is in line with the subjective reports of how self-reflection takes a shift from non-lucidity to lucidity in dreams. For example, reflecting on one's dreaming body or dreaming cognition. An inevitable limitation is that the hand-clenching task could have confounded parts of activation relating to working memory during LDs since the task required a cognitive effort.

Transcranial stimulation. Noreika, Windt, Lenggenhager, and Karim (2010) discuss different brain stimulation tools in relation to research on LDs. Three techniques are brought up and suggested for future research, especially in relation to investigating consciousness in LDs: transcranial magnetic stimulation (TMS), transcranial direct current stimulation (tDCS), and galvanic vestibular stimulation (GVS). The underlying mechanism studied with these devices is somewhat similar. Since the brain can use electrical signals as a means of communication, these techniques can in a non-invasive manner polarize or depolarize neurons beneath the scalp in certain areas. A polarization will lead to neuronal firings, activating the area of interest, and a depolarization will respectively inhibit neuronal firing, deactivating the area on interest.

The first technique, TMS, has mainly been used on the motor cortex in order to evoke motor responses but there is interest in using the technique on higher cognitive functions, e.g. working memory as well (Noreika et al., 2010). Even though TMS has been used successfully in sleeping subjects (Massimini et al., 2010), it poses some methodological issues to dream research. The instrument evokes continuous sounds as well as tactile stimuli which might awaken the sleeping subjects or create artifacts inside the dream. TMS has never been used in research on LDs and if the methodological issues can be dealt with the researchers proposes future studies involving this technique.

The second technique, GVS, works in the following manner: A pair of electrodes -- one negative and one positive – is placed on each mastoid bone. When current is applied, this creates more excitability in the neurons where the negative electrode is placed and less excitability where the positive electrode is placed. Stimulation of the vestibular system has been linked to bodily self-consciousness, derealization, and depersonalization, which are important concepts in relation to consciousness. The researchers encourage more research on LDs using GVS, especially in relation to consciousness (Noreika et al., 2010).

The third technique, tDCS, works in pretty much the same manner as GVS but instead of using the mastoid bones, the electrodes are placed on the subject's scalp. As opposed to TMS, this technique is silent and evokes no tactile sensations for the sleeping subject. A downside is that the stimulation takes between 10-20 minutes and requires the researchers' presence during this time. In a study from 2013 by Stumbrys, Erlacher, and Schredl, this technique was used to probe DLPFC in relation to its speculated involvement in lucidity (Stumbrys, Erlacher, & Schredl, 2013b). Short after this, another research team used a similar method called transcranial alternating current stimulation (tACS) – which uses alternating current instead of direct current –when they were trying to induce lucidity in their subjects (Voss et al., 2014).

As mentioned in a previous section, there are two studies that have used transcranial stimulation to investigate LDs. The first study used tDCS and was performed by Stumbrys et al. (2013b). Twenty-three subjects that could remember at least one dream per week were included in the study. The subjects were to spend three consecutive nights in a sleep laboratory with the intention of having a LD. The first night served as an adaptation night. On night 2 and 3, the subjects were randomly given either tDCS or sham stimulation during REM sleep at the site of DLPFC. Short after stimulation had been given; the researchers awoke the subjects and collected dream reports. In addition to the dream report the subjects were to answer questions regarding their emotions inside the dreams and they also got to fill out two questionnaires; one regarding metacognition and one regarding lucidity.

When dream reports and questionnaires were analyzed, 7 subjects had been excluded for multiple reasons which left a sample of 16 subjects. A post-hoc analysis divided the group in half, leaving one group of 8 frequent lucid dreamers (at least one LD per month) and one group of 8 infrequent lucid dreamers. The analysis showed that frequent dreamers had significantly higher self-ratings of lucidity during nights with stimulation compared to sham. This was not found in the other group. Measures were also taken by the researchers to control for small arousals from the stimulation that might have helped increase lucidity by arousing the subjects.

The researchers concluded that although the evidence should be interpreted with caution, it was in line with previous evidence (Voss et al., 2009; Dresler et al., 2012) hypothesizing about the involvement of DLPFC in LDs. A limitation of the study was the fact that only frequent lucid dreamers had an effect of stimulation. This effect was also only measured using self-ratings. Blind judges scored reports from tDCS nights to be somewhat more lucid but this effect disappeared when dream report length was controlled for (Stumbrys et al., 2013b).

In 2014, Voss et al. performed a similar study using tACS at frontotemporal sites to induce lucidity in subjects during sleep. Twenty-seven inexperienced lucid dreamers were included in the study. The subjects were to spend 4 nights in a sleep laboratory with polysomnographic equipment. During REM sleep, they were given tACS stimulation with the following frequencies; 2, 6, 12, 25, 40, 70 or 100 Hz or sham. 5-10 seconds after stimulation or sham had ended; the subjects were awakened by the researchers. Upon awakening, the subjects were asked to provide a dream report as well as answer 28 items on a questionnaire that measured lucidity (Voss et al., 2013).

A significant effect of increased lucidity was found with stimulation of 40 Hz and to a lesser degree with 25 Hz. Increased lucidity was assumed with elevated ratings of *insight* and *dissociation*, two factors on the LuCiD scale (Voss et al., 2013). Brainwave-activity in the respective frequency band increased during stimulation, measured with EEG, while other polysomnographic measures showed typical REM characteristics. No such effects were found for the other frequencies or sham. Although the increase in lower gamma activity following stimulation was stronger independently of lucidity, dreams scored as lucid had significantly higher gamma activity. The researchers propose that this might be due to a reciprocal effect regarding frontotemporal regions alleged involvement in reflective thought. For example, if frontotemporal activation leads to initial reflective thoughts, these reflective thoughts might create a feedback loop leading in turn to even more frontotemporal activation.

Mean scores of perceived lucidity positively correlated with both 25 and 40Hz stimulation, although the latter was a stronger effect. More specifically during 40 Hz stimulation, the strongest increase was seen in the factors *insight* and *dissociation*. During 25 Hz stimulation, the strongest increased was in the factor *control*. These three factors have previously been identified as the most prominent factors in LD in contrast to NLD (Voss et al., 2013).

Verbal reports. Dream reports are recollections the experiences that subjects have had during their sleep. In contrast to fMRI which tries to find physiological correlates of dreams, dream reports try to find psychological content from dreams to analyze (Schredl, 2010). There are different forms of dream reports such as; free reports, affirmative probes, and questionnaires. Dream reports can be gathered either orally or through writing, in either the subjects home setting, through the internet, or in the laboratory (Windt, 2015). The highest standard of dream reports is when they are gathered after timed awakenings of subjects inside a sleep laboratory. The upside to this is that the amount of confabulation or misremembering is lower due to how recent the dream reports are. The downsides are that it is difficult and time-consuming to collect larger sets of data using this method. Further, the laboratory setting has been shown to influence subjects' dreams, which lowers the ecological validity (Schredl, 2008). Dream journals are also used aside from gathering dream reports from the laboratory or through internet. A dream journal is a book that subjects have beside their bed and are encouraged to write in whenever they awaken from a dream. The upside of dream journals is the convenience and ability to be able to collect much larger amounts of dream reports, while the obvious downside is the lower constraints in the methods.

In 2013, Ursula Voss et al. wanted to investigate the phenomenological aspects of consciousness in NLDs and in LDs, to get a sense of the commonalities as well as differences between them. The researchers came up with a questionnaire containing 24 items, representing 8 factors: insight, control, thought, realism, positive emotion, negative emotion, memory, and dissociation. All the factors except two (realism and negative emotion) differed between LDs and NLDs. The researchers found the fact that realism did not differ especially interesting. Previous notions have said that dream bizarreness might induce subjects to realize they are dreaming and become lucid, but this does not seem to be the case. The biggest factors for lucid dreams were insight, thought, control – in that order – and to a lesser degree positive emotion and dissociation. Insight, measures lucid insight, control, measures control over thought and action in dreams, and thought, measures logical thought.

Metacognition and Volition

Since both metacognition and volition are versatile functions that are not yet fully understood, this section will overview the most characteristic ways in which these functions have been investigated. As will be shown below, although metacognition and volition have several functional components to them, the neural correlates seem to be involving roughly the same brain areas. Because of the limited scope of this essay, a more in-depth review of the literature on metacognition and volition will not be provided.

Neural correlates of metacognition. Depending on whether it is prospective judgments or retrospective judgments, slightly different brain areas seem to be involved. Medial PFC shows more involvement in prospective judgments whereas lateral PFC shows more involvement in retrospective judgments (Fleming & Dolan, 2012). Other studies have shown that subjects' ability to give metacognitive commentaries during tasks is related to activation of lateral PFC. One study showed linkage to increased activity in dorsolateral PFC and another to Brodmann area (BA). BA 10 is in the rostrolateral PFC and is related to executive functions. Further, higher accuracy on a performance task of metacognitive accuracy correlated with increased gray matter (GM) volume in BA10. In a similar study using fMRI, metacognitive accuracy was also correlated with increased brain activity in this area, BA10 (Fleming & Dolan, 2012).

A meta-analysis trying to assess the functional involvement of BA10 from imaging studies (Gilbert et al., 2006) found several functions related to secondary consciousness. Most prominent were working memory, episodic memory retrieval, mentalizing (i.e., reflecting on one's own conscious state), and multiple-task coordination.

Metacognition in lucid dreams. Filevich, Dresler, Brick, and Kühn (2015) wanted to investigate a direct relationship between metacognition and LDs, which to their knowledge, had previously only been related through separate studies.

Subjects were found from a subject-database and were asked over the phone if they wanted to participate in an experiment on metacognition. The researchers wanted to withhold the information in the study relating to LD until a later stage in the study, to avoid confounding results. 63 healthy, right-handed subjects were scanned using MRI. After being scanned the subjects were to perform a task on thought monitoring while lying inside an fMRI scanner. The task went in the following way. The subjects were to focus their eyes on a screen. After 20-40 seconds, a horizontal linear scale would appear with the abbreviations INT (for internal) and EXT (for external) on each end of the scale. In the experimental condition, the subjects used a curser to rate how internally vs. externally oriented their thoughts were in the moment just before the scale appeared. External thoughts were defined as “those related to the immediate external environment, such as the scanner noise, the visual aspects of the stimuli, etc.” (Filevich et al., 2015, p. 1083). Internal thoughts were defined as; “those that were not immediately related to the external environment, such as planning for the day ahead, or remembering past events” (Filevich et al., 2015,p. 1083). In the control condition, instead of evaluating their previous thought orientation, the subjects were to put the cursor inside a circle that was appearing in random places along the scale. This condition was used to separate the noise from the eye-scanning and motor output.

After this was done, the subjects were informed about LD as a phenomenon. They were instructed to fill out a questionnaire assessing the frequency of NLD recall. In addition, a questionnaire assessing LD traits in dreams, the LuCiD scale (Voss et al., 2013), were given to the subjects and asked to be filled out every morning for a week, referring to the dream from the previous night. This was done to assess both the ratings of lucidity within the subjects’ dreams and frequency of LDs.

Rates of lucidity and frequency of LDs were used to compute a mean score of lucidity, called “trait lucidity”, for each subject. The group was then further divided into two using this mean score as an indication of either high lucidity or low lucidity. The two groups’ MRI data were contrasted against each other to discriminate structural differences that might imply the differences in trait lucidity.

The analysis showed that the high-lucidity group had an increase in gray matter (GM) volume in Brodmann area 9 and 10 (BA9/10) compared to the low-lucidity group. BA 9 is situated in the PFC and is involved with self reflection. Further, they had increased GM volume in hippocampi, anterior cingulate cortex (ACC), and left supplementary motor area (SMA).

The researchers knew that BA9/10 was allegedly involved in metacognition due to previous research (Fleming, Weil, Nagy, Dolan, & Rees, 2010). Therefore, this area was further investigated in relation to the thought monitoring test. ACC served as a control area since it showed increased GM volume in the high lucidity group but had, to the researchers' knowledge, no previous involvement in metacognition. When looking at the activity from the fMRI data, increased activity was seen in BA9/10 during the thought monitoring task compared to the control condition. No such effect could be seen in ACC. The researchers therefore concluded that subjects, who exhibited a higher lucidity trait, had more GM volume the area (BA9/10) linked to the thought-monitoring task using the same subjects.

In another study, Kahn and Hobson (2005) wanted to investigate the difference between two sorts of thinking within dreams. Twenty-six subjects submitted a total 178 dream reports during two weeks. In addition to the dream reports, the subjects were told to choose an event from the dream that involved thinking and answer two questions about how that sort of thinking was similar or different from thinking in wakefulness. The first question was about the rational thinking during an event, while the second question was about the rational thinking about the event itself. For example, one subject reported being annoyed with a woman in front of him in line because she was taking too much time. The subject further said that they were standing in line to go up a ladder that went to a hatchet that would open up a restaurant. On the first question, the subject answered that he would have responded in the same manner, with annoyance, if this had occurred during wakefulness. The researchers judged his thinking during the event as rational. On the second question the subject answered that if this event would have occurred during wakefulness, he would have been very critical about the event itself. The researchers therefore judged the thinking about the event itself as irrational, inside the dream. The former kind of thinking was termed, context logic, and the latter, state logic.

The results of the study showed that context logic in dreams was overall judged by the subjects to not differ much from context logic in wakefulness. State logic, on the other hand, was judged to be different from dreams as opposed to wakefulness were subjects claimed to be more critical of the state of events. The researchers attributed the deficits in this state logical reasoning to that of decreased metacognition during sleep.

In a recent study by Speth and Speth (2018), a new tool to measure different sleep stages using linguistics was proposed. The study compared almost 400 reports from sleep onset, non-REM sleep, and REM sleep. The tool assessed the number of words related to motor imagery and cognitive agency. The results showed that there was a decline in the number of words related to cognitive agency and an increase in words related to motor imagery starting in sleep onset, increasing in non-REM sleep, and peaking in REM sleep.

The researchers (Speth & Speth, 2018) say that this in line with previous research suggesting that reflective thinking and metacognition decreases during REM sleep. The researchers further discuss the possible utility of this tool in measuring LDs as they propose that LD is not a dichotomous phenomenon but varies along a continuum.

Neural correlates of volition. Since most experiments on volition focus on behavioral output, mostly motor output, brain areas dealing with motor action appear a lot in the literature. One frequently studied area is the pre-supplementary motor area (preSMA). PreSMA is part of a broader network that includes premotor cortex, cingulate cortex, and frontopolar cortex. Lesion studies with patients that have frontal lobe damage, especially in the preSMA, exhibit random grasping of objects. This is even the case when objects are out of focus for the subject. From computational theories on human volition, it has been suggested that frontopolar cortex evaluates which of several tasks to “go for” so to speak, to achieve one’s goal. This evaluation is a continuous process where alternative tasks are kept pending. The lateral PFC then guides the behavior towards the chosen task (Haggard, 2008).

The famous veto decision, or “whether decision”, where people seem to be able to deny a prepared action just before execution (Libet, Gleason, Wright, & Pearl, 1983) has been studied using fMRI. This type of decision arises in order to evaluate a latent action at its final step. This is useful since sometimes additional information or an error will arise along the process which makes the action unfit for the proposed goal. An area that was found involved in this process was anterior frontomedian cortex, rostral to the pre-SMA. Further, decisions about “when” to perform an action has been linked to pre-SMA and dorsolateral prefrontal cortex (DLPFC). Studies that have stimulated the pre-SMA using subdural electrical stimulation on epilepsy patients found that the patients reported a strong urge to move certain body parts. With higher stimulations, the movements were actually exercised. The authors speculate that the urge might usually arise in remotely connected areas and the pre-SMA works as a nexus where the information is gathered (Haggard, 2008). Next, research on LDs will be presented including methods for studying LDs as well as neural correlates of LDs.

Volition in lucid dreams. Volition is an ability often implied to be missing in NLDs but reintegrated with the onset of lucidity. Although research on volition in dreams has been somewhat scarce, some articles seem to touch upon the aspects of volition not many studies investigated it explicitly.

In 2014, Dresler et al., tried to specifically measure how volition changed between wakefulness, NLDs, and LDs. 10 experienced lucid dreamers were recruited that had a mean frequency of 2 LDs per week. Half the group had to sleep in a laboratory with polysomnographic equipment to validate their ability to have LDs. The other half had only reported their ability through self-report. The subjects were to fill out a questionnaire regarding their volitional capabilities from three conscious states; wakefulness, non-LD, and LD. These reports were filled out either after awakening from a NLD, a LD, or before going to bed, i.e. after wakefulness (Dresler et al., 2014).

The questionnaires were a modified version of the volitional capabilities questionnaire (VCQ) that has previously been demonstrated to have good validity (Forstmeier & Rüddel, 2008). The original short version of VCQ includes 13 subscales and was here restricted to 6 subscales in order to fit the dreaming states of mind. The six subscales were as follows: self-determination, intention enactment, planning ability, integration, self-access, and powers of concentration. Both individual scores and a mean score from these 6 subscales were used in the subsequent analyses, looking for differences in volition between the three states of consciousness; wakefulness, non-lucid, and LD.

For general ratings of volition, calculated as a mean of the 6 subscales, both wakefulness and LD had higher scores compared to non-LD. There was no difference in volition in between wakefulness and LDs. When comparing the subscales, 3 out of 6 differed between the three states. These were; planning ability, self-determination, and intention enactment. Planning ability was defined as how well organized one's plans and intentions were. Self-determination was defined as the feeling of being able to act freely according to one’s will. Intention enactment was defined as how promptly and determined one’s intentions are performed (Dresler et al., 2014).

For planning ability, ratings were higher in wakefulness, compared to LDs and NLDs. There was no difference in this subscale between LDs and NLDs. For self-determination, ratings were higher in wakefulness and LDs compared to NLDs. There was no difference in this subscale between wakefulness and LDs. Last, for intention enactment, ratings were higher for LDs compared to both NLDs and wakefulness. There was no difference in this subscale between NLDs and wakefulness.

Dresler et al. (2014) say that the most prototypical subscale of volition is self-determination. Therefore, it was not surprising that subscale was rated higher in both wakefulness and LD. Further, they speculate about a possible negative correlation between intention enactment and planning ability. At first glance, the fact that intention enactment was stronger in LDs compared to wakefulness might come as a surprise. Although since LDs have no physical laws one needs to abide, the need for planning ability becomes in a sense obsolete. In other words, if anything is possible at any given time, there is no need for planning what actions to perform and when to perform them to e.g. achieve something good or avoid something bad. Therefore, the researchers say, when planning ability goes down spontaneous intention enactment might go up.

In relation to the three remaining subscales that did not differ between the three states, the following is said by the researchers. Integration, defined as “the occurrence of seemingly contradictory behaviors and emotions”, was not higher in NLDs even though irrational behavior is sometimes described in self-reports. The researchers say that although NLDs might be bizarre or inconsistent, these aspects are more often found in the environment of the dream instead of within the dreaming subject.

Self-access, defined as “the quality of access to one’s intentions and feelings in stressful situations” is probably constant since stress is known to limit higher-order cognitive functions. This could therefore explain why there is no reported difference in self-access between the three states.

The last factor, powers of concentration, the researchers had no explanation for and they found it strange to not differ between the states. Powers of concentration are defined as “how easily the subject gets distracted from his current line of intentional thought”.

Discussion

The evidence from EEG research on NLDs shows increased low frequency delta activity (1-4 Hz) during both REM sleep and NREM sleep. Imaging results on NLDs showed increased activation in the following areas: Pontine tegmentum, left thalamus, both amygdaloid complexes, anterior cingulate cortex (AAC), and right parietal operculum. It is important to note that the imaging results could also reflect REM sleep, since REM sleep and NLDs were not dissociated in the study.

When it comes to LDs, the evidence suggests an increase in low frequency gamma activity (40 Hz) during this state. The imaging studies show that prefrontal areas, which are deactivated during REM-sleep, becomes reactivated during LDs. Evidence from transcranial studies support these results as they have shown that stimulating these areas will yield increased subjective ratings of lucidity in dreams. Studies on neural correlates of metacognition and volition link these functions to prefrontal areas. This therefore, supports the claim that many dream researchers make, that lucid dreams reintroduce metacognition and volition into the dreaming consciousness.

I will now focus on three subjects: (a) How to conceptualize dreams, which includes a suggestion that dreaming may be categorized in a 2-level manner (b) the role of metacognition and volition in LDs (c) future methods for investigating LDs.

Conceptualizing Lucid Dreams

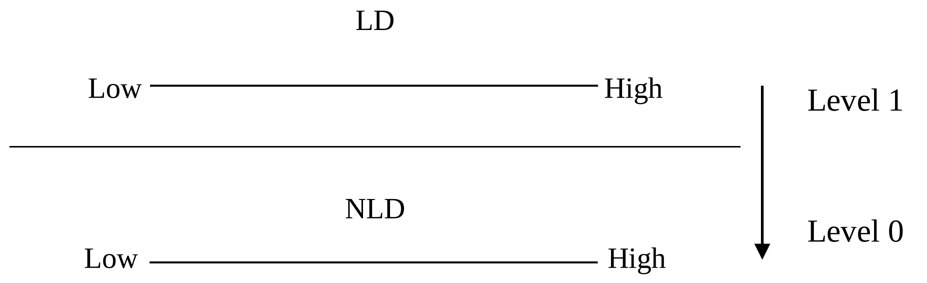

Figure 1. The figure depicts two separate, but interconnected, dimensions. These dimensions are meant to reflect differences between NLDs and LDs. The x-axes beneath each dream type reflect the amount of lucidity present in the dream experience. A dream experience can move

between the two levels if a sufficient increase or decrease in lucidity takes place. For example, a NLD with a sufficient increase in lucidity will become a LD (level 1) and vice versa, a LD with a sufficient decrease in lucidity will become a NLD (level 0).

Judging from the literature reviewed in this paper, I suggest that a rough two level categorization of dreaming can be made (see Figure 1.). Level 0 is a dimension that conceptualizes NLDs. This level has primary features of consciousness and the dreamer does not realize that he is dreaming. Level 1 is a dimension that conceptualizes LDs. This level has primary features of consciousness, adds secondary features of consciousness, and the dreamer acknowledges that he is dreaming. Extending on the work of Voss et al. (2013), I propose to add *lucidity* as a concept to this categorization, as a common underlying variable in NLDs and LDs. The purpose of this is to have a continuous variable measuring how close or distant a dream is from moving from one level to the other. For instance, lucidity could be operationalized as a grand mean from the factors insight, control and dissociation from the LuCiD scale. The factors measure, respectively: insight (i.e., lucid understanding that one is dreaming), control (i.e., control over thought and action), and thought (i.e., logical thought). These factors have been suggested by the researchers themselves to be the most substantially varying factors between NLDs and LDs (Voss et al., 2014).

Lucidity as a concept is not yet fully understood but I believe that as it increases in NLDs the experience eventually leads to a LD through a “switch on” moment for the dreamer. Exactly what mechanism is driving increases in lucidity is hard to pinpoint, but it may be that features of secondary consciousness, through a feedback-loop, are causally involved in lucidity. One could assume that a psychological mechanism, related to features of secondary consciousness, is responsible for lucidity. To illustrate, an example of how a dream experience can move along these two dimensions will be given. A NLD with low lucidity is a prototypical dream where dreamer does not realize he is dreaming and primary features of consciousness is present. As features of secondary consciousness increase, the experience becomes a NLD with high lucidity. The dreamer still does not realize he is dreaming but experiences features of secondary consciousness, e.g. reflection, control of dream plot, and autobiographical memory, to a higher degree. If lucidity further increases it finally dawns upon the dreamer that he is dreaming, turning on the “switch”. At this point a large increase of features of secondary consciousness happens rapidly, moving the experience from being a NLD (Level 0) with high lucidity, to a LD (Level 1) with low lucidity. What is important to note here is that a LD with low lucidity has features of secondary consciousness to a significantly higher degree than a NLD with high lucidity, since it is between these two stages the “switch” takes place. Once the dream experience has become lucid it can decline in lucidity and become a NLD (Level 0) with high lucidity. Alternatively, it increases in lucidity and becomes a LD with high lucidity, resembling a wake-like conscious experience, since the degree to which features of secondary consciousness is present here is at its highest. This conceptualization hopes to offer a better understanding of how dreams can move along the two dimensions and how the “switch” mechanism works.

The Role of Metacognition and Volition in Lucid Dreams

Cortical areas involved in metacognition and volition are known to be more active during LDs. In the study by Voss et al. (2014), stimulating some of these areas in subjects during REM sleep created increases in insight, control, and dissociation, measured with the LuCiD scale. The stimulation also created increased gamma wave activity (40 Hz) in these cortical areas. It seems that these functions could at least in part responsible for the underlying factor in NLDs and LDs, lucidity. Further, stimulation of these areas to the point where a LD is induced creates significantly higher rates of gamma waves, similar to those present in wakefulness. I argue, in line with Voss et al. (2014), that this is a reciprocal effect from the dreamer realizing that he is dreaming, or the "switch" being turned on. As activation in the areas responsible for metacognition and volition increases, the dreamer finally realizes he is dreaming. This realization will instantly activate these areas even further, creating a feedback loop, leading to more lucidity. Perhaps this feedback loop can explain the rapid increase in lucidity that happens when a NLD becomes a LD.

It is not clear if metacognition and volition are equally representative in generating lucidity as most studies have focused on areas involved with both. There are four ways in which metacognition and volition could be related to lucidity. The first two explanations are that either metacognition or volition alone cause more lucidity while the other function gets activated as a side-effect. The third explanation is that both are necessary and cause lucidity. The fourth explanation is that there is an unknown confounding variable responsible for metacognition, volition, and lucidity. The explanation I find most plausible from reviewing the literature is that metacognition is necessary for lucid dreams to emerge since they cause insight into the dream. Volition would then follow as a side-effect and cause increases in control. Different ways of investigating this relationship are discussed in the next section.

Future Guidelines for Investigating Lucid Dreams

In the early years of investigating LDs, alpha waves were thought to cause LDs but later research points to gamma waves, especially around 40 Hz, being responsible. An early study by Ogilvie et al. (1982), used biofeedback to elicit LDs in subjects preceding sleep without any successful results. It would be interesting for future studies to try and use biofeedback with gamma instead of alpha waves of subjects.

GVS and tDCS/tACS are prominent methods for future research as they are easy to use and cost-efficient. In the study by Voss et al. (2014), tACS stimulation on frontotemporal sites gave higher rates of lucidity in inexperienced lucid dreamers but not many subjects managed to have LDs. There were two methodological aspects of this study that future studies could address. First, they only studied inexperienced lucid dreamers. If the subjects had been experienced lucid dreamers perhaps more LDs had occurred from stimulation. Second, the time between stimulation and awakening the subjects was only 10-15 seconds. If increases in lucidity raise the chances of having a LD, perhaps this time window should be longer. It is possible that the subjects were on the verge of having LDs as they contemplated their surroundings during these 10-15 seconds, perhaps more time would have made them stumble on an inconsistency in the environment, leading to the proposed ”switch” from Level 0 to Level 1.

Further, both of the studies using transcranial stimulation focused on areas mostly involved with metacognition, as mentioned previously. A way to test the role of volition in relation to lucidity without involving metacognition could for example be to stimulate the preSMA, using tACS, since this area is known to be involved in volition, but not metacognition. If this turned out to increase lucidity, perhaps stimulating both preSMA and DLPFC (involved in metacognition) at the same time could additionally increase lucidity in subjects. The study by Filevich et al. (2015) found that the high-lucidity group which had more GM in BA 9/10 also had more GM in left SMA which supports this hypothesis.

Conclusion

Dreams can be categorized into either NLDs or LDs with an underlying common variable, lucidity. Lucidity can vary in degrees along a continuum and is possibly responsible for dream experiences transitioning from being NLDs to LDs and vice versa. It is not yet clear what lucidity as a concept is but research suggests a relationship between lucidity, functions of secondary consciousness such as metacognition and volition, and gamma activity in these areas. Areas involved in metacognition and volition are significantly more active during LDs compared to NLDs and studies stimulating these areas show increases in lucidity. Increases in lucidity also correlate with lower gamma activity (40 Hz) with significant increase in lucid dreams. A possible way of measuring lucidity could be through the LuCiD scale using the factors: insight, control, and thought. Future studies could focus on further stimulating areas involved in metacognition and/or volition in order to find out what the relationship is. To possibly generate more lucidity or LDs, biofeedback treatment focusing on gamma wave activity could be given to subjects preceding sleep, seeing how this has previously only been tried using alpha wave activity.

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