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Original Article

In the Theater of Dreams: Global Workspace Theory, Dreaming, and Consciousness

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Utilizing the Global Workspace System of Baars (1988), this paper compares conscious and unconscious processes across waking, nonlucid, and lucid dreams. Sleep psychology can display gross functional dissociation between perceptual and cognitive consciousness. We utilize this observation to develop models of sleep experience and dream generation. These models accommodate Hunt's (1989) "multiplicity of dreams", as well as the intrinsic variation of perceptual and cognitive activity during dreaming. Lucid dreams are suggested to result from the presence of a skill-based mental set, the lucid dream context, which allows voluntary interaction with the spontaneous dream process. Our view of dreaming provides an explanation of the tendency of lucid dreams to either fade or revert to nonlucid dreams. Neurobiological considerations lead us to hypothesize that, in the sleeping brain, a reversal of information flow from medial temporal lobe mnemonic structures to thalamocortical perceptual circuits imparts parameterization to dream perceptual consciousness. A consequence of our thinking is that dreaming results in a "mental recombination" of cerebral information networks, which contributes to the ability of waking consciousness to generate novel and adaptive responses.

Key Words: consciousness, unconscious, contexts, dreams, Global Workspace, lucid dreams, medial temporal lobe memory, thalamocortical circuits, recombination

INTRODUCTION

Although we have seen stunning progress in the cognitive neurosciences in the past decades, our understanding of dreaming has not shared proportionally in these advances. Substantive omissions in dream theory have made the realization of a robust science of dreaming elusive: (1) there is no consensus for comparing waking and dreaming psychology; dream theoreticians are divided over the issue of whether dream psychology is continuous or discontinuous with waking psychology (Antrobus, 1986; Purcell, Moffitt, & Hoffmann, 1993), (2) theoretical approaches to dreaming lack unity; there is still no clear conception linking biological, interpretive, and content analysis approaches to dreaming (Kahn, Pace-Schott, & Hobson, 1997; Moffitt, Kramer & Hoffmann, 1993), and (3) the study of lucid dreams has proceeded in relative isolation from the study of nonlucid dreams, and lucid dreaming data has had minimal impact on either dream theorizing or models of waking (Kahan & LaBerge, 1994; Purcell et al., 1993). The purpose of this paper is to explore the implications of a comparison of the phenomenology of gross subjective experience across waking and dreaming. The approach we utilize here begins to address the above theoretical issues.

Two assumptions seem to have played a central role in the promulgation of the above theoretical shortcomings. The first assumption has been recently formulated by Llinás and Paré (1991, 1996) in terms of thinking of the function of the central nervous systems (CNS) as an open or a closed system. To quote:

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> "…we regard as fundamental the issue of whether the functional organization of the CNS is to be considered to have a closed or open architecture. An open system is one that accepts inputs from the environment, processes them, and returns them to the external world as a reflex regardless of their complexity…This view, which is still pervasive, explains nothing about the function of the CNS or the invariance of its function among individuals….If we opt for the closed-system intrinsic hypothesis, it follows that the nervous system is primarily self-activating and capable of generating a cognitive representation of the external environment even in the absence of sensory input, for example in dreams...From this perspective, cognition as a functional state may be considered as an a priori property of the brain…" (Llinás & Paré, 1996, pg. 4-5)

The assumption of an open system view of the brain may be the basis of discontinuity views of dreaming, e.g. that dreams are fundamentally different from waking experiences (Hartmann, 1973; Hobson & McCarley, 1977; Rechtschaffen, 1978). An example of how an open system view can bias dream research is the idea that seeing in dreams is akin to waking visual imagery but not visual perception (Kerr, 1993); retinal information clearly has nothing to do with what is seen in dreams, leading to the conclusion that seeing in dreams cannot be true visual perception. However, if we adopt a closed view of the CNS, then visual perception and imagery are two innate properties of the brain, and there is no reason in principle why both cannot simultaneously occur in the sleeping brain just as they do in the waking brain. Although a closed system view implies a fundamental continuity between waking and dreaming, because the sleeping brain undergoes gross functional changes, we expect such changes to be reflected psychologically. The view we develop here is a composite continuity/discontinuity view.

A second major assumption, captured in a quote from Purcell, et al., (1993), is that there has been "…a widespread view that waking and sleeping correspond to conscious and unconscious processes." That is, to the external observer, a sleeping person appears unconscious, hence it has been natural to associate forms of sleep mentation such as dreaming with unconscious mental processing. Likewise, a waking person is clearly conscious, and so waking is associated with conscious mental processing. The distinction of conscious/unconscious is particularly strong in clinical interpretive traditions (Freud, 1900), and generally ignored in biological models of dreaming, or not treated in a systematic fashion (e.g. Kahn et al, 1997). However, during lucid dreaming for example, the dreamer is conscious, not only of the dream environment, but of the fact that they are experiencing a dream. If dreaming is associated with unconscious processing, how is it that lucid dreamers can display forms of consciousness equivalent to those expressed during waking (Kahan, LaBerge, Levitan, & Zimbardo, 1997; LaBerge, 1985; Purcell, et al., 1993)? Similar considerations apply to nonlucid dreaming where, for example, some researchers point to the recall of dreams as evidence that dreams involve conscious processing (Fiss, 1983). A related issue we shall address below is the claim that dreaming psychology is deficient relative to waking psychology, which is again difficult to sustain as a formal feature of dreams in the face of the phenomenology of lucid dreaming.

In this paper, we adopt the closed system view of CNS function advocated by Llinás and Paré, and explicitly assume that the repertoire of innate functions expressed by the waking brain is also expressed in the sleeping brain. However, we take this view a step further because the phenomenology of sleep mental experience indicates that the human CNS generates two global conscious constructs: (1) a self, and (2) representations of an external perceptual environment. With respect to dreaming, these representations correspond to the dreamer - the person undergoing the dream experience, and to the dream environment - the perceptual setting in which the dream occurs. As we shall elaborate, examples of functional dissociations between the dreamer and the dream environment exist, and these two representational constructs appear to vary independent of one another.

The main tool we will utilize for comparing the self and the perceptual environment across waking and dreaming is Bernard Baars' Global Workspace (GW) model (Baars, 1988). Our analysis will not only be an application of the GW model to dreaming, but an extension of this model to accommodate the types of mental experiences that occur during sleep. The GW definitions of "conscious" and "unconscious" can be used independent of the global state of the brain. Therefore, this model provides us with a consistent and systematic framework for discussing conscious and unconscious processes involved in representations of the self and the perceptual environment across waking and sleep. The GW model, via the notion of "context," also provides a means for conceptualizing higher order forms of mnemonic organization in the nervous system, which is particularly important for understanding the role of memory in dreaming. Clarifying the relationship of memory and dreaming serves two purposes: (1) it will begin to bridge the biological, interpretive, and content analyses approaches to dreaming, and (2) it will allow us to present a neurobiological model of how the dream perceptual environment is formed from mnemonic structures in the sleeping brain. Our GW analysis will also allow us to propose a new hypothesis of the function of dreaming: dreaming is a form of "mental recombination" that indirectly serves to enhance the flexibility and adaptability of the waking brain.

FUNCTIONAL DISSOCIATION OF THE SELF AND PERCEPTUAL ENVIRONMENT IN CONSCIOUSNESS DURING SLEEP

It is now clearly recognized that mental experiences occur throughout the entire sleep-wake cycle (Bosinelli, 1995; Foulkes, 1967; Hobson, 1988). We begin by considering the conscious aspects of sleep experiences. We will define below our usage of the terms "conscious" and "unconscious". For the moment, the term "conscious" can be taken in its common sense usage as, for example, you, the reader, are conscious of these words, or your environment, or of yourself and your thoughts, etc.. Three major forms of sleep experience contain definite conscious content (Foulkes, 1962): dreams, hypnagogia, and thought-like mentation. The conscious aspects of dreams, hypnagogia and thought-like experiences can be conceptualized in dual terms in which there is a dreamer and a perceptual environment.

In dreams, there is a subject, the dreamer, a conscious person to whom the dream happens. The dream occurs within a vivid perceptual environment in which all perceptual modalities can and do occur. The conscious aspects of the dreamer can be divided into: (1) the conative aspects of conscious cognition such as the dreamer's thoughts, attention, volitions, and imagings (Purcell et al., 1993), and (2) the dreamer's conscious perception of the dream environment. The dreamer and the dream environment can be separated on the basis of intention: the conative aspects of the dream are willed by the dreamer, the perceptual aspects are not. That is, the dream environment is not in any obvious way *intentionally* created by the dreamer. We take this to represent a fundamental dissociation between cognition and perception in dream consciousness. A major purpose of this paper is to address such a dissociation. The concept that dreams contain a "plot" or "narrative" has also guided some investigators' conceptions of dreaming (Cipolli & Poll, 1992; Foulkes, 1978; Kuiken, Neilson, Thomas, & McTaggart, 1983; Kuper, 1979). The dreamer's interaction with the dream environment can take two forms: the dreamer can be immersed within the dream perceptual environment (dreamer-as-actor dreams), or may appear to be outside the dream environment, observing it as if watching television (dreamer-as-observer dreams) (Foulkes & Kerr, 1994; LaBerge, 1985).

In this paper we are not interested in focusing on the controversy surrounding NREM versus REM dreams. Some of this controversy stems from conflicting definitions of these experiences (Kahn et al., 1997; Okuma, 1992). We note here that evidence generally indicates that NREM dreams are simpler than REM dreams along both cognitive (Cavallero, Cicogna, Natale, Occhionero, & Zito, 1992) and perceptual dimensions (Antrobus, Hartwig, Rosa, Reinsel, & Fein, 1987; Antrobus, Kondo, Reinsel, & Fein, 1995) and occur with a low frequency compared to REM dreams (Dement & Kleitman, 1957; Foulkes, 1962). In the scope of our thinking, NREM dreams result from the same mechanisms as REM dreams (Cicogna, Cavallero, & Bosinelli, 1991) although lower levels of cerebral activation may be related to their decreased complexity (Foulkes, 1967). When we refer to dreams throughout, it is implied that our logic applies to both REM and NREM dreams.

Hypnagogia, predominant at sleep onset (or during the sleep-to-wake transition, where it is called hypnopompic imagery), is associated with visual perceptions, although auditory and somatic perceptions can also occur (Schacter, 1976; Schneck, 1968). However, hypnagogic perceptions are less structured than dream perceptions, sometimes surreal in character (Gillespie, 1989), lacking "narrative" elements, and the visual imagery may appear as simple static "snapshots" (Mavromatis, 1987). Hypnagogic perceptions are observed by a relatively passive dreamer, and occur as if external to the dreamer, similar to dreamer-as-observer dreams (Mavromatis, 1987).

Thought-like mentational experiences, termed "NREM mentation" because of their association with NREM awakenings (Foulkes, 1967; Hobson, 1988), more resemble waking thinking and lack the vivid perceptual modalities associated with dreaming. Further, the form of this thinking is banal and repetitive, the content reflecting mundane waking concerns. To quote

Hobson (1988, pg 143), NREM mentation is "nonprogressive…the mind seems to be running in place."

An identical dreamer/environment dichotomy holds during lucid dreams. This dichotomy is particularly evident at the onset of wake-initiated lucid dreams (WILDs), and during the process of fading from a lucid dream (both phenomena are reviewed in LaBerge and DeGracia, 1999). The following example from D.J.D.'s personal dream journal illustrates a functional dissociation between himself as the dreamer and the perceptual environment, during the onset of a WILD:

> "Was aware of being in my body. I wanted to go out. Laid concentrating, desiring to leave…soon, I wasn't aware of anything around me. In my imagination, I imagined flying off, but got pulled back again. This happened twice. Then, I dove off my bed straight downwards. I was moving straight downwards in the void. Far below me in the darkness I saw a square floating. In the square I could see colors, like a scene was inside the square. I stretched to grab this square and my arms stretched far below me like Plastic Man, and I grabbed the floating square. I pulled it up over me like putting on a pair of pants, and was thinking to myself, 'I'm not gonna let this one go!' I stepped into this square and was all of a sudden somewhere! I was very surprised! I was in what looked like a high school hallway standing in line with people going into a room…"

This quote describes the contents of D.J.D.'s consciousness during the transition from laying awake in bed to appearing in a dream fully lucid. D.J.D. lost awareness of the external perceptual environment, leaving him momentarily in a state devoid of any external environment. However, his conscious cognition, including internal speech, self-reflective and imagery capabilities, and the ability to form episodic memories remained intact. He then *imagined* the sensations of flying upwards. This imagery transitioned almost imperceptibly to perceptual sensations occurring external to him, forming a "minimal" perceptual environment (LaBerge & DeGracia, 1999; see also section 7). The minimal environment, termed "the void," was perceived as a dark space (e.g. visual-spatial depth perception devoid of visual content), through which he could move (kinesthesis), although there was no sense of a body image (somestheses) or any other perceptual modalities. Next, within this "void," a form of hypnagogic intrusion (Hunt, 1989) occurred and D.J.D. saw, in the apparent distance, a square containing colored imagery floating. By voluntarily willing his arms to reach out and grab at the square, this somehow caused a bizarre visual appearance of arms, and the kinesthetic sensation of reaching at the square and pulling it upwards. Upon "putting on" the scene inside the square, D.J.D. then *abruptly* found himself in a fully-formed dream perceptual environment. This environment, resembling a high school hallway, contained the full repertoire of perceptual modalities, and was very similar in quality to waking perception. This environment was unfamiliar to D.J.D., had nothing to do with his conscious thoughts and intentions, and appeared spontaneously. What is striking is that the dreamer remained intact cognitively while the perceptual environment underwent such drastic variation.

It is precisely such experiences that have inspired the approach we develop in this paper. To our knowledge, no attempt has been made to quantitate the frequency of conscious WILD transitions amongst experienced lucid dreamers. D.J.D. has remained conscious across the wake-sleep border in 22 out of 103 (21%) lucid dreams, or 22 out of 45 (49%) WILDs. Because of differences in styles of lucid dreaming, we expect such statistics would vary among experienced lucid dreamers (LaBerge & DeGracia, 1999). It is also interesting to note the onset of perceptual modalities in this WILD transition: visual-spatial depth and kinesthesis during the "void" phase, followed by rich visual, somatic and auditory content during the "dream" phase. The modalities associated with the "void" phase correspond to conceptions of the dorsal visual pathway linking occipital and parietal lobes, believed to encode visual-spatial depth and motion (Bertenthal, 1996; Ungerleider & Haxby, 1994). The subsequent "dream" phase entailed simultaneous onset of modalities associated with the ventral visual pathway in inferior temporal lobe which encodes visual form and color perception (Ungerleider & Haxby, 1994), along with auditory and somatosensory modalities. This pattern of dream onset is essentially the opposite of that associated with lucid dream fading (LaBerge & DeGracia, 1999; LaBerge, DeGracia, & Zimbardo, 1999). Although evidence of differential development of sleep in cortical areas exists (Pigarev, Nothdurft, & Kastner, 1997) our phenomenological observations suggest a very specific pattern of cortical activation and deactivation associated with the formation and loss of the dream perceptual environment.

This brief review of sleep experience phenomenology indicates several important generalizations:

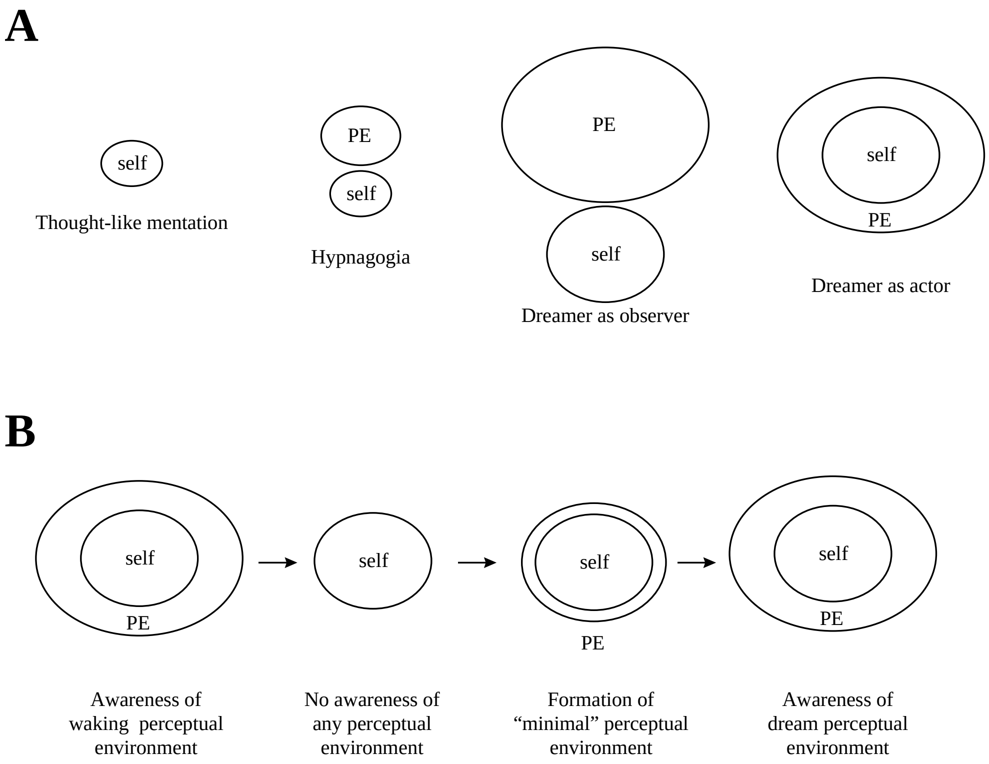


Fig. 1. The structures of sleep conscious experiences in terms of a dual representation of the dreamer (self) and the dream perceptual environment (PE). [A]. The normative types of sleep experience. The transition from thought-like mentation to dreamer-as-actor dreams shows a series of increasing activity in both generators in terms of the complexity of the representations and their interactions. [B]. Illustration of changes in consciousness during a wake-initiated lucid dream (WILD). See text for details.

The CNS generates consciousness of two global and functionally distinct representations: a self, and a perceptual environment.

The complexity of either of these representations can vary. A spectrum of complexity is observable in the perceptual environment, ranging from none in the case of NREM mentational experiences, to simple, static imagery in the case of hypnagogia, to complex multimodal environments in the case of dreams. A similar spectrum of complexity of the dreamer is observed, ranging from the banal thinking of NREM mentational experiences, through the relatively passive observer of hypnagogia and dreamer-as-observer dreams, to the actively participating dreamer of nonlucid dreams, and culminating in the waking-like cognition of the lucid dreamer.

The relative complexity of the dreamer and perceptual environment appears to vary independent of one another. In the case of mentational experiences, a dreamer exists, but a perceptual environment does not, indicating that conscious cognition can occur in the absence of perceptual consciousness. Although the perceptual environments of nonlucid and lucid dreams are similar (Gackenbach, 1988), the conscious cognition of the dreamer is different between nonlucid and lucid dreams (a distinction we elaborate more fully below), indicating that the complexity of the dreamer can vary while the perceptual environment stays relatively constant. The WILD example above shows a cognitive constancy of the dreamer while the perceptual environment varied drastically.

The degree of interaction between the dreamer and the dream environment can vary, ranging from no interaction in the case of NREM mentation, through simple observation of the environment by the dreamer in hypnagogia and dreamer-as-observer dreams, to a complete perceptual and motoric immersion of the dreamer within the environment in fully formed nonlucid and lucid dreams.

In Figure 1, we have developed a simple graphical notation to depict the conscious representations of self and the perceptual environment, and their relationship, in the sleep experiences discussed above. The dreamer and the perceptual environment are depicted simply as bubbles, the relative size of which indicates the complexity of the representations. The interactions are shown by the relative locations of the bubbles: observer-like interactions show the bubbles separated, immersion interactions show the self embedded in the perceptual environment. Depicting conscious sleep experiences as in Figure 1A suggests a formal relationship between these forms of experience. From left to right in Figure 1A we observe a progressive increase in the complexity of both representations and the interaction between them, indicating that a spectrum of activation relates forms of sleep experience, which we address more precisely in section 5.2. Such a relationship parallels the global activation state of the brain during the sleep stages predominantly associated with each of these types of sleep experience: REM dreams > stage II sleep onset hypnagogia > stage III/IV thought-like mentation (Gastaut, 1969). Figure 4B shows a graphic representation of the WILD transition described above. Interestingly, this transition seems to approximate a NREM to REM transition with respect to the increasing complexity of the perceptual environment, although the representation of the dreamer remains constant.

The above view of sleep experience has relevance to the Activation/Input/Modulation (AIM) model presented by Hobson and colleagues (Hobson & Stickgold, 1995; Kahn et al., 1997). The AIM model provides phase space representations of three variables: activation, A (representing brain activation as measured by EEG power), input/output gating, I (a measure of external to internal input as measured by sensory thresholds or motor output), and neurotransmitter modulation, M (a measure of the global neurotransmitter state of the brain as assessed by the ratio of aminergic to cholinergic brainstem neurotransmission). The AIM model plots states of consciousness as a single AIM triad. It seems reasonable to ask if a single triad of AIM variables can account for the apparently independent activities of the dream environment and the dreamer? Also, input/output gating is not a unitary phenomena; sensory input is a perceptual function, effector output is a cognitive function mediated by the dreaming self. If we compare central activity during REM, then input and output are vastly different. For example, primary visual cortex is virtually silent during REM (Braun, Balkin, Wesensten, Gwadry, Carson, Varga, Baldwin, Belenky, & Herscovitch, 1998), motor cortex is active by several criteria (Hess, Mills, Murray, & Schriefer, 1987; Steriade, Iosif, & Apostol, 1969; Porte & Hobson, 1996), but is inhibited from peripheral expression (Hishikawa & Shimiz, 1995; Steriade, 1992). These changes represent different perceptual and cognitive activities, respectively, and further suggest the need to dichotomize the AIM portrayal of sleep experiences.

In summary, the phenomenologies of the variety of sleep experiences are evidence for a functional dissociation of conscious representations of the self and the perceptual environment within the CNS during sleep. We utilize this observation, in conjunction with the GW model, to develop a framework that will allow us to systematically compare conscious and unconscious processes across dreaming and waking.

The arguments presented in Llinás and Paré (1991), the essence of which is quoted above, indicate that a third gross function occurs in the awake nervous system: the parameterization of the perceptual generator with input from the senses.

Inspired by Stephen Thaler's (1996a, 1996b) Creativity Machine Paradigm, we imagine the perceptual and cognitive generators as interacting information networks in which sensory input parameterization to the perceptual generator is optional. We can visualize these ideas (Figure 2) by *metaphorically* depicting sensory input, and the perceptual and cognitive generators as gears: a "sensory input gear," a "perceptual gear" (representing the perceptual generator and its conscious output), and a

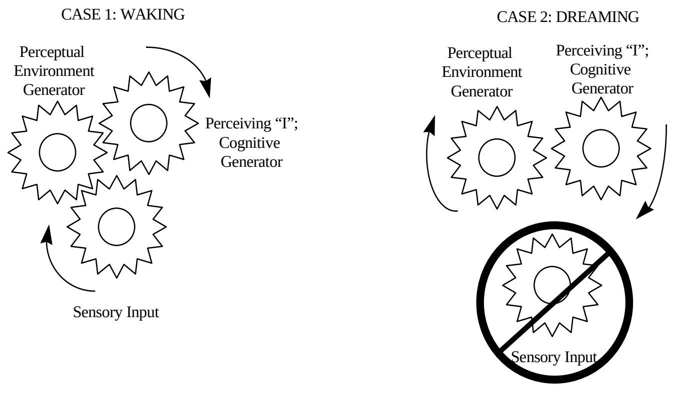


Fig. 2. Simplified view of conscious processes during waking and dreaming. During waking, sensory input serves to parameterize the generation of a perceptual environment; the consistent perceptual structure serves as a basis for consistent cognitive activities. During dreaming, loss of sensory input parameterization leads to inconsistency in the perceptual generator, and increased lability between perceptual and cognitive activities of consciousness.

"cognitive gear" (representing the cognitive generator and its conscious output). During waking, the three gears engage each other and move in synchrony. Sensory input gives content to, or "parameterizes," the perceptual generator. The self, encompassing the conative, cognitive and metacognitive components of consciousness, reacts to and acts upon its perceived environment in a consistent fashion. However, during sleep, sensory thresholds increase across all sleep stages (Bonnet, 1986; Bonnet & Johnson, 1978; Busby, Mercier, & Pivik, 1994; Niiyama, Sekine, Fushimi, & Hishikawa, 1997; Rechtschaffen, Hauri, & Zeitlin, 1966), which can be construed as "disengaging" the "sensory gear" from the equation, and leaving only the "perceptual" and "cognitive" gears in functional operation. The operation of the cognitive and perceptual generators minus sensory input parameterization results in the conscious sleep experiences described above. We now fill in the details of this model by first focusing on waking experience, and then returning to a more detailed discussion of nonlucid and lucid dreaming.

OVERVIEW OF THE GLOBAL WORKSPACE SYSTEM DURING WAKING

When we talk about the perceptual and cognitive generators above, we are discussing the major, salient, phenomenological aspects of conscious awareness. Our normal waking subjectivity contains consciousness of an external perceptual environment *and* of being an "I" with memory access, volition and other cognitive abilities within this environment. Both aspects of consciousness have substructure and both ride astride many complex, some as yet undetermined, *unconscious* processes. We now refine and expand upon these concepts within the framework of Bernard Baars' GW model.

The GW model (Baars, 1988; Baars, 1997a; Neuman & Baars, 1993) is an elegantly simple, yet powerful framework that envisions waking psychology as an unceasing interplay of conscious and unconscious processes (Figure 3). Conscious processes manifest as a "global workspace" which in turn is structured and conditioned by a host of unconscious neurocognitive processes. The central metaphor of the GW model is quite simple: consciousness serves as a system-wide receiving and broadcast medium for the entire nervous system. To use Baars' terminology, consciousness is the "publicity organ" of the nervous system. Unconscious elements input structure into consciousness such as perceptions, emotions, thoughts, and motivations. Consciousness in turn serves to broadcast its contents to the entire nervous system, and in doing so activates or recruits other relevant unconscious processes related to attentional, cognitive, metacognitive, mnemonic or effector actions. In this sense then, consciousness is a *global* "workspace" - a global medium - in which transactions of information occur throughout the entire CNS.

CONSCIOUSNESS DURING WAKING

The "stream of consciousness" is clearly a composite of many facets including perceptions, imaginings, recollections, attention, emotions, thoughts, metacognitions and volitions. Baars suggests that conscious operations can be divided into three areas. *Conscious experiences* are perceptual or "quasi-perceptual" and are the direct, immediate content of our consciousness: sensory-based perceptions, internal imagery, emotions, thoughts, recollections and so forth. *Consciously-mediated access* involves access to contents that are not currently conscious, but can be made so readily. This suggests a type of "penumbra" surrounding focal consciousness, an area of "preconsciousness" to which consciousness can immediately shift (Baars, 1996a; LaBerge & Rheingold, 1990). Conscious access operations are closely associated with voluntary attention, voluntary memory access, and imagery operations (Baars, 1997b). *Conscious-mediated control* is, essentially, volition, the ability to consciously initiate access and action operations.

We can map Baars' three aspects of conscious operations onto our dichotomy of perceptual and cognitive generators, as shown in Figure 4, illustrating the gross structure of the global workspace of consciousness as we will define it in this paper. Conscious control and access operations are initiated by the self, and hence considered by us as products of the cognitive generator. Conscious experiences, however, are produced by both the cognitive and perceptual generators. Consciousness experiences of an external environment are the most vivid aspects of conscious experience (Baars, 1988). However, conscious experiences of internal imagery, including modal (visual, auditory, verbal, tactile, kinesthetic, etc.) and amodal (semantic, intuitive) imagery, and affect, are initiated by and/or occur *within* the self, and are therefore products of the cognitive generator within our framework.

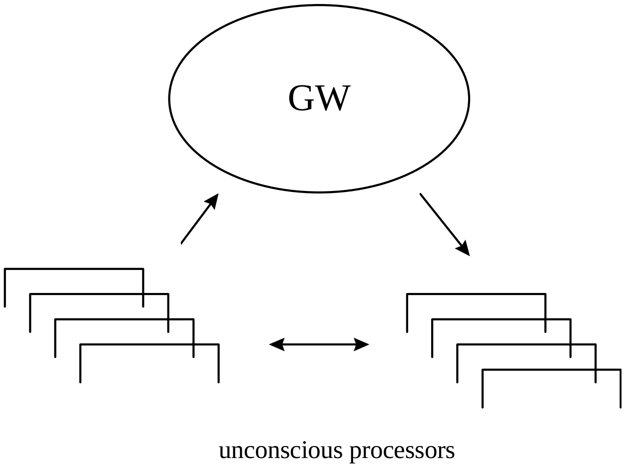


Fig. 3. The GW model portrays consciousness as a "global workspace" (GW) supported by unconscious processors that input structure into consciousness and use the contents of consciousness to mediate changes in the nervous system. Diagram modeled after Baars (1988).

Such an assignment of conscious experiences across both generators may seem somewhat arbitrary but for the following considerations: (1) the perceptual generator is directly parameterized by sensory input, but the cognitive generator is not, which is why, during both waking (Kosslyn, 1994) and dreaming (Worsley, 1988), the imaginal contents of consciousness can occur in parallel to the perception of an external environment. (2) Neuroimaging data indicates that modality specific internal imagery shares components with networks mediating direct perceptual experiences (Chen, Kato, Zhu, Ogawa, Tank, & Ugurbil, 1998; Farah, Peronnet, Gonon, & Girard, 1988; Kosyln, 1994). However, imagery and perception are two different systems both anatomically (Howard, Fytche, Barnes, McKeefry, Ha, Woodruff, Bullmore, Simmons, Williams, David & Brammer, 1998) and functionally (Mellet, Petit, Mazoyer, Denis, & Tzourio, 1998), and the fidelity of these systems can be compromised by dividing attention between them (Baars, 1988; Posner, 1982). (3) The distinction between perceiving what appears to be external to our self and internal to our self is consistent with the phenomenology of normal subjective experience during both waking and dreaming.

Baars (1988) offers further characteristics of conscious processes. Conscious processes are computationally inefficient in some respects; they are error prone, slow, of limited capacity, subject to mutual interference, and are serially ordered over time. On the other hand, consciousness provides a medium for associating an almost endless variety of contents (a relational capability), but is also acutely sensitive to context, which provides for an internal consistency to conscious contents. Our precise usage of the term "context" will be provided below.

UNCONSCIOUS PROCESSES DURING WAKING

In contrast to conscious processes, Baars (1988) points out that unconscious processes are limited in functional range (e.g. are dedicated to one or a few processing functions) but, taken as a whole, have a large computational capacity. Unconscious processes are computationally more efficient; they occur in parallel, have a low error rate, high speed and display little mutual interference. The detailed operation of these special-

Conscious processes	Unconscious processes
Computationally inefficient; High number of errors, low speed, and mutual interference between conscious computations.	Highly efficient in their own task; Low number of errors, high speed, and little mutual interference
Great range of different contents over time (differentiation and complexity); great ability to relate different conscious contents to each other (relational capacity);great ability to relate conscious events to their unconscious contexts (context-sensitivity); conscious contents are informative.	Each specialized processor has limited range over time; each one is relatively isolated and autonomous
Have internal consistency, seriality, and limited capacity.	Diverse, can operate in parallel, and together have great capacity.

Table 1: Comparison of conscious and unconscious processes. Adapted from Baars (1988).

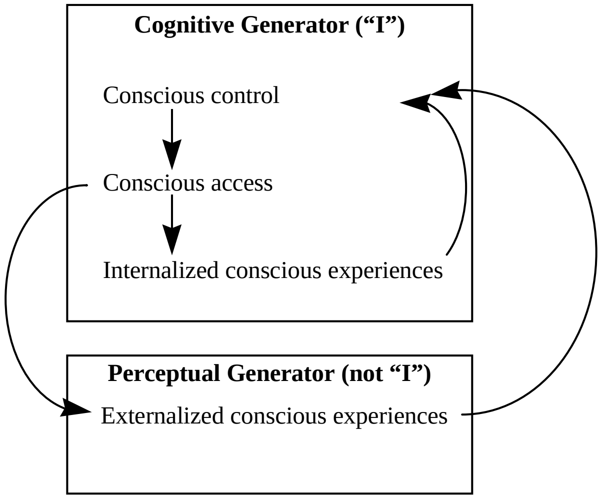


Fig. 4. The Global Workspace of consciousness. Mapping the ideas of cognitive and perceptual generators to Baars’ (1988) functions of conscious control, access, and experience. Conscious control and access are mediated by the “I” of the cognitive generator. Conscious experiences are a product of both the perceptual and cognitive generators; the former producing externalized objects of awareness, the latter producing both modal and amodal forms of internal imagery and recall.

ized subsystems critically affects the contents of consciousness yet remains outside of direct conscious awareness. A comparison of conscious and unconscious processes is provided in Table 1. In bringing the notion of unconscious processes explicitly into our discussion we begin to introduce important details to the models presented in Figures 2 and 4. More specifically, conscious experience, access, and control operations are mediated by unconscious processes (Baars, 1988; Rock, 1997).

Two examples illustrate the distinction between the terms “conscious” and “unconscious” as used in the GW model. Opening one’s eyes results in the intense conscious experience of seeing. Seeing is not merely passive; directed attention, motivation, and goals influence what we see (reviewed in Theeuwes, 1994). However, beyond these *modulating* influences, the generation of vision proceeds automatically and unconsciously. We know a great deal about unconscious visual processing modules and their pathways, from the actions of light in the retina (Sterling, 1998), to the complex columnar structure of area 17, the generation of color and complex form in the ventral visual pathway, and the generation of motion, depth and spatial perception in the dorsal visual pathway (reviews can be found in Gulyas, 1997; Schiller, 1997; Zeki, 1997). The activity of these systems generates our conscious experience of seeing, and yet occurs outside of direct conscious awareness, which is presumably the composite end result of these lower level unconscious processing stages (Marr, 1983; Moore & Engel, 1999). A second apt example of the role of unconscious processing is the reading of these words. As you read these words, you quite automatically and unconsciously convert patterns of light and dark contrast to meanings in your consciousness. There are many intervening neurocomputational stages of visual and linguistic processing between seeing this sentence and knowing the meaning of these words in your mind. The intervening visual, syntactical, grammatical, semantic, and mnemonic processing stages are essentially invisible to your consciousness (Baars, 1988). And, wth a lttl mr cnscs effrt u cn qte atmtclly dcd ths sntnc. The foregoing is a feat of pattern recognition far beyond any current technology, and its neurocomputational underpinnings happened unconsciously, automatically.

More precisely, Baars’ use of the concept “unconscious processors” corresponds almost exactly to Llinás and Paré’s (1996) concept of the “neurological a priori” properties of the brain. To use examples provided by these latter authors, abilities such as hearing, seeing, acquiring language, and so forth do not have to be learned; these are genetically determined properties of the human brain, although their optimum expression is use-dependent (Black & Greenough, 1986). Both of these concepts are widely recognized today as referring to the discreet “processing modules” associated with specific cortical and subcortical regions.

On the basis of the above considerations, we can expand our conception of the perceptual and cognitive generators to indicate that they are generating conscious operations from a host of unconscious processors (Figure 5). In fact, we can now state that inclusion of sensory parameterization in Figure 2 was but one specific type of unconscious influence on conscious processing. Sensory input is unique, however, because it is functionally “optional”; it dominates waking, but is attenuated during sleep. In Figure 5, the generators are now depicted as boxes with a third dimension of depth. The top surface of each box indicates the conscious output of the generators, the depth is meant to convey the unconscious processes occurring underneath the surface of consciousness, “behind the scenes” so to speak.

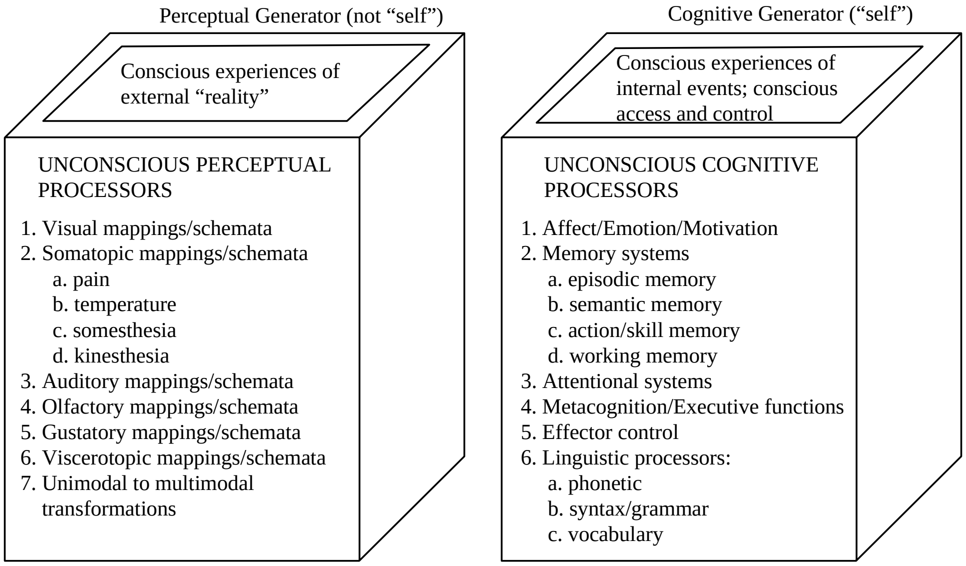


Fig. 5. The conscious output of the perceptual and cognitive generators is mediated by a host of unconscious neurocognitive processes.

The unconscious processors of the perceptual generator involve brain regions dedicated to sensory processing. Anatomically, these consist of complex feedback circuits between unimodal and multimodal sensory cortex and their respective thalamic nuclei (the thalamocortical loops of Llinás and Paré, 1991), with some variation in pain and olfactory systems (Smythies, 1997). During waking, perceptual modalities are parameterized by input from ascending sensory pathways which, in fact, represent a minority of input to the perceptual generator (Erisir, Van Horn, & Sherman, 1997; Sherman & Koch, 1986; Wilson, Friedlander, & Sherman, 1984). In Figure 5, the term "mappings/schemata" used to describe the unconscious processors of the perceptual generator refers to the sensory-specific representations of each modality, and the multiple topographic mappings and coordinate transformations that exist throughout cortical and subcortical sensory pathways (Cline, 1998; Kaas, 1997; Obermayer, Sejnowski, & Blasdel, 1995). Unimodal sensory cortices contain relatively discreet processing modules capable of representing different aspects of a given modality (Felleman & Van Essen, 1991; Mesulam, 1998). Unimodal sensory pathways converge to multimodal cortices where evidence suggests that alignment of various unimodal mappings are transformed into multimodal representations (Bertenthal, 1996).

The cognitive generator is clearly more complex than the perceptual generator. Our list of unconscious processors mediating conscious cognition of the self (Figure 5) is not meant to be exhaustive, but representative of such processors, all of which are subject to conscious access and control by the self. These include facilities for mediating directed attention, various forms of voluntarily accessible memory (including declarative and short-term/working memory), affect/emotion, motivation, forms of executive control (D'esposito & Grossman, 1996) such as volition and metacognition (thinking that reflects on thinking), and effector control.

The neuroanatomical substrates of cognition are not fully understood presently, but do involve higher order cerebral cortices and their associated subcortical connections. Multimodal association cortices project to supramodal cortical sites, where highly processed sensory information converges with limbic, attentional, motor, mnemonic, and other forms of nonsensory information (Cohen & Eichenbaum, 1993). Together these systems serve as nodes in parallel distributed networks (Bullmor, Rabe-Hesketh, Morris, Williams, Gregory, Gray, & Brammer, 1996; Felleman & Van Essen, 1991; Goldman-Rakic, 1995), from which cognitive functions arise. Since our main concern in this paper is developing a framework for discussing the general structure of subjective consciousness, neuroanatomical loci or neurophysiological functions associated with aspects of cognition will be introduced as needed in the discussion.

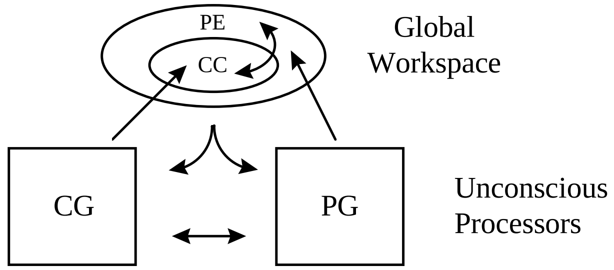


Fig. 6. Our adaption of the GW model dichotomizes consciousness into conscious perception of the external environment (PE = perceptual environment) and the conative aspects of conscious cognition (CC). This diagram illustrates potential pathways of information flow operating at either conscious or unconscious levels of neurocognitive processing. See text for details.

Clearly, perception structures cognitive functions such as thinking and planning. Likewise, cognitive operations direct the machinery of perception. Thus, an important aspect of perceptual and cognitive generator function is that they interact with one another. By "interaction" we mean the transfer of information between the perceptual and cognitive generators. An important distinction of generator interactions is whether these occur in consciousness or via unconscious forms of processing.

Figure 6 provides a graphical depiction of the ideas stated to this point. Consciousness (the GW) is dichotomized into representations of an external perceptual environment and the conscious cognition associated with the self. Both of these derive from the concerted action of many unconscious processing modules, which are depicted simply as the perceptual and cognitive generators. Figure 6 also shows the information flow pathways possible in this model. Information flows into the GW from the unconscious processors and in turn, the GW can project information back to the unconscious processors in both generators. That is, information can be indirectly transferred between generators using consciousness as an intermediary. Information can also be directly transferred between the modules of the generators, bypassing conscious awareness altogether.

COOPERATION, CONTEXTS, AND PERSONALITY

We now elaborate in some detail on how the information content of unconscious modules affects conscious operations by describing Baars' (1988) concepts of "cooperation" and "contexts," ideas intimately related to learning and memory. These ideas are central in our application of the GW model to dreaming.

"Cooperation" means that transient coalitions of unconscious processes can be recruited on an "as needed" basis and thereby affect conscious operations as a unit. Such a view is consistent with the results of neuroimaging studies showing activation of different networks of brain regions during execution of specific cognitive and behavioral tasks (Posner, DiGirolamo, & Fernandez-Duque, 1997; Posner & Raichle, 1994). A similar type of modular cooperation is to be found in cognitive models of linguistic production in which discreet processing modules for phonetics, grammar, syntax, semantics, and pragmatics are hypothesized to interact (cooperate) in the flow of language comprehension and production (Foss & Hakes, 1978; Winograd, 1972).

However, regularities in perceptual and cognitive activities produce regularities in cooperative activity among unconscious processors. These more permanent associations of unconscious processes Baars' terms "contexts." Baars defines contexts as "relatively enduring [information] structures that are unconscious, but that can evoke and be evoked by conscious events" (Baars, 1988, p. xx), and also as "a system (or set of systems) that constrains conscious contents without itself being conscious" (op. cit., p. 372).

To provide a bridge between Baars' psychological concept of "context" and current ideas in the neurobiology of memory, we now introduce a formal model of memory presented in Cohen and Eichenbaum (1993). The intent of this model is to explain results from memory studies of normal and amnesic human subjects, and lesion data from animal studies. The Cohen and Eichenbaum model defines two forms of memory in the CNS: declarative and procedural memory. The authors' own words best describe this distinction:

> "…the declarative memory system receives, and plays a mediating role in the storage of, the outcomes of processing events. Declarative memory is a fundamentally relational representation system. The relational nature of declarative memory gives rise to two properties…representational flexibility and promiscuity…declarative memory is promiscuously accessible to, or can be activated by, various processing modules, regardless of which processing modules were engaged in the processing of the original learning event; and, once accessed, it can be manipulated and flexibly expressed in various…contexts, regardless of how much those contexts differ from the circumstances in which the information

> was initially acquired." (Cohen & Eichenbaum, 1993, pg. 73)
>
> "By contrast, procedural representations, supported by memory systems that operate independently of the hippocampal system, are inflexible and dedicated. Their storage resides with and remains inextricably linked to the processing modules that were engaged during the initial learning. This type of memory involves not the storage of outcomes of processing operations, but rather tuning of and changes in the way those operations actually run--that is, modifications of the processing elements themselves. This type of representation is therefore inflexible; it is only accessible to those processing modules that were engaged during the original learning experiences, and only when they are again engaged. The representations, therefore can only be expressed or otherwise exert their influence under...conditions that so closely mirror the ..original learning...as to constitute a repetition of the original learning situation." (Ibid, pg. 74).

To put the above description of the declarative memory system in perspective, we need some sense of input/output relationship of this system with other brain regions. Therefore, we here introduce some of the anatomy of this system, which will be important later when we present a neurobiological model of the formation of the dream environment.

Declarative memory is mediated by what we shall term in this paper the medial temporal lobe memory system (MTMS). The MTMS includes the hippocampal system (HS = hippocampus proper, subicular complexes, and dentate gyrus [DG]), and related rhinal cortices (the entorhinal [EC], parahippocampal [PHC], and perirhinal [PRC] cortices) (Cohen & Eichenbaum, 1993; Suzuki, 1996). The information flow into the MTMS involves highly processed outputs from higher order cortices feeding into the PHC and PRC. These project to the EC (Amaral, Insausti, & Cowan, 1987; Braak & Braak, 1992; Insausti, Amaral, & Cowan, 1987) which in turn projects to the HS. All of these pathways are bidirectional so that HS output follows the reverse pathway. A highly oversimplified flow diagram is:

higher order unimodal and supramodal cortices ⇆
PHC & PRC ⇆ EC ⇆ HS

Although there is significant overlap, the input to the rhinal cortices displays a gross modality specificity. The PRC receives a large input from visual pathways in the inferior temporal lobe related to object recognition, form and color processing (e.g. visual areas TE and TEO) (Suzuki & Amaral, 1994a). The PHC is further divided into areas TH and TF (Bonin & Baily, 1947). TH has significant auditory and spatial inputs (Suzuki & Amaral, 1994a). Area TF has strong somatosensory and visual-spatial inputs, including connections with dorsolateral prefrontal cortex and posterior parietal lobe (Cavada & Goldman-Rakic, 1989). The PHC and PRC share significant bidirectional interaction amongst each other and with the EC (Suzuki & Amaral, 1994b). All of the rhinal cortices are further bidirectionally connected with multi- or supra-modal sites in the prefrontal cortex, dorsal superior temporal sulcus, cingulate cortex or retrosplenial cortex (Suzuki & Amaral, 1994a; Suzuki, 1996; Witter, Groenewegan, Lopes da Silva & Lohman, 1989). Thus, there is a huge convergence of highly processed cerebral information serving as input to the MTMS; the outcome of sensory processing converges with information pertaining to attention, affect, motivation, planning, and motor behavior (Eichenbaum & Otto, 1993).

Cohen and Eichenbaum discuss why there would be two types of memory systems in the CNS. The declarative system is a set of processing modules whose function is to flexibly relate the output from other processing modules into long-term declarative memories, which then become promiscuously accessible to the entire nervous system. Procedural memory, on the other hand, seems to be a generic property of all of the processing modules, such that repetitive activity in a given module will fine-tune and optimize the operating characteristics of that module. Hence, procedural memory is a local form of memory apparently innate in nervous tissue, whereas declarative memory is a global form of memory, requiring specific modules (the MTMS) to instantiate it. Cohen and Eichenbaum recognize that the declarative system is in fact a multiple memory system from the point of view of content, and that legitimate distinctions can be drawn for episodic, semantic, or other content-specific forms of declarative memory (Schacter & Tulving, 1994; Squire, 1994; Tulving, 1987).

Cohen and Eichenbaum's declarative/procedural distinction is strikingly similar to Baars' functional differentiation between conscious and unconscious processing. Consciousness is associated with global CNS access, content flexibility and relational capability. Unconscious processors are associated with local, dedicated processing. Clearly, declarative memory is an important component underlying conscious processing operations, and procedural memory underlies changes in unconscious processing modules. On this basis, it is not unreasonable to assert that the contents of consciousness serve as input to the declarative memory system; not all conscious contents enter the declarative system, but all input to the declarative system comes from conscious contents. As Baars (1988) has pointed out, associative learning only occurs in conscious animals: even Pavlovian conditioning cannot be performed on an unconscious animal.

Baars' concept of "context" encompasses both declarative and procedural memory systems. When changes occur in a single unconscious processor, leading to changes in conscious operations, this is a form of contextual learning in the GW system. Examples of single processor changes affecting consciousness, without the change being conscious, might include perceptual (Schacter & Buckner, 1998) or conceptual priming (Graf & Schacter, 1985), or the learning of motor skills (Willingham, 1998), activities which would improve reaction times in repetitions of the original learning situation.

However, patterns of relationships *amongst* processors could lead to higher order procedural modification of many separate processors simultaneously. This is an implication not explored in Cohen and Eichenbaum (1993); that the declarative memory system itself could be subjected to procedural memory effects. Which is to say, styles of learning and styles of relating information entering the declarative system can become optimized and fine-tuned over time. The procedural fine-tuning of the declarative memory system would occur with exposure to repeating patterns of learning and relationship encountered during perceptual or behavioral activities. Hence, within the declarative/procedural memory distinction, Baars' concept of "context" actually encompasses two distinct levels of the organization of mnemonic information in the nervous system: (1) it can refer to procedural modifications of individual processors, or more importantly, (2) it can refer to higher order patterns of relationship produced by the declarative system but made implicit over time by procedural effects within the MTMS. In this paper, our use of the term context will be meant to refer to the second usage, unless otherwise specified.

It is this second sense of "context" by which Baars (1988) describes how the specific information content of the CNS forms higher order memory structures which impart an implicit "framing" effect on conscious processes. Baars defines specific types of contexts, which are relationships between multiple processors that are implicit, not explicit, in on-going conscious operations. For example, he defines "goal contexts" as complex mnemonic composites, combining semantic and episodic memory, motivational, and effector modules required to envision and execute specific goals. During the real-time execution of a goal, the overall goal-context fades from direct consciousness, but continues to implicitly frame real-time conscious activities. Baars defines "belief contexts", which can be thought of as patterns of learning by which the individual conceptualizes and organizes new experiences. Over time, these patterns of learning become progressively more implicit in, yet still exert influence over, conscious activities. In section 6.1.2 we shall define a specific multicomponent mnemonic structure, the "lucid dream context," the operation of which, we will argue, distinguishes lucid from nonlucid dreams.

Returning to our dichotomy of the perceptual and cognitive generators, the modules of both of these are subject to procedural and declarative effects, and can participate in the formation of higher order contexts. Perceptual contexts will frame conscious perceptions of the external environment. A simple example is that when we look outside, the sky is always up. It is not unreasonable to imagine that, through constant repetition of this visual stimulus, visual-spatial brain regions are highly optimized at always representing the sky in an upward direction relative, say, to the overall visual scene or the pull of gravity. Such a "the sky is always up" context would explain why the sky is typically in an upward direction in dreams. Similarly, habits of thinking, habits of learning, habits of self-perception, etc. will form contexts within the cognitive generator.

Baars, however, goes even further and suggests that different contexts do not exist in isolation from one another, but form "context hierarchies," where broader, more encompassing contexts contain within them more local contexts. This idea culminates in the notion of a "Dominant Context Hierarchy" which Baars equates with representations of Self. That is, the Dominant Context Hierarchy is the sum total of all contextual organizations in an individual's nervous system. At this level of conceptualization, in fact, the GW model is a model of the structure of the human personality and, as such, is highly consistent with cognitive-affective personality paradigms in personality research (Mischel & Shoda, 1998) and other models of the self (Damasio & Damasio, 1996).

The impetus behind these ideas is clearly to understand how information is organized and utilized in the nervous system, and specifically how preexisting memories provide *implicit organizations* which frame, structure, or limit real-time conscious operations. We feel it is critical to recognize that Baars' notion of Dominant Context Hierarchy converges to the psychology of personality. When we discuss changes in conscious and unconscious processes during dreams, we will take the waking personality, conceptualized as a structure of contextual hierarchies, to be our basic unit for all across-state comparisons.

COMPETITION AMONG UNCONSCIOUS PROCESSES

The contextual structuring of conscious operations is a neurocomputational strategy for dealing with the limited capacity of conscious operations; with the formation of habits of thinking and action, any given conscious operation contains more information than it would otherwise. Another method, elaborated by Baars (1988, 1993), for increasing the efficiency of conscious operations, is to set barriers for access to consciousness by forcing unconscious processes to *compete* with each other for access to consciousness. One conscious result of unconscious competitive processes involves the shifting of attention; when unconscious processes compete, the "winner" gains access to consciousness (dominates the global workspace, to use Baars' terminology) and typically becomes the focus of attention. In this fashion the salient and most urgent information gains access to and control of consciousness.

Baars (1988) defines two forms of competition: (1) competition between potentially conscious stimuli, and (2) competition between different context hierarchies. The former clearly is relevant to the perceptual generator, the second form of competition occurs within and/or among both generators. In the first, and better studied case, competition can occur between sensory modalities, or between stimuli within a modality, directly affecting conscious perceptual experiences (Flowers, 1990). An example of perceptual competition is the Necker cube, which can only be seen in one perspective in any instant. Competition amongst different context hierarchies involves significant cognitive complexity. A simple example may be whether one should go golfing or write the grant whose deadline approaches. Such competition involves displacement of the current contextual hierarchy by another, altering the implicit structuring of conscious operations (Baars, 1988). This would manifest consciously as shifts in mental set and orientation, shifts in attitude, or shifts in goal objectives. Competition for conscious experience can also occur between the perceptual and cognitive generators, for example, the competition between perception and imagery (e.g. Greenberg, 1977). We utilize the idea of competition between context hierarchies in section 7.2 to explain the observation that lucid dreams are relatively susceptible to reversion to nonlucid dreams.

NOVELTY, LEARNING, AND CONSCIOUSNESS DURING WAKING

The GW model contains important functional implications for waking conscious operations. The transient cooperation of unconscious processors imparts a large degree of flexibility to conscious operations. Waking consciousness can be seen as a mechanism for responding to novelty, and for providing a medium of association between a wide variety of potentially conscious contents. On the other hand, regularities of perception and action produce regularities in cooperative activity among processing modules, leading to the contextual structuring of conscious operations. In this regard, consciousness can be seen as the medium through which repetitive forms of perception, cognition, and action are converted into the more efficient form of relatively automatic and unconscious habits and routines via both procedural and declarative memory systems. Thus, waking consciousness is a (global) "work space" substantially linked to adaptability and learning; conscious contents can reorganize into new patterns, but can also transfer relevant patterns to long-term storage as more efficient unconscious contexts. Clearly, as psychological maturation proceeds, increasingly established perceptual and cognitive contextual structures will limit the flexibility of waking conscious operations. As dream theorist have noted, dreaming consciousness is characterized by a "hyper-associativity" (Freud, 1900; Hobson, 1988; Kahn et al., 1997). In section 9 we will formulate this observation in terms of the flexibility aspect of consciousness strongly predominating over the formation of habit-responses during dreams, which will allow us to suggest a function for dreaming within the overall economy of the nervous system.

FUNCTIONAL REORGANIZATION OF THE BRAIN DURING SLEEP

There is divergence among dream theorists as to the role of sleep neurobiology as a causative factor in sleep psychology. Some investigators question a direct causal link between sleep biology and psychology (Foulkes & Cavallero, 1993; Moffitt & Hoffmann, 1987). Other investigators have constrained their views of sleep psychology based on our current knowledge of sleep neurobiology (Hartmann, 1982; Hobson & McCarley, 1977; Kahn et al., 1997; Koukkou & Lehmann, 1983). Clearly, the brain undergoes significant changes during sleep, and it would be unreasonable to believe that this cannot directly alter the psychological functioning, and even gross function, of the sleeping brain. We now outline the salient aspects of sleep neurobiology to set a stage for discussing the gross psychology of sleep.

The most obvious feature of the sleeping brain is the sleep cycle: the time course of alternation between stages I-IV NREM and REM (Rechtschaffen & Kales, 1968). Considerable evidence from animal-based studies shows that these periodic alterations are mediated by changes in brainstem neurotransmission involving primarily the serotonergic raphe nuclei, noradrenergic locus ceruleus, and the cholinergic pedunculopontine and laterodorsal tegmental nuclei (reviewed in Gaillard, 1985; Hobson & Steriade, 1986; Jones, 1991). The reciprocal interaction model (Hobson & Schmajuk, 1988) states that aminergic transmission decreases while cholinergic transmission increases across NREM stages I-IV, reaching their minimum and maximum, respectively, during REM sleep. The original activation-synthesis model posited that cholinergic transmission served as a diffuse activation source for the forebrain via PGO waves; this view has been expanded by culminating evidence that there are changes in other neurotransmitter systems (reviewed in Kahn et al., 1997). One of the more well-established consequences of altered neurotransmission during sleep is an attenuation of sensory-input processing (Geof, Allison, Shapiro, & Rosner, 1966; Velasco, Velasco, Cepeda, & Munoz, 1980). Considerable evidence indicates that changes in brainstem neurotransmission during sleep are consistent with increased sensory thresholds and alternations of burst- and transmission-modes in the thalamo-cortical perceptual system (reviewed in Guido & Lu, 1995; McCormick, 1992; Steriade & Llinás, 1988).

Ideas of a diffuse activation of the brain during sleep, or ideas of asymmetrical cerebral activation (Antrobus, 1987; Green & McCreery, 1994) have had to be modified by evidence that patterns of forebrain activity are more focal than had initially been suggested by EEG studies. Two lines of investigation have provided evidence for focal changes in brain activity during sleep in humans: neuroimaging studies, and neuropsychological studies of the dreams of patients with focalized brain lesions.

The neuroimaging studies, in particular, are in their earliest stages and have produced both conflicting and consistent results. For example, three imaging studies of REM all saw increased activity (after subtraction of waking scans) in the amygdala, anterior cingulate gyrus and temporal lobe regions associated with the MTMS (e.g. parahippocampal, and/or entorhinal cortex) and all saw decreased activity in the posterior cingulate gyrus (Braun, et al., 1997; Maquet, Peters, Aerts, Delfiore, Degueldre, Luxen, & Franck, 1996; Nofzinger, Mintun, Wiseman, Kupfer, & Moore, 1997). However, each study reported activity changes in regions not necessarily reported by the other two studies. For example, Braun et al. (1997) and Nofzinger et al. (1997) saw increased basal ganglia activity, which was not reported by Maquet et al. (1996). Descriptions of changes in cerebral cortical regions were particularly disparate between the three studies. These discrepancies are likely due to differences in imaging procedures, sleep paradigms, subject samples, and what was going on in the minds of the subjects at the time of brain scans.

Data about sleep psychology acquired from brain damaged patients is difficult to interpret. Patients with similar symptomology will be grouped together, but none of the patients have exactly the same pattern of brain damage. Brain damage interrupts white matter tracts as well as lesioning nuclei, making functional assignments ambiguous (Farah, 1994). Furthermore, obtaining such data is difficult: these patients often cannot talk or comprehend language well, and have sensory, motor, mnemonic, emotional or motivational deficits to varying extents. Distinguishing between dream recall and true cessation of dreaming is problematic, although not insurmountable (Solms, 1997). Thus, trying to obtain data about sleep experience in this way is a brave task. However, some generalizations have emerged. Specific types of focal damage result in alterations in dream consciousness or in global cessation of dreaming (Epstein, 1979; Murri, Arena, Siciliano, Mazzotta, & Muratorio, 1984; Schanfald, Pearlman, & Greenberg, 1985; Solms, 1997). For example, occipital damage producing visual irreminiscence during waking leads to loss of visual dreaming (Solms, 1997). Mark Solms (1995, 1997), in perhaps the most extensive study of the dreams of brain lesioned patients to date, has suggested that damage to two rather gross regions - the white matter tracts feeding the ventral frontal lobes, and the posterior parietal cortex - can lead to complete cessation of dreaming. We return to Solms' thinking below.

Although Hobson, et al. (1998b) has claimed that the neuroimaging studies are consistent with the patient data, it is clear from our brief review that regions consistently displaying high activity in neuroimaging studies are not the same regions Solms claims are necessary for preventing cessation of dreaming. Perhaps the largest inconsistency in this regard is that Solms' patient data indicates the continuation of dreaming in patients with pontine damage, ostensibly contradicting the central role of brainstem transmission suggested by animal-based studies, and at least one of the neuroimaging studies (Braun et al., 1997). Clearly then, increased regional activity does not imply that activity is necessary and sufficient for dream production.

Given the limits of present imaging technology and neuropsychological analysis, we have gained intriguing hints that suggest definite patterns of cerebral activation, but nothing so definite we can build unassailable models of dreaming solely on these bases. In section 8.3, we utilize the above data, in conjunction with phenomenological data of dream subjectivity, to construct a neurobiological model of the genesis of the dream environment. However, we present our model clearly recognizing its susceptibility to revision as new and more precise data emerges. What is clear presently is that the brain undergoes substantial functional changes during sleep which represent clear discontinuities across the sleep-wake cycle. We believe a fusion of continuity and discontinuity views is required. From a closed system perspective of the CNS, there is continuity because it is fundamentally the same system operating across the sleep-wake cycle. The discontinuities, evident in both the biology and the psychology (as we discuss below), result from a functional reorganization of the brain-mind system during sleep.

DREAM CONSCIOUSNESS AS ACTIVATION OF THE COGNITIVE AND PERCEPTUAL GENERATORS

Hunt (1989) explicates the subtle difficulties of defining dreams and of comparing them to waking experience. Perhaps counterintuitively, distinguishing dreaming from waking in a fashion all can agree upon has proven elusive. Several researchers analyzing the specific content of dreams have been impressed with the general similarity between dreams and waking experience (Boss, 1958; Dorus, Dorus, & Rechtschaffen, 1971; Hall & van de Castle, 1966; Hunt, Ogilvie, Belicki, Beliki, & Atalik, 1982; Kahan, et al., 1997). Other investigators stress differences between waking and dreaming (Antrobus, 1987; Foulkes, 1991; Hobson, 1988; Retschaffen, 1978).

As we stated in section 2, the phenomenology of subjective experience during sleep indicates that there is a spectrum of activation operating in both the perceptual and cognitive domains. The idea of "activation" figures prominently in several conceptions of dreaming. The original formulation of the activation-synthesis model was that ascending brainstem impulses serve as a source of forebrain activation (Hobson & McCarley, 1977), a necessary prerequisite to produce the rich conscious content of dreams (Hobson & Steriade, 1986). The AIM model has formalized the continuous variation of cerebral activation during sleep (Hobson & Stickgold, 1995). John Antrobus' notion of "cortical activation" during dreaming refers to the spread of activation through network nodes (Antrobus, 1986; Antrobus, 1991). Hunt's (1989) notion of "intensity spectrum" describes the range of cognitive fidelity occurring in dreams: confusion and clouding of consciousness at one extreme, ego-transcending transpersonal states of consciousness at the other extreme of this spectrum. Lequerica (1996) has also explicitly recognized a continuum in dream cognition. With the exception, perhaps, of the original formulation of the activation-synthesis model, what all of these views share is the recognition that cognition in dreams occurs along a continuum, be it cortical activation, fidelity of cortical networks, or degrees of cognitive expression.

What all of these views lack is the recognition that the dreamer and dream environment can be conceptualized as two separate entities that can undergo alterations seemingly independent of one another. From a third person perspective (e.g. reading dream reports by others), it is natural and logical to think of the dream perceptual environment as just another element within the dreamer's consciousness, and lump changes in the dream environment along other aspects of the dreamer's cognition. Again, however, from the first person viewpoint we have experienced many times in the dream state, it is clear to us that the dream environment seems to behave as if it is a thing quite independent of our conscious cognitive activities. As well, we have both personally observed variations in our own conscious cognition during dreaming, being at times more like waking and at times less than waking, and these cognitive alterations appear to occur independent of the dream perceptual environment. Hence our dual characterization.

We explicitly associate the dreamer and the dream perceptual environment with the activities of the cognitive and perceptual generators, respectively, as these were defined throughout section 4. Our main idea is relatively simple: both generators can undergo degrees of degeneration as their activation levels decrease. Two terms are important in our characterization of the activation levels of the dreamer and the dream environment. The "intensity" of a given conscious or unconscious process is the *amount* of that process expressed during sleep relative to waking. The "fidelity" of a given process is the *quality* with which that process expresses itself relative to waking. Changes in subjective phenomenology across waking and sleep can then be expressed as changes in intensity and/or fidelity of either conscious or unconscious processes, in either the cognitive (dreamer) or perceptual (dream environment) domains. We apply this thinking first to the dreamer, and then to the dream environment.

THE DREAMER'S COGNITION

Within our framework, the activation of the cognitive generator during sleep can range from very low to being equivalent to waking. High cognitive generator activity will result in the waking personality appearing as the dreamer; decreasing cognitive generator activity will result in a dreamer who has less and less fidelity relative to the waking personality, yet who is still composed of elements of the waking personality.

We envision the dreamer undergoes something akin to "graceful degradation", in the neural network sense of Hopfield (1982). "Graceful degradation" occurs in parallel-distributed networks (PDPs), such as neural nets, as component nodes are removed one by one. Since infomation in a PDP is stored through connection weights involving many nodes simultaneously, removal of nodes one by one does not result in abrupt breakdown of network fidelity, but a gradual breakdown where information stored in the network becomes progressively more blurred, imprecise or overlapping (Brown & Zador, 1990). We imagine that the "graceful degradation" of the dreamer will result from decreased intensity and/or fidelity of unconscious cognitive processors. Thus, looking at changes in conscious cognition during dreaming should shed light on which unconscious processors are involved in sleep-wake cognitive differences.

In a series of recent papers, J. Allan Hobson, David Kahn, Edward Pace-Schott, and Robert Stickgold have posited a catalogue of changes in consciousness during dreaming. We take this formulation as our point of departure for contrasting waking and dreaming consciousness. In Table 2, we have developed a composite list of the state-dependent changes in dream consciousness derived mainly from Hobson, Stickgold, and Pace-Schott (1998) and Kahn et al. (1997). Their characterization of the differences in consciousness across states is, in fact, readily interpretable in terms of our notions of perceptual and cognitive generators. In Table 2 we have classified these authors' differences in terms of four categories. Does the change occur in: (1) the perceptual generator, (2) the cognitive generator, (3) the interaction between perceptual and cognitive generators, or (4) across major brain states (e.g. wake to dream, dream to wake, dream to dream)?

We also need to point out that there is controversy in regards to specific items in Table 2; this list by no means represents a consensus view of dream consciousness (Kahan & LaBerge, 1994; Purcell et al., 1993). The view expressed in Table 2 has been termed the "deficiency view" of dreaming (Kahan & LaBerge, 1994; Purcell et al., 1993) because it portrays the dreamer as cognitively deficient relative to the waking self. This view further lacks an appreciation of the "multiplicity" of dreams (Hunt, 1989) to which we refer ahead.

In this section we focus on the list of alterations in the dreamer's cognition presented in Table 2. First, affect is generally enhanced, particularly in the negative direction of stress, fear, and anxiety. Correspondingly, "fight or flight" reactions occur relatively more frequently in dreams than in waking. Multiple differences in cognition and memory are noted in Table 2.

Generally, these are all deficiencies relative to waking, with the exception of hyperassociativity - an increase in associative processing in dream consciousness compared to waking (Kahn et al., 1997). Changes in thinking processes include weak logical rigor, *ad hoc* reasoning and a substantial incidence of confabulation. Thought is considered delusional in dreams by these authors because "we are consistently duped into believing that we are awake" (Hobson et al., 1998b, Table 1), although it is noted in Hobson et al. (1998b) that lucid dreams are an exception to this feature. Volition is claimed to be weak, and self-reflection (a metacognitive or executive function) is claimed to be absent or greatly diminished relative to waking.

Several changes in the dreamer's memory are noted: recent memory is diminished, remote memory is enhanced, and working memory decreased.

A similar deficiency view of dream cognition is captured in Alan Rechtschaffen's (1978) famous notion of the "single mindedness and isolation" of dreams. Rechtschaffen describes dreams as self-contained experiences, isolated from the on-going episodic experience of the waking self. Within this self-contained experience, the dreamer is completely absorbed in the ongoing sequence of events, lacking the overarching framework of waking

PG-related	**CG-related**	**PG-CG interactions**	**Across States**
IO gating: • External perception diminished. • Internal perception enhanced (e.g. hallucinations).	Affect: • Increased emotion, dominated by fear and anxiety. • Instinctual programs (especially fight-flight) often incorporated into dreams.	Attention is lost. (Conscious PG-CG interaction).	Memory deficits across dream-wake, wake-dream, and dream-dream transitions.
PG defects: • Incongruity (perceptual): dream imagery is strange, unusual, or impossible. • Discontinuity (perceptual): discreet or abrupt transition in dream imagery.	Thought: • Reasoning *ad hoc*. • Logical rigor weak. • Processing by hyperassociativity. • Confabulation prevalent. • Thought is delusional.	Orientation: • Semantic uncertainty of the dreamer toward persons, places, and events in the dream. (Conscious PG-CG interaction).	
	Volition: • Volitional control weak, greatly attenuated.	Incongruity (semantic): conceptions of persons, places, and things are fused, plastic, incongruent, and unstable. (Conscious PG-CG interaction).	
	Metacognition: • Self-reflection absent or greatly diminished relative to waking.	Discontinuity of dream "plot." (Unconscious PG-CG interaction).	
	Memory: • Recent memory diminished. • Remote memory enhanced. • Decreased working memory.	Confabulatory narrative construction of the dream "plot." (Unconscious PG-CG interaction).	

Table 2: Comparison of waking and dreaming consciousness taken from Hobson et al. (1998b) and Kahn et al. (1997). We have categorized these authors' characterizations of across-state differences in consciousness in terms of the notions of perceptual generator (PG-related), cognitive generator (CG-related), the interaction of the perceptual and cognitive generators (PG-CG interactions) at either conscious or unconscious levels, and across-state differences. The cognitive features in particular represent a deficiency view of dreaming consciousness (Kahan & LaBerge, 1994).

experience to guide the dreamer's thinking and action. The dreamer appears to be at the mercy of the "relentlessly unfolding" (Kahn et al., 1997, pg. 17) quality of the dream perceptual environment.

In contrast, some cognitive functions appear unaltered in dream consciousness. Language during dreaming, occupying as much as 30% of all dream activity (Hall & Van de Castle, 1966; Meier, 1993), is essentially identical to waking. Language in dreams occurs as both overt and covert vocalizations, in the same variety of contexts as during waking. The results of Strauch and Meier (1992) stress the "ordinary, everyday nature" of dream speech. Salzarulo and Cipolli (1974) have shown that the syntactic organization of dream speech is similar to waking speech. The formal characteristics of dream speech include its pragmatic competence, complexity, well-formedness, grammaticality, lexical correctness, and syntactic competence (Meirer, 1993). Dreamers also make voluntary choices within the context of the dream, reflect on, and pay attention to dream events (Kahan et al., 1997). Dreamers are involved in the execution of goals which are local to the dream circumstances. Although the overall context of waking experience is not present, there is still substantial spontaneous explicit recall of waking episodic memories by the nonlucid dreamer (unpublished data). Habitual forms of metacognition occur in dreams (Kahan, et al., 1997), which we feel is the basis of being "duped into believing that we are awake" while dreaming; most people do not make a habit of reflecting on their state of consciousness while awake, so why should they when dreaming?

The profile in Table 2 seems to indicate executive cognitive functions are more sensitive than nonexecutive functions to the "graceful degradation" of the cognitive generator (see Benson, 1994, for a comparison of executive and nonexecutive cognitive functions). However, this is a superficial generalization because the average dreamer *does* exercise executive cognitive functions such as directed attention, volitional actions, metacognitive thinking and so forth, but *these are all expressed with respect to events occurring in the dream, not with respect to waking experience* (Kahan & LaBerge, 1994).

We would suggest that a list of ostensibly formal "cognitive deficiencies" of the dreamer, important as it is for characterizing dream phenomenology, gives a misleading impression of the mechanisms of cognitive degradation during dreaming. If we look closely at the above profile, what it indicates is that highly automatic procedural-type actions, such as language use, attention, and even styles of thinking and metacognition retain fidelity relative to waking, but that cognitive activities dependent upon promiscuous access to memory structures stored in the brain show degradation. That is, the *content* of thinking is faulty, not thinking per se. Thus, we do not feel that executive functions undergo substantial degradation during typical normative dreaming, but that mnemonic systems are transformed across the sleep-wake cycle. The claims about memory defects in Table 2, of a diminution of "recent memory" and working memory, and enhancement of remote memory, suggest changes to the processors underlying these mnemonic functions. Interestingly, alterations of memory co-occur with exaggerated emotion; this phenomenology is supported by neuroimaging observations of increased activation of the amygdala (Maquet et al., 1996; Nofzinger et al., 1997) during REM sleep compared to waking. Both the emotional and mnemonic alterations point to changes in medial temporal lobe structures as playing an important role in the functional reorganization of the sleeping brain. Ahead we will elaborate extensively on the role of across-state memory changes when we present our neurobiological model of dream genesis.

Our view of dream cognition not only addresses deficiencies relative to waking, but posits that, at high levels of cognitive generator activity, the dreamer will approach the fidelity of the waking personality. Such experiences have been termed "lucid dreams" (Hunt, 1989; Green, 1968; Snyder & Gackenbach, 1988). The experiences to which we here refer are typically brief, spontaneous experiences, occurring in the context of nightmares and/or immediately preceding awakening (Green, 1968), suggesting these experiences result from shifts in cerebral activation and neuromodulation as the brain prepares to awaken. As we explicate below, this type of dream lucidity is a "lucid dream" in only the most circumscribed sense. Snyder and Gackenbach, (1988) discuss the difficulties with assessing incidences and frequencies, but present the conservative estimates that 58% of the population has experienced this form of dream lucidity at least once in their life, and that, on average, about 13% of an individual's dreams contain such elements of lucidity.

When the dreamer approaches the fidelity of the waking personality, a consequence is that the dreamer displays memory similar to that of the waking personality. This being the case, dream events become perceived with respect to memories of waking experience, and the dreamer can realize he or she is dreaming. In the average circumstance, following this mnemonic alteration the dreamer awakens. This low frequency case of the waking personality "coalescing", as it were, within a dream environment, may be considered an "embryonic" lucid dream. We now discuss how this experience provides a phenomenological bridge between lucid and nonlucid dreaming.

LUCID DREAMS

If the comparison of waking and dreaming has been an elusive endeavor, so too has been the attempt to compare lucid and nonlucid dreams. Lucid dreams have traditionally been defined as "dreams in which the dreamer knows they are dreaming" (Green, 1968; LaBerge, 1985). After personally spending a considerable amount of time in this state of consciousness, we do not believe this conception adequately reflects the essence of these experiences. Previously, LaBerge presented the notion of a "lucid dream schema" as a means to characterize the *cumulative* cognitive nature of these experience (LaBerge, 1985). Here we expand this notion and describe what we shall call the "lucid dream context." In both our opinion and experience, it is the operation of a lucid dream context that necessarily distinguishes lucid from nonlucid dreams. Issues of physiological brain activation remain relevant with regard to the innate variability of lucid dreaming (discussed below). We also discuss the imperative to be sensitive to the degree of development of the lucid dreamer's skill base in characterizations of dream lucidity.

A review by Gackenbach (1988) of the content of lucid and nonlucid dreams concludes "lucid dreams are more *like* nonlucid dreams than different." The phenomenological details of lucid dreams indicate that they partake substantially of psychological elements from both nonlucid dreams and waking (Green & McCreery, 1994; Kahan et al., 1997; Kahan & LaBerge, 1994; LaBerge & DeGracia, 1999). We feel that ideas such as Covello's (1984) characterization of lucid dreams as "an incongruous blend of waking and dreaming", Mahowald and Schenck's (1992) idea of the overlapping of dreaming and waking, or Charles Tart's (1988) suggestion that the lucid dreamer *is* the waking self, approach a more accurate characterization of these experiences. The lucid dreamer purportedly has a heightening of those same cognitive functions that are deficient in nonlucid dreamers but present during waking: voluntary control of action, wider voluntary memory access, increased self-reflectiveness, and increased quality of thinking. In contrast to nonlucid dreams, lucid dreams are generally remembered by the waking personality following awakening. Stated more precisely, lucid dream experiences contribute substantially to the episodic memory structure of the waking personality. Many studies have attempted to correlate overt waking cognitive, perceptual, or personality characteristics with the propensity to lucid dream (reviewed in Snyder & Gackenbach, 1988). However, given the imprecise and variable definitions of dream lucidity in these early studies, it has been difficult to draw any firm conclusions on this issue. Perhaps the most robust result is that lucid dreaming has been correlated with increased dream recall ability (Gackenbach, 1988; Gackenbach, 1991a, 1991b; Hunt, 1989; Snyder & Gackenbach, 1988; Spadafora & Hunt, 1990).

Such observations, along with REM state neuroimaging (Braun et al., 1997; Maquet et al., 1996; Nofzinger et al., 1997) and brain lesion data (Solms, 1995, 1997), have led Hobson et al. (1998b) to suggest that lucid dreaming results from the activation of dorsolateral prefrontal cortex (DLPFC) and the concomitant appearance, in the dreamer's cognition, of the executive cognitive functions associated with this brain region (D'esposito & Grossman, 1996; Weinberger, 1993). We have, in part, addressed this, increasing the fidelity of the cognitive generator during sleep will produce experiences of "embryonic" lucidity as described above. The major weakness to the suggestion that DLPFC activity is the sole basis distinguishing lucid and nonlucid dreams is its failure to account for the expression of executive functions in nonlucid dreams as discussed above, or the failure of executive functions during lucid dreams (Gillespie, 1983; Gillespie, 1984; Green & McCreery, 1994; LaBerge & DeGracia, 1999). In spite of ostensible differences with nonlucid dreams, many of the same cognitive deficits associated with nonlucid dreams can occur in lucid dreams: lapses in thinking, failure of voluntary memory access, incidences of confabulation, decreased rigour of thinking, and difficulty in recalling of lucid dreams after awakening (Hunt, 1989; Levitan 1994; LaBerge & DeGracia, 1999). A lucid dreamer's cognitive fidelity can vary both within and between lucid dreams. Such variations in the lucid dreamer's cognition are part of the innate variability of lucid dreaming (LaBerge & DeGracia, 1999) referred to above. Again, these deficits appear to revolve around issues of promiscuous memory access as opposed to executive function. In short, the spectrum of cognitive variation associated with nonlucid dreaming also occurs in lucid dreaming.

THE LUCID DREAM CONTEXT

If lucid dreams are not simply an increase in prefrontal executive cognitive function (or more generally, enhanced cognitive generator activity) over nonlucid dreams, then what distinguishes lucid and nonlucid dreaming? Hunt (1989) refers to lucid dreaming as the development of the dimension of self-reflectiveness within dreams. We feel a more precise definition along such lines is required:

Lucid dreaming is a line of skill development initiated and sustained by the waking personality, that seeks to create a framework of belief and action which serves to bring the waking personality into the dream state on a repeatable basis.

This definition indicates that lucid dreams are less a specific type of dream, and more a specific type of experience of the waking personality. The mental set that allows this control is what we call the "lucid dream context." We have recently expounded (LaBerge & DeGracia, 1999) that the lucid dream context consists of at least three cooperatively acting components operating at metacognitive, declarative, and action/skill levels of cognitive organization (Figure 7).

The *reference to state* (RTS) is a metacognitive reference to one's state of consciousness while dreaming. It is not the mere statement "I am dreaming" made while dreaming, because this statement can be made as simple abstract knowledge lacking the metacognitive component (Hunt, 1989; Tart, 1988). Although the RTS would seem to be an increase in executive functioning (e.g. increased metacognition), the basis for the RTS is the increased fidelity of the lucid dreamer's voluntarily-accessible memory. It is only by contrast to memories of waking that a dreamer can know they are dreaming (Tart, 1988). Thus, the dreamer's accessible memory must resemble that of the waking self. The RTS can be explicit, as when one realizes, "I am dreaming." For experienced lucid dreamers, the RTS is implicit; it forms a contextual basis framing the dreamer's thoughts and metacognitive reflections (DeGracia & LaBerge, 1999). The comparison of the RTS underlying dream lucidity to the waking experience of transpersonal states of consciousness has been suggested (Gackenbach, Cranson, & Alexander, 1986; Hunt, 1989). We do not agree with this characterization; our more modest experience has been that the waking equivalent of the RTS condition during dreaming is simply the metacognitive realization one is not dreaming while awake.

The *declarative framework* includes: (1) a set of semantic beliefs used by the waking personality to conceptualize lucid dream experiences, and (2) the accumulation of episodic memories of these experiences. We have indicated (LaBerge & DeGracia, 1999; LaBerge, Levitan, DeGracia, & Zarcone, 1999) that it is *not* necessary for the waking personality to conceptualize their experiences as dreaming; equally prevalent semantic concepts for this experience include "out-of-body experiences" and "astral projections" (DeGracia, 1997). As has been previously argued (LaBerge, 1985; Levitan & LaBerge, 1991), astral projections, out-of-body experiences and lucid dreams are all the same phenomena. These terms, we believe, emphasize different aspects of the innate variability of lucid dreams (LaBerge & DeGracia, 1999). The only substantial distinction between these terms is that they represent different semantic notions used by individuals to conceptualize their experience. Semantic beliefs are important because they constrain what the dreamer believes is and is not possible within the dream state (LaBerge, 1985).

The *goal-options framework* consists of a set of goal-options, or action/skill choices associated with lucid dreaming. There are two categories of action/skills contained in the lucid dream context: (1) the range of behaviors exercised while in the dream state, and (2) the actual practices that allow the waking personality to pull itself into the dream state. The former set of actions is heavily conditioned by the semantic framework (LaBerge & DeGracia, 1999); the latter is relatively independent of semantic beliefs but not of episodic memory (e.g. compare LaBerge and Rheingold, 1990 to Rogo, 1986).

Examples of action skills voluntarily executed by lucid dreamers include those particular to the dream state - flying, passing through walls, and similar pseudo-magical actions (LaBerge & DeGracia, 1999) - and those carried over from waking, such as reading (albeit with difficulty as described in Green and McCreery, 1994; LaBerge,1985), speaking, walking, etc. Paul Tholey (1988, 1991) has pursued research on the development of waking skills in lucid dreams. Some actions are unintentional and forced on the dreamer by the dream envi-

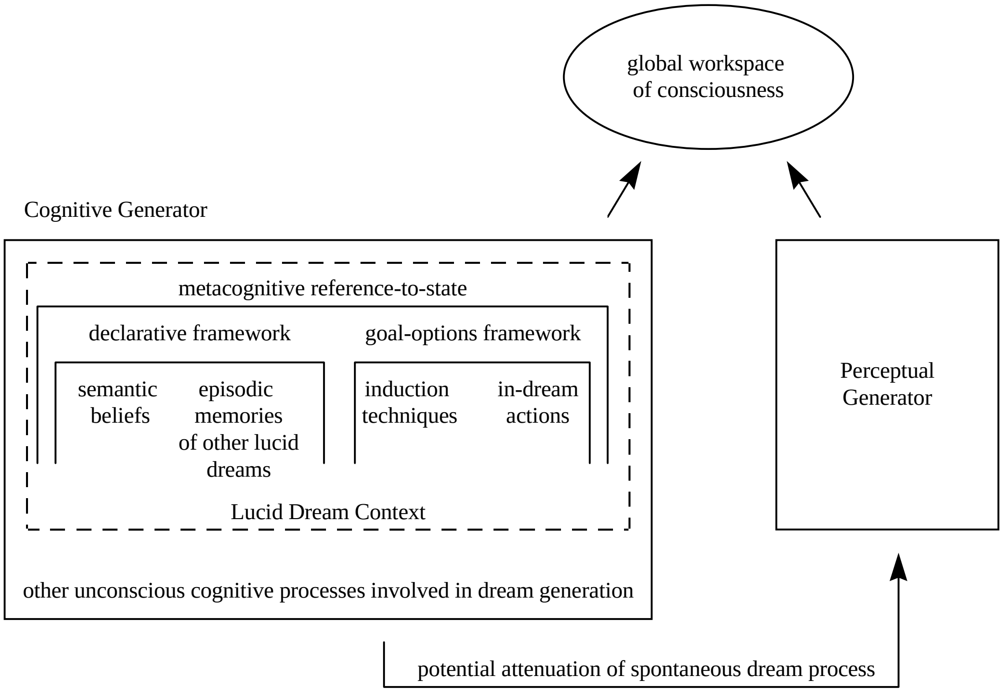


Fig. 7. Structure of the lucid dream context and its relation to the spontaneous process of dreaming. The lucid dream context is a cognitive contextual set developed during waking, and expressed and sustained by the self during dreaming. Specific metacognitive, declarative (semantic and episodic), and procedural elements are required for the skilled execution of lucid dreaming The lucid dream context results in the voluntary-induced heightening of cognitive activity during dreaming, allowing the waking personality to manifest as the dreamer. The lucid dream context places an increased computing load on the cognitive generator during dreams and may potentially withdraw computing resources from unconscious cognitive processes contributing to the structure of the dream perceptual environment. This mechanism explains the propensity of lucid dreams to fade.

ronment. Perhaps the most common of these are skills lucid dreamers develop to prevent the loss of lucidity (LaBerge & Rheingold, 1990), and skills to prevent lucid dreams from fading (LaBerge, DeGracia, & Zimbardo, 1999; LaBerge & Rheingold, 1990); the necessity to develop such skills is very significant and is elaborated below.

Other actions carried out by lucid dreamers are conscious cognitive access and control operations: accessing waking memories, thinking of dream events in terms of waking experience, making explicit effort to remember lucid dream experiences, and actively paying attention to, and exploring, the dream perceptual environment (LaBerge & Rheingold, 1990).

The methods in the goal-options framework that allow the waking personality to voluntarily enter the dream state are of particular interest. These methods (LaBerge, 1985; LaBerge & Rheingold, 1990; Rogo, 1983; Price & Cohen, 1988; Ophiel, 1982) include some mix of: (1) cultivating the desire to appear in the dream state, (2) developing dream recall abilities, (3) a set of concentration techniques that allow the waking personality to maintain conscious cognition across the wake-sleep border (as illustrated in Figure 1B), and (4) the practice of techniques that condition one to metacognitively reflect on one's state of consciousness while both waking and dreaming, called "state-testing" (LaBerge and Rheingold, 1990; Purcell, Mullington, Moffitt, Hoffmann, & Pigeau, 1986; Purcell et al., 1993).

Current views generally see dreaming as a passive process; dreams just "happen" to the sleeping self (Empson, 1989). Clearly dreaming is a spontaneous activity of the nervous systems but, like other aspects of our physiology and psychology, dreaming can be controlled and refined. All lucidity induction techniques are initiated and sustained by the waking personality. Both the declarative and goal-options frameworks of the lucid dream context are subject to procedural memory effects;

relevant processors can be fine-tuned and optimized through practice, and lead to the development of skilled and habitual behaviors. Thus, lucidity induction techniques, dream recall abilities, in-dream actions, and semantic beliefs about the nature of the experiences can all become habitual (form contextual hierarchies) to the experienced lucid dreamer. Lucid dreaming is thus a skill the waking personality can choose to cultivate like any other skill such as playing piano, painting, doing mathematics, etc. (LaBerge, 1980; Moffitt & Hoffmann, 1987).

The lucid dream context is our name for the mental set that allows the waking personality to exercise some degree of voluntary control over the dreaming processes. Stated somewhat differently, in lucid dreaming, the personality seeks to control its own brain activity during sleep and bring itself into the dream. As lucid dreaming techniques require the strong active participation of the waking personality, and undergo the transformation from requiring conscious effort to a relatively unconscious routine (next section), this suggests a plastic reorganization of dream neurophysiology via intentional effort. The intentional effort results in a reorganization of mnemonic processes during sleep such that the conscious cognition of the sleeping brain approaches that of the waking brain. It is this intentional effort that separates skilled lucid dreaming from spontaneous, “embryonic” dream lucidity. For developed lucid dreamers, the increased brain activation derives from intentional control superimposed over the dreaming process, whereas embryonic lucid dreams result from the spontaneous and unconscious neurophysiology associated with the sleep-wake transition. The underlying global brain physiology may turn out to be quite similar in both cases. However, it is the *source* of brain activation that is significantly different. Hence, lucid dreaming is defined by us primarily in cognitive terms. This cognitive structure - the lucid dream context - becomes another contextual structure in the hierarchy of contexts that make up the waking personality. This is not to say issues of unconscious brain physiology are unimportant in the phenomenology of lucid dreaming, only that they are not the primary distinguishing factor between lucid and nonlucid dreaming.

INTENTIONAL CULTIVATION OF A LUCID DREAM CONTEXT

A lucid dream context does not appear fully formed in the mind of the lucid dreamer. Skilled lucid dreaming results from a developmental sequence of learning and practice. Like any other skill learning, this development involves a transformation from intense conscious participation to relatively unconscious expectations and rote skills (Baars, 1988). Because of the imprecision that exists in conceptions of lucid dreaming (Blackmore, 1982), we here explicate the developmental progression of skilled lucid dreaming. We draw on Baars’ (1988) notion of the *adaptation cycle* as a means to conceptualize this developmental process. In Baars’ words:

> "In learning about a new source of knowledge we often start with considerable uncertainty and confusion. By paying attention to the problem, a sense of clarity is often gained, as we become conscious of what is to be learned. Finally, with practice, the material becomes highly predictable and fades from consciousness. These three stages make up what we call the adaptation cycle: Starting only with the knowledge that there is something to be learned, the first stage of *context creation* is resolved as the elements to be learned are defined; in the second stage we have a working context for understanding new material, which is now *informative* - that is, input now serves to reduce uncertainty within the working context. In the third stage, we have *adapted* completely, and lose conscious access to the learned material" (Baars, 1988, pg. 184).

Thus, according to Baars' account, there are three phases to learning: (1) context creation, (2) context development, and (3) adaptation. In the first two phases, consciousness plays a critical role in defining and assimilating the new context, respectively. In the final phase, the context is established and aspects of the context become, to a large extent, unconscious mnemonic factors framing conscious operations. We suggest it is essential to view lucid dreaming from this perspective.

The creation phase of a lucid dream context leads to the first experience of the waking personality manifesting as the dreamer. An individual can cultivate a spontaneous RTS experience on a trial-by-error basis, or via instruction, into a lucid dream context. Alternatively, the possibility of lucid dreaming may be introduced at the semantic level by some form of instruction. However, semantic knowledge of lucid dreaming does not lead to formation of a lucid dream context. The important semantic information to be acquired at this stage is to learn methods to induce the RTS condition during dreaming. There must be an experiential occurrence of the RTS in a dream at some stage, allowing the waking personality to actually manifest as the dreamer. This experience then serves as a point of nucleation in memory around which a lucid dream context can develop.

Once the waking personality has had a direct experience of being in the dream state, and has learned techniques for intentional RTS induction, there follows an exploratory phase involving practice of the lucid dream induction methodology and the learning of new experiences obtained as a result of these practices; this is the informative, or context development phase. The functional importance of the declarative framework grows during this phase as it provides a basis within which to conceptualize episodic experiences and set action boundaries within lucid dreams. The goal-option framework also grows as effective and possible behaviors are identified.

After time, procedural elements of dream lucidity induction become habitual (Worsley, 1991). Repeating features of RTS occurrences in lucid dreams are assimilated and begin to transform into unconscious metacognitive habits and patterns of expectation. Aspects of lucid dream behavior that initially required conscious participation become unconscious expectations, conditioned by the increasingly implicit declarative framework. Thus, with the adaptation phase of establishing a lucid dream context, many aspects of the context become habitual.

This latter consideration has implications in regard to identifying putative patterns of brain activation associated with lucid and nonlucid dreams. It has been shown that development of new skills is associated with widespread brain activation, particularly involving prefrontal cortex, but as the skill becomes more refined, and transfers to unconscious rote, brain activation becomes more focal, involving only those regions needed to mediate the task (Posner & Tudela, 1997). Such considerations may also apply to lucid dreaming. For experienced lucid dreamers who have made the process of lucidity induction habitual, there may be no difference in regional activation patterns between such individuals and nonlucid dreamers undergoing dreams with equivalent degrees of global cerebral activation. Confirmation of this possibility would underscore the cognitive, as opposed to biological, conception of lucid dreaming.

One consequence of our view is that lucid dream reports need to be analyzed with respect to the developmental stage of the lucid dreamer. Reports from experienced lucid dreamers will tend to be richer than those of inexperienced lucid dreamers. However, facets of the lucid dream may be implicit in the reports of experienced lucid dreamers, but fail to be recognized in the reports of inexperienced lucid dreamers. Another consideration involves sensitivity to subjects' semantic conceptions; lack of such sensitivity accounts for some of the ostensible cognitive deficiencies of lucid dreams (LaBerge & DeGracia, 1999). We believe these considerations begin to clarify issues that have confused the study of lucid dreams (Blackmore, 1982) and their relationship to both waking and nonlucid dreaming. In effect, what we are saying is that a lucid dream is not a lucid dream is not a lucid dream. In analyzing lucid dreams, it is critical to be able to pinpoint where along the developmental spectrum a particular subject lies. Different criteria of analysis will necessarily apply at different stages of development. Clearly the cognitive considerations are vastly different between isolated, spontaneous occurrences of lucidity preceding awakening, and the intentionally-induced lucid dreaming we are describing here. The former reflects spontaneous and unconscious neurophysiology, the latter is the result of conscious and intentional development of the skills, conceptions, and experience base outlined above.

Thus, to summarize our view of the dreamer's cognition: this can undergo a spectrum of activation ranging from the low complexity NREM-associated mentation, to the expression of the waking personality and associated forms of lucidity. The aspects of the dreaming self most sensitive to "graceful degradation" appear to be those involved in declarative memory formation and access; the most insensitive aspects appear to be overlearned cognitive activities. As the declarative mnemonic system degrades, this creates the *appearance* of executive control dysfunction that has been associated with deficiency views of dream cognition. The waking personality can develop a lucid dream context, a set of methods for intentionally taking the waking personality into the dream state relatively intact. This effort is superimposed over the innate activity spectrum associated with the cognitive generator such that lucid dreamers can display cognitive deficits similar to nonlucid dreamers.

THE DREAM PERCEPTUAL ENVIRONMENT

If the dreamer undergoes "graceful degradation" during sleep, the perceptual environment (PE) displays much more abrupt change. Here we outline the phenomenology of sleep perceptual environments.

In section 2 (see also Figure 1) we spoke of the spectrum of complexity of the sleep PEs. Given our present understanding of the cerebral organization of sensory modalities, we can discuss these changes in terms of the presence or absence of specific modalities. Thus, no modalities operate in pure mentational experiences. Hypnagogic imagery is characterised by: (1) the presence of visual object modalities minus visual-spatial context, (2) the occasional presence of auditory "object" modalities minus an auditory-spatial context, and (3) the rare occurrence of somatosensory modalities, which more often are not present. In dreams proper, the whole repertoire of sensory modalities exist. Some authors have associated dreaming predominantly with visual imagery, but when we consider that roughly 50% of cerebral cortical area is dedicated to visual processing (Felleman & Van Essen, 1991), then it is no surprise that vision is prevalent in dreaming. The difference between dreamer-as-actor dreams and dreamer-as-observer dreams involves somatosensory spatial immersion in the PE for the former and not the latter.

Content analysis of dreaming provides us with information as to the frequency of occurrence of things in dream PEs. Generally, anything found in the waking PE can exist in dream PEs. The Hall and Van de Castle (1966) content rating scale looks like a categorization of normal waking perception. When we look at the normative content data collected by Hall and Van de Castle, it indicates that dream PEs are much more like waking than the usual idea of dreams as disjointed bizarre constructions (Hunt, 1989). However, dream PEs contain a broader variety of content than waking. For example, there is a classification for characters that metamorphize: "It sometimes happens…that a character changes his or her sex, identity, or age…[or]…to change into an animal or vice versa." This broadening of perceptual content can be considered a form of conscious perceptual hyperassociativity characteristic of dreaming.

In Table 2 are listed the major changes in the dream PE according to Hobson and colleagues. Stated in our terms, the major change in the perceptual generator across dreaming and waking is that sensory parameterization is diminished and perception of internally generated hallucinations increases. Perceptions of the dream PE are characterized as "bizarre." Perceptual incongruities are the superimposition of perceptual features from multiple objects onto a single object, and perceptual discontinuities are the abrupt changes in the dream PE or things encountered therein (Hobson, 1988; Kahn et al., 1997). Kahn et al., (1997) presented the hypothesis that perceptual bizzareness can be thought of as the "defective" binding (Hardcastle, 1994; Llinás & Ribary, 1993; Von der Malsburg, 1996) of dream perceptions, resulting from the lack of sensory stabilization over time. The normative data indicates that bizzareness is less frequent than its absence (Hunt et al., 1982), but it is clearly a perceptual phenomena characteristic of dreaming, and not waking, consciousness.

We discussed variations in the lucid dreamer's cognition above. The other important component to the innate variability of lucid dreams is the tremendous variation in lucid dream PEs, of which we have identified three types: "minimal," "typical," and "surreal" (LaBerge & DeGracia, 1999). All three types share the feature of being an external perceptual space within which the lucid dreamer is immersed. An example of a minimal PE was described and characterized in section 2. Magallón (1991) has described minimal perceptual environments as "imageless lucid dreams." Typical dream environments are those of normative nonlucid dream PEs, and resemble waking perception. Surreal PEs are abstract spaces of color and motion that bear no resemblance to waking and nonlucid dream PEs. Hunt et al. (1982) has described surreal environments as psychedelic transformations of the formal properties of vision. It should be emphasized that surreal environments are *not* forms of dream perceptual bizarreness, but are abstract perceptual spaces within which the dreamer is immersed.

There is substantial variation in the expression of minimal and typical PEs across lucid dreams. For example, any given typical environment may contain more or less perceptual bizarreness, may appear more or less realistic (Green & McCreery, 1994; McCreery, 1973), and can appear hyper-vivid compared to waking perception (LaBerge, 1985). Minimal environments may sometimes contain weak expression of visual form and/or color perception, and the "void-like" space of these dreamscapes can take on a variety of qualities or textures (LaBerge & DeGracia, 1999). To speak of variability of surreal environments makes no sense because what is perceived in these environments is not even comprehendible by the lucid dreamer (LaBerge & DeGracia, 1999).

The differences between mentational, hypnagogic, and nonlucid dream PEs have served to distinguish these experiences, along with the statistical association of each with specific sleep stages. The parallel between these and the three lucid dream PEs is intriguing. Minimal environments are reminiscent of the lack of a

PE during mentational experiences. Visual imagery is abstract by definition in surreal environments, but hypnagogic imagery tends in this direction as well. What distinguishes these pairs is a definite sense of immersion in the lucid dream-associated PEs. Typical dream environments, which are very much like waking perceptions, occur in both lucid and nonlucid dreams.

What is truly interesting is that different stable states of perceptual consciousness are at all possible. From our perspective, these variations reflect different states of activity of the perceptual generator. Based on the idea that chaotic dynamics can model large scale neuronal assembly behavior (Freeman, 1994; Freeman & Skarda, 1985; Globus, 1992, Hardcastle, 1994), a reasonable speculation is that the different PEs could correspond to discreet attractor states of cortical-subcortical perceptual activity, and represent major stable phases of conscious perceptual output. Our personal experience with surreal environments suggests they may be semi-stable attractor states of perception falling between minimal and typical environments (LaBerge & DeGracia, 1999). The abstract and geometric imagery of surreal and hypnagogic environments, reminiscent also of psychedelic drug-induced hallucinations (Aaronson & Osmond, 1970), may be the direct conscious perception of neurocomputational processing stages that are normally unconscious, but underlie the content of typical environments and normal waking perception (Hunt et al., 1982; Mavromatis, 1987).

INTERACTION OF THE DREAMER AND DREAM ENVIRONMENT IN NONLUCID DREAMS

Above we discussed that the interactions between dreamer and PE vary across types of sleep experience ranging from none (mentational experiences), to relatively passive observation (hypnagogia and dreamer-as-observer dreams) to full perceptual-motoric immersion (nonlucid and lucid dreaming). Clearly an important basis for these types of dreamer-PE interactions is the repertoire of modalities present in the dream. For example, if the dreamer does not possess somatic modalities or somatic-spatial immersion within the PE, then interactions will necessarily exclude somatic-motor activity, and the dreamer can only “passively” watch the dream perceptions.

In immersion dreams, several of the features of dream consciousness identified by Hobson and colleagues can be construed as representing interactions between the dreamer and the dream PE (Table 2). As illustrated in Figure 6, our framework indicates that the interaction between the dreamer and the dream PE can occur via either conscious or unconscious information flow pathways, and that the direction of the interaction can be from the cognitive to the perceptual generator or vice versa. We now apply this logic to the dreamer-PE interactions listed in Table 2.

Hobson and colleagues claim that attention is lost during dreaming. One wonders how the dreamer’s thoughts with respect to the dream PE could be so well organized if the dreamer was not actively paying attention to the dream PE. In fact, a dream quoted in Kahn et al., (1997) shows the dreamer consciously attending to several details of the dream environment. We have discussed above that dreamers indeed pay attention to the dream environment, and this can be construed as a cognitive-to-perceptual interaction occurring in consciousness.

Hobson and colleagues suggest instability of the dreamer’s mental orientation is a formal feature of dream consciousness. This is true in the sense that the dreamer will tend to display more mental orientational instability than the waking self, but all dream cognition is not characterized by this property. Orientational instability encompasses two distinct processes: (1) a *semantic uncertainty* whereby the dreamer is uncertain of the identity of persons, places, or things in the dream, or (2) *semantic incongruities* whereby conceptions of persons, places, and things fuse and/or are unstable. Such factors represent the dreamer’s semantic interpretation of the dream PE, and can thus be construed as consciousness cognitive-to-perceptual interactions. Kahn et al. (1997) offers the hypothesis, similar to that of Antrobus (1986), that instability of mental orientation may be due to decreased working memory capacity. Decreased working memory would prevent the dreamer from holding perceptions of the dream environment in working memory long enough to detect errors between perceptions and semantic responses, thereby leading to instability of mental orientation. We note that such a hypothesis implies alterations in the unconscious functioning of working memory. We also note that this feature of dream consciousness is again related to the promiscuity of consciously accessible memory.

Discontinuity of the dream “plot” is noted; discontinuity at this level of the dream’s organization would be expected to directly follow dream perceptual discontinuities (Montangero, 1991), suggesting to us a perceptual-to-cognitive generator interaction. Dream discontinuities are in no obvious way related to the dreamer's conscious cognition or intentions, are grounded in brain neurophysiology (Hobson & McCarley, 1977; Kahn & Hobson, 1993), and hence can be construed as unconscious events. In nonlucid dreams, perceptual discontinuities are not recognized as such by the dreamer, but they alter the dreamer's conscious cognition such as goal orientations or mental set (again see the dream example provided in Kahn et al., 1997), suggesting that perceptual discontinuities serve as a trigger to initiate transformations of the contextual hierarchy framing the dreamer's cognition.

Finally, it is stated that there is confabulatory narrative construction of the dream "plot." This is a very ambiguous statement, attributing unintentional actions to the dreamer, and implying a formal narrative construction of dreams. Confabulation is the *unintentional* generation of falsehoods, is common with brain damage that upsets prefrontal circuits (Johnson, O'Conner, & Cantor, 1997), and is hypothesized to be due to different types of memory dysfunction such as faulty retrieval or faulty error checking (Schacter, Norman, & Koutstaal, 1998). Our evaluation of nonlucid dream reports suggests that some forms of dream confabulation are, in fact, incongruous associations of waking memories (unpublished data), implicating faulty retrieval mechanisms. The notion that the dreamer unintentionally generates the dream plot is equivalent to saying the dreamer unintentionally generates the dream. Thus, this supposed "feature" of dream consciousness actually implies a mechanisms of dream generation. We return to this issue in section 8.4, when we present a model of dream generation which offers a definite relationship between the dreamer and the dream environment at both conscious and unconscious levels of cerebral function.

Again, if we look closely at the above interactions, we see patterns emerge consistent with changes in the dreamer's cognition and perception discussed above. Perceptual-to-cognitive interactions tend to be abrupt and propagate through the dream by altering unconscious contextual levels of the dreamer's cognition. The typical nonlucid dreamer spontaneously responds to perceptual discontinuities by altering mental orientation, goal objectives and other elements indicative of the operation of cognitive context hierarchies. The cognitive-to-perceptual interactions tend to reflect dysfunctions in promiscuously accessible memory systems resulting in mental disorientation or confabulation by the dreamer.

INTERACTION OF THE DREAMER AND DREAM ENVIRONMENT IN LUCID DREAMS

Dreamer-environment interactions become particularly discreet during lucid dreams. Lucid dreamers come to learn that their conscious thoughts are not, *in any obvious fashion*, creating the dream perceptual environment. The lucid dreamer's mental orientation is not one of actively creating the dream environment, but is more akin to active exploration of the PE (LaBerge & Rheingold, 1990). Lucid dreamer's interact extensively with the PE, and many discussions of lucid dreaming have characterized "dream control" as an important element of lucid dreaming (Moffitt, Hoffmann, Mullington, Purcell, Pigeau, & Wells, 1988; Purcell, et al., 1993; Schwartz & Godwyn, 1988; Tart, 1988).

However, there has been less discussion and focus on the limits of the lucid dreamer to control the dream environment. These limits are substantial, and provide important clues to basic processes underlying dream generation. The content (places and objects) of the PE is generally not arbitrarily manipulatable by the lucid dreamer in the manner imaginative imagery is (e.g. see example in Kahan and LaBerge, 1994; Worsley, 1988). Nor does the lucid dreamer intentionally create the dream PE; it spontaneously "appears" as it does in nonlucid dreams (Green & McCreery, 1994; Hartmann, 1973). Further, events in the PE occur independent of, and often contrary to, the conscious intentions and expectations of the lucid dreamer. Examples include: (1) the "light switch phenomena" (Hearne, 1981; Green, 1968), (2) experiences of uncontrollable kinesthetic sensations that manifest as bizarre motor experiences, such as being uncontrollably whisked along by the "wind" (LaBerge & DeGracia, 1999), (3) the inability to perform magical actions such as flying or passing through walls, in spite of having done so in previous lucid dreams (LaBerge & DeGracia, 1999), (4) being chased by unintended hostile dream characters (Tholey, 1988), or (5) finding the dream environment transform in unpredictable and unintended ways, e.g. perceptual discontinuities (Gillespie, 1984).

Above we spoke of the innate variability of lucid dreaming in terms of variation in the dreamer's conscious cognition and variations in lucid dream perceptual environments. The interactions between the lucid dreamer and the dream PE are highlighted in the methods lucid dreamers use to cope with this innate variability. These methods include: (1) some degree of control over which *type* of PE they occupy, (2) the ability to "stabilize" their presence and prevent fading of the PE, and (3) the ability to prevent the loss of their lucidity.

Lucid dreams possess a propensity to "fade" (LaBerge, DeGracia, & Zimbardo, 1999). Fading is related to an important, and perhaps underappreciated, relationship between the lucid dreamer and the lucid dream PE: lucid dreamers learn that they can consciously sense how stable or unstable their presence is in the dream PE (LaBerge & DeGracia, 1999; Gillespie, 1984; Hunt, 1989). That is, the lucid dreamer may "feel" very stable within the dream perceptual environment, or may "feel" very unstable, with a continuum of variation between these extremes. When a lucid dream is "unstable", the lucid dreamer's vision may phase in and out of blindness, colors may become pale and washed out, somesthetic sensations may weaken (for example: Lischka, 1979; Marcot, 1987; both quoted in Green & McCreery, 1994). If dream perception becomes too unstable, the dream PE simply fades, and the lucid dreamer usually awakens in full consciousness. The loss of perceptual modalities during lucid dream fading is opposite that described in section 2 for the onset of the perceptual environment, with vision being the most sensitive to disruption (LaBerge, DeGracia, & Zimbardo, 1999). Sensations of stability occur in all three types of lucid dream PEs. It is significant to note that such sensations do *not* occur in the nonlucid dreamer's consciousness, with the occasional exception of the sensation of fading from the dream concomitant with awakening. In contrast, sensations of perceptual instability can occur through an entire lucid dream, and vary substantially amongst lucid dreams. The most effective methods for stabilizing the lucid dream PE and preventing it from fading involve enhancement of conscious somatic sensations (LaBerge, DeGracia, & Zimbardo, 1999).

It is also recognized that lucid dreams possess a propensity to revert to nonlucid dreams (Hunt, 1989; Green and McCreery, 1994; LaBerge & Rheingold, 1990). A close look at such transitions reveals that the lucid dreamer becomes absorbed in a spontaneously unfolding dream "narrative" which distracts and absorbs the lucid dreamer's attention and thought processes (Green & McCreery, 1994; Hunt, 1989, pg. 120; DeGracia & LaBerge, 1999). This transformation, we suggest, can be conceptualized by Baars' notion of competition amongst contextual hierarchies. Competition occurs between the spontaneous dream process and the lucid dream context for control of the conscious cognition of the dreamer. This competition process manifests as the spontaneous dream process attempting to absorb the dreamer's attention, intentions, and thought processes by drawing the dreamer into a series of spontaneously unfolding dream perceptual events (DeGracia & LaBerge, 1999; Gillespie, 1984). The lucid dreamer must exert intentional effort to overcome being absorbed by the unfolding dream sequence and maintain the lucid dream context. A successful lucid dream is a balance of participating in the unfolding dream events, yet maintaining vigilance to not lose lucidity (LaBerge, 1985; Price & Cohen, 1988). If, however, events in the dream environment overwhelm the dreamer's attention and thoughts, then these events come to frame the conscious cognition of the dreamer, displace the lucid dream context, and the lucid dream reverts to a nonlucid dream. In fact, this competition mechanism explains the observation that a lucid dreamer can phase in and out of lucidity during a single lucid dream (LaBerge & DeGracia, 1999).

The above perceptual and cognitive limits clearly indicate that lucid dreaming is a nontrivial balancing act. There is a fine line between allowing the brain to become too activated (and hence awake), or relaxing vigilance so much that the spontaneous dream process displaces the lucid dream context from structuring the lucid dreamer's conscious cognition. Lucid dreamers are thus perhaps more at the mercy of the "relentlessly unfolding" nature of the dream than are nonlucid dreamers (Green & McCreery, 1994).

The relationship between cognitive lucidity, perceptual environment type, and the stability of the perceptual environment is neither simple nor clear. One can be highly lucid, but feel either very stable, very unstable or any degree in between. However, when cognitive lucidity is lost, and the lucid dream reverts to a nonlucid dream, the perceptual environment generally becomes "typical", and the nonlucid dreamer has no awareness of "stability," suggesting that there must be some relationship between cognitive lucidity and the dream perceptual environment. Our model of the generation of the dream environment will offer an explanation for these phenomena (section 8.6).

DREAM GENERATION

We have outlined the key cognitive and perceptual subjective phenomenology of sleep experiences. Our analysis has suggested that key psychological differences across waking and sleep revolve around issues of memory. We now combine these observations and hypothesize a model of dream production in the sleeping brain. We build this model in stages. First we address the phenomenology of dream types to ascertain the memory sources of dreaming. We then present a neurobiological model of the generation of the dream PE in terms of current findings in the neurobiology of sleep, memory, and perception. Next is presented a model of dreaming in terms of information flows in the perceptual and cognitive generators. After building our model we comment on its implications with respect to dream function in section 9.

MEMORY SOURCES AND DREAMS

Theories of dream production and memory are inextricably interwoven. Freud (1900) saw dreams as disguised wish fulfillment, implying that memories of goals and desires structured dreams. Recent authors' conceptions have been influenced by modern concepts of memory. Bosinelli (1995) has invoked "long-term memory" as a source of dream patterning. Studies by Cavallero and colleagues have categorized memory sources as autobiographical episodes, abstract self-references, or semantic knowledge (Cavallero, 1987; Cavallero, Foulkes, Hollifield, & Terry, 1990; Cavallero, Cicogna, Natale, Occhionero, & Zito, 1992; Cicogna, Cavallero, & Bosinelli, 1991). Antrobus (1986) has drawn upon the memory structure of ACT*, with its working, long-term, and behavioral forms of memory, to model dream production.

A comprehensive view of the role of memory in dreaming has remained elusive, not the least because of the variegated roles memory plays. Sleep itself is associated with a profound anterograde amnesia (Roth, Roehrs, Zwyghuizen-Doorenbos, Stepanski, & Wittig, 1988), and the dreams we do spontaneously recall provide only a tantalizing glimpse into our nighttime mental experiences. It seems intuitively obvious that dreams are in some sense drawn from the memory structure of the waking personality. Yet the substantial novelty in dreams indicates they cannot simply be exact reproductions of waking memory. Neither does the dreamer "imagine" or intentionally create the dream environment (Green & McCreery, 1994). As discussed above, the conscious mnemonic operations of the dreamer are altered compared to the waking self, and some apparent cognitive deficiencies can be reduced to alterations in promiscuously-accessible memory fidelity across states. Our distinction between lucid and nonlucid dreams relies exclusively on differences in memory content and activity, and how this affects the entire personality/CNS. Studies attempting to correlate sleep stage changes with the quality of waking learning and memory performance have not contributed substantial illumination on the role of memory in dreaming (Purcell et al., 1993). All of this is further complicated by current models, many derived from animal studies, linking the function of sleep to a variety of forms of cerebral information processing (Stickgold, 1999).

Clearly, memory is not a unitary phenomena. Different forms of memory can be classified as either declarative or procedural and, as we argued above, contextual; each of these categories has further subdivision (Gabrieli, 1998; Gaffan, 1994). Moreover, specific cognitive operations depend on different memory systems to varying extents. We can ask questions about "within-dream" utilization of memory: what memory sources are used in construction of the dream environment? What sources of memory are utilized by the dreamer during cognitive activities in the dream? We can inquire into "across-state" memory: how is the memory utilized in dreams related to waking memory? How do dreams affect or alter waking memory? We can ask these questions for declarative, procedural, and contextual forms of memory. It is therefore imperative to be as precise as possible when discussing the putative roles of memory in dreaming. When we speak here of sources of memory "structuring" the dream, there are two distinct levels to which we refer: the structuring of the dream PE, and the contextual structuring of the dreamer's conscious cognition. We focus now on the former.

The structuring of the dream environment is a spontaneous activity of the CNS, and occurs outside of the conscious operations of either the waking self or the dreamer. That is to say, *the generation of the dream environment is grounded in unconscious processing*. Within our framework, the dream environment is the output of the perceptual generator. The central assumption to our conception of dream genesis is that, *for the perceptual generator to produce conscious perceptual experiences, it must have a source of parameterizing input.* Sensory input serves this function during waking. But what serves the equivalent function during sleep?

We suggest that, during dreams, patterns of relationship derived from the declarative memory system serve to parameterize, or structure, the conscious output of the perceptual generator. Or more precisely, a flow of information from the MTMS serves as surrogate sensory input to perceptual thalamo-cortical circuits to generate the dream PE. This transaction of information represents the first stage in dream genesis. Subsequent stages will also be outlined, allowing us to clarify the relative roles of the dreamer and the dream environment in the dream production process. We now develop these ideas.

Harry Hunt (1989) has interpreted the phenomenology of dreaming to indicate that there are multiple types of dreams, and that this typology follows a psychological, or content-specific type distinction. We feel that that Hunt's characterization of the multiplicity of dreams is perhaps the most comprehensive formulation of dreaming available, and thus can provide us with the broadest view of memory sources of dreaming. The following is a list of nine dream types identified by Hunt, which we interpret as representing different sources of memory serving as focal points from which different types of dreams emerge:

1. *Dreams of verbal metonymy.* Verbal metonymy is the causal semantic relationship between words, suggesting that this type of dream is related to the causal linkage of experiences within episodic memory, and the description of experience in linear verbal terms. Dreams of verbal metonymy are the normative dreams observed in the sleep laboratory and in home dream reports, and are overwhelmingly life-like. Such dreams derive from the episodic memory system (Tulving, 1972) that records everyday experience.

2. *Dreams of verbal metaphor*. This dream type refers to dreams in which content is based on linguistic processes not obviously related to episodic experience, but reflects instead the innate structure of the linguistic processors themselves, such as semantic equivalence, clang association, phonetic similarity, rhyme and pun. Such dreams literally seem to emerge from a play on words (Hunt, 1989). We suggest that linguistic processors, dissociated from everyday episodic or pragmatic usage, are acting as the source of memory for structuring dreams of verbal metaphor.

3. *Objective dreams*. Hunt (1989), following Jung (1961), recognizes some dreams as "outwardly directed," "as surprisingly accurate and/or creative depictions of external matters" and associates these types of dreams with "creative breakthroughs in the sciences and the arts." We would suggest that such dreams are also structured by the episodic mnemonic system, yet biased heavily towards goal contexts and motivational factors.

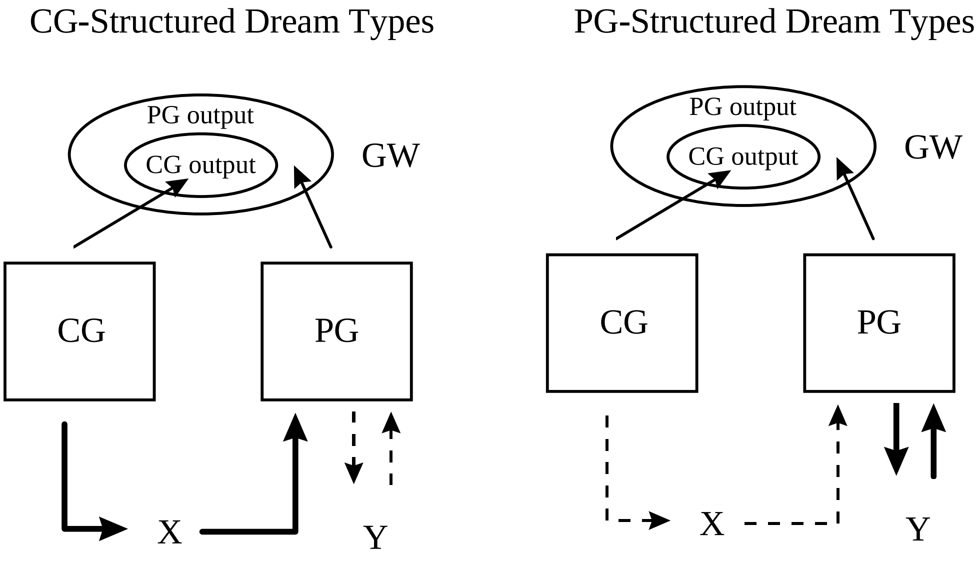
4. *Culture-pattern dreams*. This type of dream derives particularly from anthropological investigations of dreaming in native cultures (Cawte, 1984; Tedlock, 1987). It is the dream type of the Shaman who uses dreams as a divinatory or healing tool to fulfill his or her cultural role. We feel that such dreams are based on the semantic memory system (Tulving, 1972), with a heavy emphasis on cultural roles, mores, myths, and customs.

5. *Archetypical dreams*. Archetypical dreams are associated particularly with the psychology of Jung (Kluger, 1975). These dreams are characterized by "their uncanny-numinous quality and aesthetically rich structure...the powerful sense of felt meaning and portent" (Hunt, 1989, pg 129). These dreams seem to be structured by "intuitive" memories, a coupling of emotional feelings of profundity and relatively unexplicated insight.

6. *Nightmares*. Hunt defines nightmares less as a specific dream type and more as a degree of dream intensity. Clearly nightmares are characterized by intensity of negative affect and can lead to forms of dream lucidity. It appears to us, however, that nightmares are drawn from sources of memory closely associated with fear, fright, and other forms of negative affect

7. *Visual-spatial dreams*. Hunt suggests that, in some circumstances, the visual-spatial aspects of dreams are their own expression independent of episodic or linguistic factors. This line of thought may be particularly true of hypnagogic imagery, and what we have termed "surreal" PEs. These dreams likely represent direct intrusions of lower level, normally unconscious, forms of visual processing into consciousness. Which is to say, the source of memories from which these dreams are drawn is the innate structuring of the visual system.

8. *Titanic dreams*. Hunt coined the term "titanic dream" based on Silberer's (1917) recognition that some dreams contain very strong somatosensory elements. These include strong kinesthetic sensations, forms of mutilation, dismemberment, physical attacks, intense sexual activity, sensations of suffocation, paralysis, flying, floating, falling, and spinning, as well as expressions of natural forces such as wind, tornadoes, fire, and water. Analogously to visual-spatial dreams, we suggest that the memory source underlying titanic dreams is the innate structuring of the somatosensory-motor system.



Dream Types	Dominant Mnemonic Loci	Tentative Localization
CG-Structured Dreams		
Declarative subtypes:	**X =**	
1. Verbal metonymy	Episodic memory	MTMS
2. Objective	Goal representations	MTMS
3. Culture pattern	Social representations/roles	MTMS
4. Archetypical	Intuition/semantic memory	MTMS
5. Nightmares	Affect	MTLM /Amygdala
6. Verbal metaphor	Linguistics processors	Wernicke's area
PG-Structured Dreams	**Y =**	
7. Visual-spatial	Visual processors	Visual cortex
8. Titanic	Somatosensory processors	Somatosensory cortex
9. Medical	Somato-viscerotopic representations	Somatosensory cortex, brainstem viserotopic maps?

Fig. 8. Different mnemonic loci in either the cognitive (CG-structured) or perceptual (PG-structured) generators substitute for sensory input parameterization to the perceptual generator during dreaming. The accompanying table shows the dominant loci associated with each of Hunt's (1989) dream types. A tentative neuroanatomical localization associated with each category is provided. GW = global workspace, MTMS = medial temporal lobe memory system.

9. *Medical dreams*. Medical dreams are, according to Hunt, "those in which the dream directly presents somatic and medical conditions of which the individual may not be consciously aware" (Hunt, 1989, pg. 111). Several studies suggest that specific dream content accompanies specific medical conditions with more or less reliability (Heather-Greener, Comstock, & Joyce, 1996; Levitan, 1976; Smith, 1986). Hunt attributes such dreams to "background tactile-kinesthetic patterns." We would suggest that such dreams represent the structuring of the dream by somatic and/or viserotopic (Loewy, 1990) representations.

What Hunt's view of dreaming implies is that different loci of memory serve as sources of surrogate sensory input and provide "parameters" that structure the dream PE. The nine dream types above can be divided into two broad categories (Figure 8): (1) those in which modules we associate with the cognitive generator are parameterizing the perceptual generator (CG-structured dreams), and (2) those in which modules within the perceptual generator provide parameterization to the perceptual generator (PG-structured dreams). We have classified four of the CG-structured dreams as subtypes of declarative memory because their memory sources are clearly encompassed within this distinction. A core notion to Hunt's taxonomy is that some dream types reflect specific information content within the nervous system, while others reflect the structure of neurocognitive processing relatively independent from specific content. We agree with this general notion; the dream type "verbal metaphor" and all of the PG-structured dreams represent the latter category.

Our classification of Hunt's typology is illustrated in Figure 8 where the diagrams and accompanying table illustrate the major sources of memory within the cognitive (X) or perceptual (Y) generators providing the dominant structuring input to the perceptual generator. We explicitly posit that the input information structuring the perceptual generator flows along *unconscious* processing pathways; this is depicted by the arrows entering and exiting the bottom of the generators. The outputs from the tops of the cognitive and perceptual generators are depicted as forming the global workspace of the dream. A neuroanatomical assignment of each memory loci is provided and will be referenced ahead.

In presenting these classifications, we also agree with Hunt on the following critical point: "…all dimensions of dream formation may be more or less nascent in all dreams…the dreaming process would selectively exaggerate one or more of these dimensions…" (Hunt, 1989, pg. 101). Thus, our claim is that specific loci of memory have an enhanced influence on the perceptual generator, leading to the generation of the different dream types. The types are not mutually exclusive. This is indicated in Figure 8 by the dashed lines, showing that both PG- and CG-structured dreams have the same formal structure. In our terms, this means that *all* unconscious processes necessary for the action of perceptual and cognitive generation operate in all dream types, but that specific loci of these processors divert activity from conscious cognitive or perceptual output to serve an unconscious role in parameterizing perceptual generator output.

Since the dominant unconscious cognitive or perceptual loci ultimately serve to structure conscious dream perception, we can say that normally unconscious forms of waking information take conscious form as the dream environment (Malamud, 1988). This is not the mysterious subconscious mind envisioned by Freud, because we are referring to precise forms of memory in the CNS. In this sense then, during dreams, the global workspace - consciousness - becomes a type of "theatre" within which unconscious information manifests in the perceptual consciousness of the dreamer.

THE GENERATION OF THE DREAM ENVIRONMENT

A number of significant question are raised by the above analysis. How precisely does mnemonic information substitute for sensory input parameterization and lead to the genesis of the dream PE? How does the overt conscious activity of the dreamer relate to the unconscious activities responsible for parameterizing the perceptual generator? What is the relationship between the dreamer and the PE? Who creates whom? Where does the "intention" or impetus behind dreaming come from?

To accurately answer these questions, we would need to know the precise time course and patterns of regional brain activation leading to dream generation, and this does not yet exist. The temporal view of sleep provided by EEG analysis does not allow assignment of regional cerebral activation patterns (Hobson et al., 1998a). The activation-synthesis model was expanded to include changes in hippocampal function during REM (Hobson & Schmajuk, 1988), but does not provide a specific pathway of forebrain activation. Neuroimaging studies of the REM brain provide a static snapshot of cerebral activation patterns but cannot yet approach the temporal resolution required to visualize dream onset. Neuropsychological data also offers a snapshot view of which brain regions mediate and support dreaming. Mark Solms (1997) has extrapolated this data to present what he terms a "tentative model" of brain activation underlying dream generation.

The model put forward by Solms invokes a "regressive activation" from frontal to parietal lobes as central to the dream generation processes. By this he is referring to a *reverse flow of information* in the cerebral cortex. Solms conceptualizes the forward waking flow of cortical information to be from posterior sensory cortices forward to frontal cortex and hence motor output. Admittedly, this is an oversimplification because the idea of a linear flow from sensory input to motor output has been superseded by a view of complex parallel processing architecture in the brain (Felleman & Van Essen, 1991). Nonetheless, at a coarse-grained resolution, Solms' notion of "regressive activation" is relevant. It invokes the bidirectionality of intracortical circuits to posit that reverse information flows dominate the dreaming process. Echoing a Freudian-type view of dreaming, Solms postulates that the “initiator” region of dreams involves frontal structures related to “appetitive interests.” To prevent awakening via motor command output (the normal waking information flow), frontal activity is “deflected” in the reverse direction and activates multimodal inferior parietal lobe. The spatial-kinetic and “symbolic-integrative” aspects of dreaming derive from activation of right and left inferior parietal lobes, respectively. This frontal-to-parietal activation is structured by frontal “appetitive interests,” providing a Freudian-like “wish fulfillment” dream. Solms considers the relevant frontal and parietal regions “essential,” meaning that lesions in these areas abate dreaming altogether.

Okuma (1992) has also posited an activation pathway for dreaming. In this model a stream of vague and disorganized thinking begins during NREM and, with the onset of REM sleep, draws out sensory images from memory to generate the dream PE. Unlike Solms, and following the activation-synthesis model, Okuma reviews data indicating that the activation source for dreams is random and nonspecific activation of the cerebral cortex and hippocampal system via brainstem neurotransmission. From this nonspecific activating input, perceptual imagery is drawn out of memory by a process of free association with the thought-like activity. Stating Okuma’s model in our terms, the conscious output of the cognitive generator (covert or inner speech) structures the perceptual generator (via free association) and neither activates the other. In contrast, the model we now present explicitly indicates that unconscious activity in the cognitive generator structures the perceptual environment *and* supports conscious sleep cognition.

A NEUROBIOLOGICAL MODEL OF DREAM GENESIS

Our model is predicated on: (1) a fundamental reversal of information flow in the sleeping compared to the waking brain, but in different cortical circuits than those hypothesized by Solms, and (2) on Okuma’s notion, derived from the activation-synthesis model (Hobson & McCarley, 1977) of nonspecific activation of hippocampal and cortical circuits. We suggest that the dream perceptual environment is parameterized by the reverse flow of information from the MTMS to the multimodal sensory cortex afferent to this system. That is, the circuits that, during waking, mediate the storage of long-term declarative memory - the MTMS - operate in reverse and activate multimodal cortical representations of the dream PE.

The sequence of events by which we envision the dream PE to be generated are depicted in Figure 9. Changes in brainstem neurotransmission during sleep result simultaneously in: (1) nonspecific activation of the rhinal cortices, via the ventral cholinergic/basal forebrain pathways (Kahn et al., 1997; Kitt, Mitchell, DeLong, Wainer, & Price, 1987) (2) nonspecific activation of higher order thalamo-cortical perceptual systems, via the dorsal cholinergic pathways (Hoover & Baisden, 1980; Jones & Cuello, 1989; Kahn et al., 1997; Rye, Saper, Lee, & Wainer, 1987), and (3) attenuation of the forward flow through the MTMS via enhanced cholinergic (Ridley, Harder, & Baker, 1996) and decreased aminergic neurotransmission (Harley, 1987, 1991, 1998; Quartermain, 1983). Studies of the REM state brain have consistently shown activation of the parahippocampal and/or entorhinal cortices (Braun et al., 1997; Maquet et al., 1996; Nofzinger et al., 1997; Ravagnati, Halgren, Babb, & Crandall, 1979), and areas afferent, particularly anterior cingulate gyrus, but also inferior temporal gyrus (Braun et al., 1997), medial prefrontal cortex, and insular cortex (Braun et al., 1997; Nofzinger et al., 1997). Because the rhinal cortices are nodes within bidirectional circuits, we envision that both forward and reverse conduction will propagate from randomly activated sites in the rhinal cortices.

The forward propagation would enter the hippocampal system via the dentate gyrus, and such activity may be the basis for hippocampal theta rhythms observed during REM sleep and associated with the orienting response in awake animals (Buzsáki, 1989; Morrison, 1983). During waking, the orienting response is associated with forward information flow through the hippocampus, and with enhanced learning (Buzsáki, 1989; Chrobak & Buzsáki, 1998). However, sleep is a state of almost total amnesia (Roth et al., 1988), suggesting an attenuation of forward flow into the hippocampal system. The forward flow through the hippocampus would be expected to be attenuated by aminergic demodulation, which is at a maximum in the REM brain (McCormick, 1992), thereby attenuating a system important for long-term memory formation in the waking brain (Berridge, Page, Valentino, & Foote, 1993; Hasselmeo, 1995; Izquierdo & Medina, 1995; Izumi & Zorumski, 1999; Quartermain, 1983).

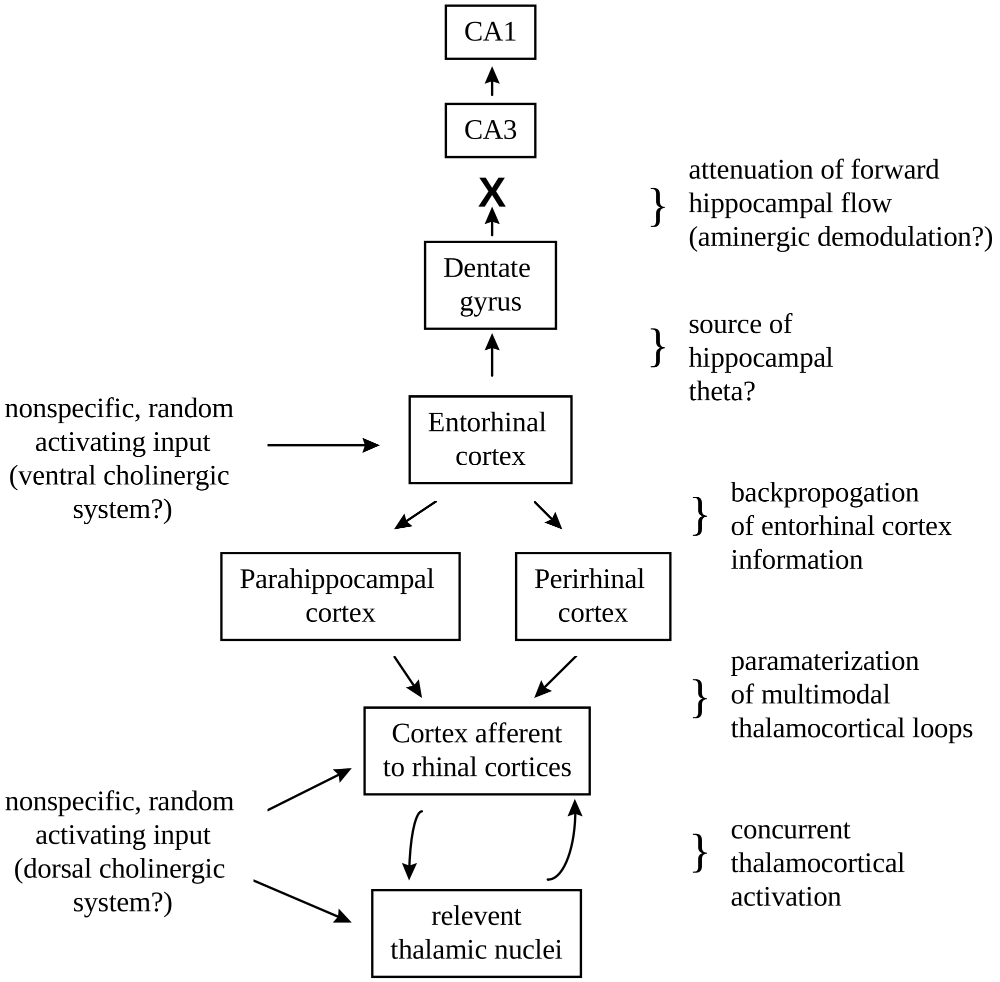


Fig. 9. A neurobiological model of the generation of the dream perceptual environment. Nonspecific activation of loci in the rhinal cortices back propagates to afferent sites, resulting in a mnemonic parameterization of multimodal and higher order sensory cerebral cortices. Forward propagation into the hippocampal system is presumed to be attenuated by altered brainstem neurotransmission.

Reverse propagation from the rhinal cortices would be expected to spread from entorhinal to parahippocampal and perirhinal cortices and thence to their afferent sites in widely separated multi- and supramodal cortical regions. This backpropagation of information from the MTMS, we suggest, serves as a source of “surrogate sensory input” and parameterizes, structures, or gives content to, multimodal and higher order unimodal sensory cortices to generate the dream PE. We have stated that this pathway is unconscious, which means it is not in any obvious way manipulatable by conscious access and control operations. We now more precisely define the nature of this information.

Autoassociative neural network models of hippocampal function offer clues as to the nature of this information. Modeled as an autoassociative network, the hippocampal system must be capable of accepting any arbitrary pattern of inputs (Gluck & Myers, 1997). Specifically, Myers, Gluck, and Granger (1995) suggested that entorhinal cortex may perform a redundancy compression between different modalities, or across polymodal features of a stimulus, similar to Eichenbaum and Bunsey’s (1995) suggestion that entorhinal cortex “fuses” coincident stimuli. In the formation of long-term explicit memories during waking, this “compressed” input then enters dentate gyrus where it is subject to the forward hippocampal pathway through regions CA3 (the autoassociator, see Gluck & Myers, 1997) and CA1, and ultimately back to afferent sites in the cerebral cortex (section 4.4) where it is encoded as long-term memory by “binding” (Cohen & Eichenbaum, 1993) or correlating connection weights in widely disparate areas of cerebral cortex (Halgren, 1984).

What kind of information would be expected to be contained in a “compressed” entorhinal representation? The rhinal cortices, as we reviewed in section 4.4, receive massive input of highly processed sensory information. Hippocampal function has long been associated with “place cells” and spatial maps in the rat (O’Keefe, 1979, 1990), and spatial learning deficits are associated with hippocampal system damage in monkeys (Rupniak & Gaffan, 1987) and humans (Petrides, 1985). A recent report by Epstein and Kanwisher (1998) has identified in humans a region they term the “parahippocampal place area” which appears to encode the geometry of the local environment during explicit storage, and is most strongly activated when subjects must memorize the placement of objects within an organized environment setting. The PRC has been shown to play an important role in visual object recognition memory (Brown & Xiang, 1998; Murray & Bussey, 1999). Ablation of PRC and PHC produces both visual and tactile memory impairments (Suzuki, Zola-Morgan, Squire, & Amaral, 1993). Given the convergence of supramodal inputs specifically to the entorhinal cortex, it would be expected to represent the behavioral salience of sensory environments, in terms of affective value, motor behavioral activities and salience to homeostatic drives (Suzuki, 1996).

In some sense, therefore, the information “compressed” by the rhinal cortices is a distilled representation of the “parameters” required to generate perceptual environments, as well as the patterns of relationship amongst these parameters. We suggest that, within the scope of autoassociative models of the hippocampus, the backpropagation of information from the rhinal cortices to their afferent sites can be construed as a *decompression operation*. Rhinal cortical representations are “decompressed” when backpropagation of representations both imparts parameterization and reinstates patterns of relationship (e.g. concurrent activation) to afferent sites. The result is a surrogate sensory input into the relevant thalamocortical loops of multimodal and higher order unimodal sensory cortex (Figure 9).

Following the tenets of the activation-synthesis model, we presume the rhinal cortices are nonspecifically, that is, *randomly*, activated by cholinergic neurotransmission. Random activation elicits an *arbitrary* output from the rhinal cortices, which then backpropagates to their afferent sites. It is critical to grasp the implication of random activation of MTLM sites. The MTMS is a system that, by its very nature and function, has evolved to represent any *arbitrary* set of inputs as structured compressions, as these are prepared for long-term consolidation under normal waking conditions. During waking, MTMS activity is determined by ever-changing sensory and cognitive input. During sleep, this activity is determined by random extrinsic activation. Either source of activating input is, from the MTMS’s point of view, arbitrary to begin with. Running this system backwards with random input should lead to the “decompression” of a highly organized, but completely arbitrary, representation within MTMS afferent sites. Therefore, given current views of MTMS function, it is not implausible to postulate that a random input could produce a highly organized output to serve as parameterization for the dream PE (step 1, Figure 10). The random activation of the MTMS will output any *arbitrary* set of parameters to afferent sensory cortices, leading to a dream perceptual environment that, although highly structured, is arbitrary.

The phenomenological result is the arbitrary generation of a dream perceptual environment in the dreamer’s consciousness. The WILD experience described in section 2, and other such descriptions (LaBerge & DeGracia, 1999), may actually be first-hand descriptions of the parameterization of the perceptual generator by a backpropagated “decompression” from the rhinal cortices. Likewise, hypnagogic hallucinations may represent exactly the same phenomena. Through these phenomenologies, we can see that the perceptual parameterization process can occur in stages, first as initial “blips” of perceptual imagery, which eventually cascade and dominate the perceptual generator as full-scale perceptual environments.

Within the scope of our model, Hunt’s typology of dreaming takes on a new significance. The categories of dreaming he has identified may represent functionally distinct pathways operating in the human declarative memory system. Hunt’s dream typology suggests that different anatomical regions may serve as primary loci for providing parameterization to the dream PE (Figure 8). The four declarative subtypes of dreams derive from complex patterns of relationship produced by the MTMS. Nightmares would be expected to involve MTML-amygdala representations (Suzuki, 1996). Dreams of verbal metaphor could involve representations derived from language production centers, such as

Wernicke's area, that feed into the MTML system (Alkire, Haier, Fallon, & Cahill, 1998; Grasby, Frith, Friston, Frackowiak & Dolan, 1993). What's more, his typology indicates that some forms of dreaming are less dependent on the MTMS than others such as dreams of verbal metaphor and PG-structured dreams. In these cases, the parameterization comes from regions upstream of the MTMS. The implication, as alluded to by Antrobus (1993), is that the study of dreaming may shed light on the organization of the human mnemonic system, for which many methods used in animal research cannot be applied. This view may also explain, at least in part, why such disparate patterns of cortical activity have been reported from neuroimaging studies.

Although our thinking relies on the activation-synthesis model to provide the "impetus" for dream generation in terms of nonspecific activation of the rhinal cortices, it is consistent with Solms' model. Both of Solms' "required" brain regions are afferent to the MTMS. In broad terms, the frontal and the parietal regions he identified as essential to dreaming correspond roughly to our concepts of cognitive and perceptual generators, respectively. Solms' "essential" regions may well be those involved in generating the conscious aspects of dreams, and hence their loss would abolish dream consciousness. Our mechanism would be the unconscious precursor standing upstream to the generation of the dream PE.

What would we expect of the dreams of patients with MTMS damage? Such damage results in anterograde amnesia during waking (Cohen & Eichenbaum, 1993) but not gross alterations of consciousness per se. We would not expect abatement of dreaming with MTLM damage because these regions are not responsible for generating the conscious output of dreams. Our model suggests that damage to the MTMS should result in dreams of reduced complexity, and abatement of declarative memory subtypes of dreams as a function of the extent of MTMS damage. Lesions producing anterograde amnesia do in fact alter dreaming. Anterograde amnesia is, not surprisingly, associated with poor dream recall (Greenberg, Pearlman, Brooks, Mayer & Hartmann, 1968; Talland, 1965). Cathala and colleagues (1983) reported altered dream content in amnesic patients, and Torda (1969) reported reduced narrative complexity and emotionality with patients suffering postencephalitic amnesia. Again, given the complexity of interpreting brain lesion data in humans, we cautiously take these observations as support for our model.

Our model is inspired primarily by the relevance of recent findings on the MTML system to the subjective phenomenology of sleep experiences. However, the precedence for our model dates to the 19th century discovery by Hughlings Jackson that medial temporal lobe seizures can result in a "dreamy state," a component of which is vivid "memory-like" hallucinations (Bancaud, Brunet-Bourgin, Chauvel, & Halgren, 1994). Wilder Penfield amplified upon this finding by generating similar "waking dreams" through evoked electrical stimulation of the superior temporal gyrus (Penfield & Perot, 1963). More recent studies have investigated the roles of the hippocampal formation and amygdala (Halgren & Wilson, 1985) and medial temporal lobe (Gloor, 1990) in the generation of the "dreamy state." The similarities between spontaneous epileptic seizures, dreams, and responses to electrical brain stimulation in patients with temporal lobe epilepsy has been described (Ferguson, Rayport, Gardner, Kass, Weiner, & Reiser, 1969). Hence, the mechanism we suggest above may not be confined exclusively to sleep, but may play a more general role in the genesis of hallucinations during both waking and sleep.

DREAMING AS A SELF-CONTAINED INFORMATION LOOP

Once the dream PE is generated, a further sequence of events serves to complete the dream generation process. We imagine, like Bosinelli (1995), that a dream is a self-contained information loop.

Figure 10 depicts our model of the dream production processes in terms of GW concepts. In figure 10, A1 and A2 refer to hypothesized sources of independent activation for the cognitive and perceptual generators, expressing the dreamer and the dream PE, respectively. Arrow 1 is the backpropagation, from the MTMS to the perceptual generator, of randomly generated patterns of relationship between sensory parameters as discussed above. After this point, however, randomness no longer plays a role, and all of the subsequent events are highly structured by the mnemonic content of the brain. The output of the perceptual generator is the perceptual consciousness of the dreamer (step 2, Figure 10). There is next a conscious transaction of information from the perceptual environment to the conscious cognition of the dreamer (step 3, Figure 10).

Stated simply, the dreamer consciously comprehends the perceptual environment. Following Baars' notion that information in the global workspace recruits unconscious contextual information, the conscious comprehension of the dream environment recruits a contextual hierarchy (step 4, Figure 10), which immediately frames the conscious cognition of the dreamer (step 5, Figure 10). The fidelity of this response is a function of the degree of activation of the cognitive generator. Less activation means the dreamer's response is a degraded form of a potential waking response to the same situation, more activation means the dreamer will more closely approximate the responses of the waking personality.

The perceptual recruitment of a cognitive context to frame the dreamer's conscious cognition speaks to the notion that dreams possess a formal narrative construction (Cipolli & Poll, 1992; Foulkes, 1978; Kuiken, Neilson, Thomas, & McTaggart, 1983). Our model, along with other lines of evidence (discussed in Hunt, 1989), suggest that dreams are not formally similar to narrative constructions. The appearance that dreams are "stories," "plots," or "narrative" is the result, we suggest, of temporal elements in: (1) the perceptual generation process and, (2) in the cognitive context hierarchies elicited by the dream PE. Activation of cognitive contexts will elicit goal-directed behaviors, semantic frameworks, and other mnemonic structures containing substantial temporal dynamics. The temporal unfolding of "routines" or "programs" contained in elicited contexts will create the appearance of a "plot" or "narrative." Thus, the ostensible narratives of dreams are the time-course of expression of mnemonic elements in the elicited context. That is to say, the temporal unfolding of dream events in terms of the dreamer's conscious cognition will not reflect abstract properties of narrative, but will reflect the innate temporal dynamics of elicited contexts, which may be degraded to a greater or lesser extent relative to their waking expression.

Once the sequence of events depicted in Figure 8 is started, the dream becomes a self-contained information loop at both conscious and unconscious levels of information transfer. Taken together, the conscious output of the perceptual and cognitive generators can be construed as the "manifest" dream. There is also an indirect, unconscious interaction from the cognitive generator to the perceptual generator, via the back propagation pathway outlined above. As can be seen in Figure 10, this is actually an unconscious and indirect interaction between different levels of mnemonic information in the cognitive generator. In some sense, we could consider this unconscious interaction of information as the dream's "latent" content. This cycle will continue until either a discreet perceptual discontinuity causes a change in the perceptual environment, and hence begins the sequence anew, or until the generators can no longer support this activity due to decreased activation of the generators, or awakening.

LUCID DREAMING AND THE DREAM GENERATION PROCESS

Our model of dreaming also speaks to the propensity of lucid dreams to either fade or revert to nonlucid dreams. During lucid dreams, the cognitive generator now bears an increased computing load to support the lucid dream context and output conscious cognition approaching that of the waking personality. The presence of the lucid dream context appears to alter a spontaneous equilibrium of information transfer from the cognitive to the perceptual generator

If cognitive computing resources are withdrawn from the perceptual generator and used instead to support the lucid dreamer's conscious cognition, then there is potentially less structuring influence on the perceptual generator (this information flow pathway is labeled in Figure 7). Such a mechanism - a cognitive "loading" - may play some role in the appearance of minimal and surreal environments, which clearly represent perceptual environments of decreased structure. At its farthest extreme, too much diversion of cognitive generator computing resources away from the perceptual generator could result in fading of the lucid dream and awakening. In this case, the lucid dreamer draws so heavily on cognitive computing resources in fulfilling their intention to become the waking personality that they do so by waking up!

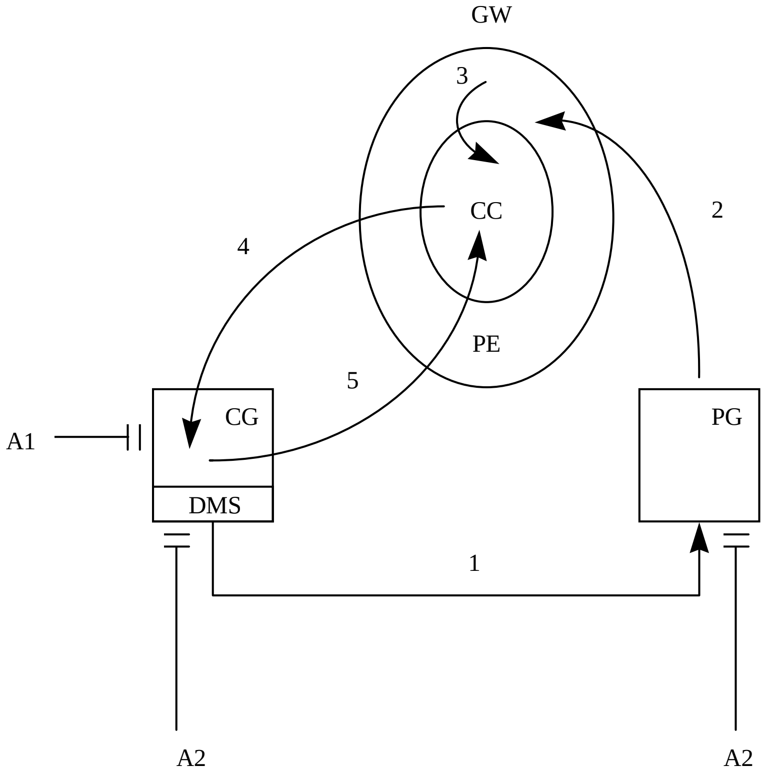


Fig. 10. Hypothesized sequence for the generation of dreams based on the MTMS operating in reverse. A1 and A2 represent extrinsic sources of activation into the cognitive (CG) and perceptual (PG) generators, respectively. Activation by A1 in the absence of A2 gives rise to conscious cognition (CC) during sleep devoid of a perceptual environment. With the concurrent activation of A1 and A2, the following sequence of information flow generates dreaming: (1) random activation (by A2) of the declarative memory system (DMS) elicits an arbitrary output of unconscious mnemonic information that, because of a posited attenuation of the forward hippocampal circuit, backpropagates to sites afferent to MTMS. This information act as a surrogate "sensory input" to multimodal cortex, providing structuring (parameterization) input that gives rise to the dream perceptual environment; this is an unconscious information flow. (2) The perceptual generator outputs consciousness of the perceptual environment (PE). (3) The perceptual environment is consciously comprehended by the dreamer; a conscious information transaction from the perceptual to the cognitive generator, (4) The conscious cognition of the perceptual environment recruits unconscious cognitive contexts which come to (5) frame the dreamer's conscious cognition during the dream. The dream then becomes a feedback cycle at conscious and unconscious levels: conscious between the dreamer's overt perception and cognition, and unconscious between the input to the perceptual generator and the context framing the dreamer's conscious cognition. The net result of these information interactions is a random, yet highly structured, recombination of the elements of mnemonic information, which we term "mental recombination." This cycle will continue until fluctuations in activation alter the input to the perceptual generator, creating a perceptual discontinuity, and beginning the cycle anew. The cycle ends when either (1) activation levels decrease below that needed to support this activity, or (2) the person wakes up and the forward flow of cerebral information reasserts itself due to sensory input.

Interestingly, cognitive "loading" and fading do not appear to occur in reverse. That is, with increasing perceptual environment structure, implying "adequate" parameterization of the perceptual generator, there is not an automatic nor incremental decrease in the lucidity of the dreamer. However, with the onset of a fully structured dream perceptual environment, the "relentlessly unfolding" nature of the spontaneous dream process attempts to decrease cognitive generator activity by causing the lucid dream to revert to a nonlucid dream via the competition mechanism discussed in section 7.2.

Hence there appears to be a type of equilibrium associated with nonlucid dreaming: a balance of information transfer between the perceptual and cognitive generators. Lucid dreaming is a perturbation on this equilibrium, shifting the balance towards cognitive process-

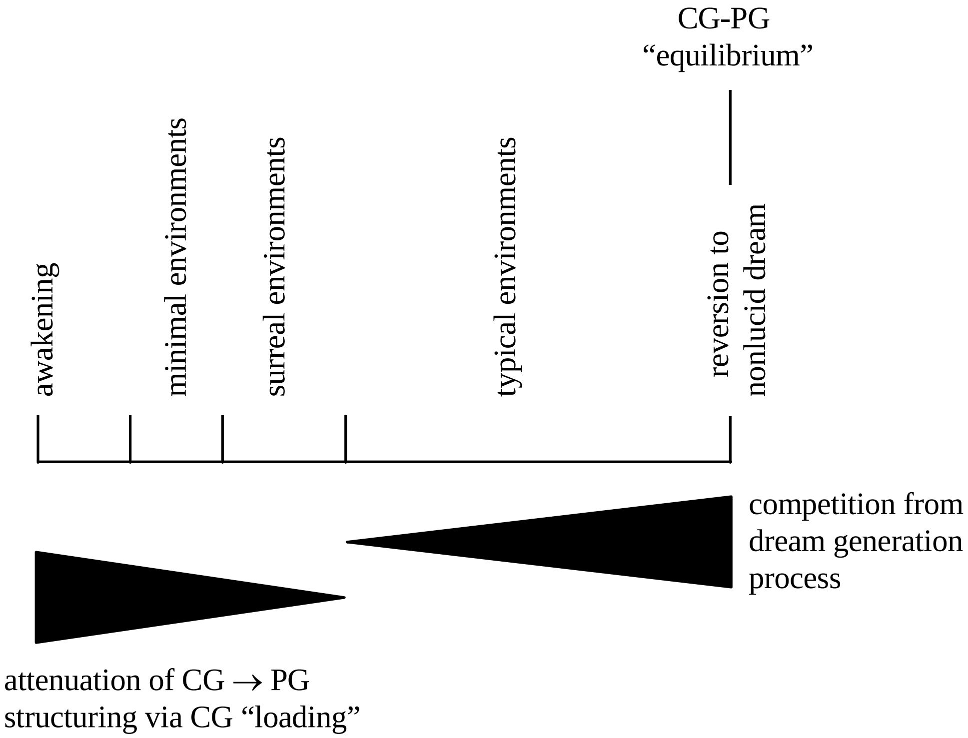


Fig. 11. The interaction of the lucid dream context with the spontaneous dream process. The lucid dream context increases the computing demands on the cognitive generator (CG), which upsets a conjectured information equilibrium between the cognitive and perceptual generators (PG) during spontaneous nonlucid dreams. To the left, increasing cognitive computing demands divert unconscious computing activity used to structure the dream environment away from the perceptual generator and into conscious cognition (the “loading effect”). The result is decreased structure in the perceptual environment. There appear to be two global “attractor states” in perceptual processing, giving rise to surreal and minimal perceptual environments, before the loading effect is so great that lucid dreaming fading followed by awakening occurs. To the right, when activation levels can sustain both the lucid dream context, and the structuring of the perceptual environment, the spontaneous dream process still seeks to achieve equilibrium by attempting to displace the lucid dream context via cognitive competion, and thereby lower cognitive computing demands. This model suggests that there is some critical level of brain activation that serves as the bifurcation point between the left and right scenarios.

ing. This disequilibrium attempts to resolve by either (1) fading of the lucid dream, or (2) reversion to a nonlucid dream. This interplay of the lucid dream context with perceptual structuring and the spontaneous dream generation process is depicted in Figure 11.

Whether cognitive generator “loading” or competition will dominate a given lucid dream appears to be a function of global brain activation. If global activation is below a critical threshold, then cognitive generator loading occurs along with consequent loss of perceptual richness and content. It is as if there is not enough activation to simultaneously support the lucid dream context *and* a typical dream environment. This may be the underlying cause of sensations of dream instability, as well as the onset of surreal and minimal perceptual environments. Above a critical threshold, the brain becomes activated enough to support both the lucid dream context and a typical dream environment, in which case the competition scenario can occur. Therefore, our model predicts that general levels of brain activation (as assessed by EEG power analysis or functional neuroimaging) will correlate with either “cognitive loading” or competition scenarios, being lower in the former case. Without the excess load imposed by the lucid dream context, this whole series of events does not come into play in nonlucid dreams, with the exception of “embryonic” dream lucidity, which typically leads to awakening, suggesting a cognitive loading/fading scenario.

MENTAL RECOMBINATION

A key implication of our view of dream generation derives from contrasting the contextual structuring of dreams to that of waking. Perceptual structuring is, according to our model, essentially random; dream environments simply may or may not resemble familiar waking environments. Perceptual discontinuities of the dream environment are also random (Kahn & Hobson, 1993; Hobson & McCarley, 1977). The cognitive contextual structuring of the nonlucid dreamer's consciousness is also different from the waking personality for two reasons. First, because the dreamer's cognition is framed by a degraded version of waking contexts that may form incongruous fusions (Antrobus, 1986), and secondly because whatever cognitive context is evoked occurs in a perceptual environment that may or may not have anything to do with waking experience. Further, all of this occurs within the amnesia of sleep. The net result, *in the average case,* is Rechtschaffen's "single-mindedness and isolation of dreams", even if there is significant resemblance to waking life in any given dream. What we suggest is happening in dreams is that unconscious elements of the waking personality (e.g. the information parameterizing the perceptual environment and the evoked cognitive contexts) are *recombined* in novel ways within consciousness.

Recall the discussion in section 4.6, that during waking, Baars' GW model indicates that the function of consciousness is a blend of adapting to novelty and forming long-term contextual structures. The trend of waking conscious function is toward the accumulation of contexts that manifest as habits and routines. As we age and mature, we encounter less novelty and increase our repertoire of habits and expectations. Contrast this now with nonlucid dreams, where there is almost no contribution to consciously accessible long-term memory, and where we see a "hyperassociative" mixing of cognitive and perceptual mnemonic elements. It is clear that dream consciousness does not possess the same function as waking consciousness. Is there anything we can say about putative functions of consciousness in the dream state?

The contrast of consciousness across waking and dreaming suggests that dreams are a form of biological information processing that function analogously to the cellular process of genetic recombination. In genetic recombination, stretches of DNA information exchange position along the length of the chromosome, increasing the diversity of genetic information (Smith & Nicolas, 1998). Increased genetic diversity enhances adaptability - the ability of biological information structures to alter, and therefore be able respond to unpredictable changes in the environment (Conrad, 1983). At a functional level, genetic recombination is random (Dobzhansky, Ayala, Stebbins, & Valentine, 1977). However, the information that is randomly exchanged is itself highly structured. We suggest dreams serve a similar biocomputational adaptational role. The generative basis for dreaming within our scheme is that of Hobson & McCarley (1977) and is essentially random. However, random activation of the MTMS leads to the formation of highly structured, albeit arbitrary, perceptual environments which elicit structured cognitive behavior from the dreamer. The result is a recombination of cerebral information structures during the course of the dream. We refer to this process as *mental recombination,* by analogy with genetic recombination.

How can mental recombination be functional within the economy of the nervous system? Following a line of thinking that dreams possess adaptive psychological function (Cohen, 1979; Greenberg & Pearlman, 1974; Palambo, 1978; Rotenberg, 1992a, 1992b, 1996), we suggest that dreaming, as mental recombination, serves as a counterpoint to the waking tendency towards context (e.g. habit, rote, expectation) formation. Dreaming serves to "loosen" or "mix up" the information contained in the brain. Unlike genetic recombination - which is permanent - dreaming, as mental recombination, occurs on a temporary basis. Because of the amnesia associated with dreaming, dreams typically have no immediate, consciously-accessible effect on the structure of the waking personality. In this sense, mental recombination is akin to, for lack of a better term, a type of "novelty priming." The brief temporal span of dreams is similar to how priming is a temporary, but not a long-term, modification of mnemonic processes (Flowers, 1990; Schacter & Buckner, 1998). In dreams, the brain is *briefly* exposed to new activity patterns, leaving in most instances only unconscious traces, but not consciously accessible effects. A single dream (recombination event) is unlikely to have any substantial impact on the waking personality; only very rarely do dreams enter waking consciousness and have a substantial long-term impact (Hunt, 1989). It would be expected that the contribution of dreaming to the structure of waking personality is to enhance the flexibility of waking consciousness through numerous "novelty priming" events which "prime" alternative pathways of neural activation, pathways different from those laid down and reinforced during waking. The increased flexibility of waking consciousness would be expected to be a long-term consequence of dreaming. Our idea of mental recombination falls into a class 2 interpretation of the functional significance of dreams (Fishbein, 1981).

To put the idea that dreams are random recombinations of specific levels of neural information into perspective, we need to be cognizant of the fact that the "constructive utilization of randomness" is a general feature of biological information processing (Conrad, 1985). Random mutations and recombinations of genetic information are the fodder from which the evolution of species arise. Heat (e.g. random molecular motion), a notorious source of noise to the engineer, is the basis of diffusional forces which allow biological chemical reactions to operate (Conrad, 1985). The release of synaptic vesicles (Katz & Miledi, 1972), the opening and closing of ion channels (Liebovitch & Tóth, 1991), and single neuron pulse trains (Freeman, 1996) are stochastic processes, the macroscopic results of which are the electrical and neurocomputational properties of the brain. Steven Thaler's Creativity Engines are neural network systems that display creative behavior; this effect is achieved by introducing a precise degree of random perturbation into the neural networks (Thaler, 1996a, 1996b). Thaler's model indicates there is an optimal degree of randomness that is "good" for a biological system: too much randomness and you get a mess, too little, and things do not change enough to allow "creativity" to emerge. Dreams may play a similar optimization role in the balance between flexibility and stability in cerebral information structures.

Stated simply, within biological systems randomness can be a good thing. Randomness serves as the necessary basis for ostensibly creative actions by biological systems which, in fact, are not intentionally creative but simply spontaneously emerge. More precisely, randomness is the necessary basis for the flexibility that allows biological systems to adapt to unpredictable changes in their environment. The brain, as a product of evolution by natural selection, would be fully expected to utilize the same types of adaptive mechanisms as any other biological information system. Hence, Hobson and McCarley's infamous notion that dreams are random has been misconstrued (such as the discussion in Moffitt, Kramer, & Hoffmann, 1993). This randomness is not meaningless, but is an essential ingredient that allows dreams to serve a role in the adaptive biocomputational properties of the brain. This, we suggest is precisely why dreaming evolved: it imparts an adaptive advantage over a hypothetical nondreaming brain which, according to the GW model, would become encrusted with habits of thought and action over time as context formation would overwhelm the flexibility aspects of consciousness. Because we dream, our minds experience a flexibility that provides the fodder for our adaptive, creative and new responses during waking (Greenberg & Pearlman, 1974). Since the essential function of dreaming as mental recombination is to simply recombine mnemonic information on a temporary basis, there is, at least in principle, no intrinsic need to remember our dreams overtly; the unconscious "novelty priming" effects are sufficient for dreaming to exert its function. In fact, remembering all of our dreams would waste neural computing resources and would be counter-adaptive, as some authors have pointed out (e.g. Kavanau, 1996). However, there are important caveats to this point we discuss below.

COMPARISON OF MENTAL RECOMBINATION TO OTHER MODELS OF DREAM FUNCTION

We would like to end by contrasting a few contemporary ideas of dream function with our concept of mental recombination.

Hunt (1989) has presented the idea that dreams serve a "recombinatory" function, a notion also expressed in Mancia (1995). The result of recombination in dreams, according to Hunt (1989), is to integrate newly learned information into stores of older information, or that dreaming plays a role in short-term to long-term explicit memory consolidation. In contrast, we envision dreams as a literal "mixing up" of cerebral information solely for the purpose of increasing the flexibility of neural circuitry. Hunt's idea predicts that we should be able to consciously recall new information better after dreaming. Our idea predicts that dreaming should make waking cognitive activities more flexible (e.g. adaptable) than if dreaming was not present, but no single dream, on average, will have an overt affect on waking conscious operations. We suggest that the ambiguity of the results from sleep deprivation experiments on waking learning and memory performance (Rosa & Bonnet, 1985; Rotenberg, 1992b; Vogel, 1975) indicates that dream deprivation does not have an immediate, readily discernible effect on waking explicit recall. Increased REM duration following unprepared learning seems to support some role of REM in the consolidation process (Rotenberg, 1996). However, Rotenberg's arguments that increased REM following unprepared learning is due to anxiety reduction mechanisms not necessarily related to memory consolidation cannot be lightly dismissed (Rotenberg & Arshavsky 1979; Rotenberg 1992a, 1992b).

Nonetheless, our and Hunt's notions are not mutually exclusive. First, the addition of any newly learned waking material can serve as fodder in the random recombination process, which would also serve to reinforce and integrate newly learned material. Perhaps more importantly, the impact of "day-residue," or immediate problems of waking life (Beauchemin & Hays, 1996; Cartwright, 1993), can serve as modulating influences on the random basis of dream generation. Waking concerns and problems could readily serve as perturbations and bias the random dream generation process towards the mnemonic structure of waking concerns and problems, which is the opposite emphasis of Cohen (1979) who saw dreams as generating novel solutions to presleep problems. The random mechanism we postulated above is not rigid and fixed, but can be modulated by existent memories. Such a position reconciles the random biological basis of dreaming with the widely recognized psychological significance of dreaming. Perhaps the ultimate example of a mnemonic structure modulating the random dream process is the lucid dream context, where the waking personality directly intervenes in the spontaneous dream generation process. We will not pursue this line of thought further here. The issue of how the conscious cognition of the waking personality can bias the unconscious structuring of the perceptual environment is an important question (e.g. Worsley, 1988; Tholey, 1988), and one that we hope our ideas make more tractable.

Our views also speak to Crick and Mitchenson's (1983, 1995) concept that dreams are a form of "reverse learning." Under certain conditions, overlapping inputs to a neural net will result in overlapping outputs. Specific mathematical manipulations of the neural net will cause it to cease overlapping the outputs even when the inputs continue to overlap. This change in the neural net is called "reverse learning." Crick and Mitchenson have postulated that dreaming plays an analogous role in brain function such that dreams lead to a refinement of waking information structures by erasing "noise" from mnemonic circuits. However, the mechanism of reverse learning is similar to the act of intentional practice, which refines behavior during waking, and hence plays a role in the tendency towards habit formation during waking. That is to say, reverse learning is probably an important aspect of the neurocomputations underlying procedural memory formation, or Baars' (1988) adaptation cycle, but it probably plays little role, if any, in normative nonlucid dreams. Reverse learning could potentially operate in lucid dreams when refinement of the lucid dream context occurs.

In a somewhat similar vein, Kavanau (1996) has suggested that dreams have evolved to allow a "dynamic stabilization" of infrequently used neural circuits, and suggests that this is also the basis for the evolution of the inability to remember our dreams. We point out that this view fails to take into account the well known "use it or lose it" principle in the brain. The waking brain has a mechanism for dealing with infrequently used explicit information: it overwrites it with relevant and frequently used information. On the other hand, procedural memories can be maintained for long periods without waking reinforcement, and there is evidence of the involvement of REM sleep with consolidation of procedural memories (Karni, Tanne, Rubenstein, Askenasy, & Sagi, 1994; Smith & Lapp, 1986; Smith, 1996). Kavanau's postulated mechanism may play some role in maintaining procedural memory during dreaming, and is perhaps related to the consistent fidelity of overlearned activities across waking and dreaming identified above.

Finally, we would like to comment on how lucid dreaming fits into the view of dream function we have outlined here. Reasonable estimates suggest that lucid dreams take up only a very small percentage of an experienced lucid dreamer's total dream time (LaBerge, Levitan, DeGracia, & Zarcone, 1999). Hence, over the long-term, lucid dreaming would not be expected to interfere with dream function as we have construed it here. In spite of being a somewhat fragile balancing act, lucid dreams are remembered well after waking, as opposed to leaving only unconscious "novelty priming" traces in the brain after awakening from nonlucid dreaming. From the point of view that the spontaneous dream process can be biased towards manifesting waking problems or concerns, or even imbalances in the waking personality, lucid dreaming clearly provides a huge acceleration over nonlucid dreams in bringing these factors to the attention of the waking personality. Hence, lucid dreams can, and should, be used as a form of self-understanding (Malamud, 1988; Tholey, 1988).

Otherwise, the recognition that dreaming is ultimately an expression of unconscious forms of information into the consciousness of the dreamer, via the type of synesthetic mechanisms discussed by Hunt (1989), or via the model we have developed above, has within it the potential to allow the development of a whole new level of subjective description of conscious experience via lucid dreaming. Specifically, the development of methods and ideas that will allow us to begin to comprehend the nature of surreal dream environments and other forms of conscious experience with no waking counterpart is strongly inviting (e.g. see Rifat, 1980, 1997). This has been approached in the Tibetan lucid dreaming tradition (Gillespie, 1988). However, the modern lucid dreamer has all the knowledge and discoveries of modern cognitive neuroscience upon which to draw in ascertaining the nature of things experienced uniquely in the lucid dream state. We strongly encourage this line of intellectual evolution.

CONCLUSION

Table 3 summarizes the salient similarities and differences we have identified between conscious and unconscious processes across waking, nonlucid and lucid dreaming. These ideas have been presented in the spirit of unifying our understanding of the mind-brain system in its entirety. By integrating the phenomenology of sleep experiences into the Global Workspace model, we have developed a framework that we feel provides a means for discussing across-state changes in conscious and unconscious processes. We have explored a number of the implications of this way of thinking, but have by no means exhausted the potential contained therein. Our thinking has been primarily inspired by the phenomenology of actual human experiences in the sleep state. Therein lies both its strength and its weakness. Whether or not every detail we discussed above turns out to be accurate, our ultimate intention is to stimulate a more unified dialogue, one which seeks to encompass

	Waking	Nonlucid Dreaming	Lucid Dreaming
PERCEPTUAL			
PG parameterization source	sensory	mnemonic	mnemonic
Environment types	typical	typical	typical, minimal and surreal
Bizarreness	none: consistent	present	present
Conscious sensations of perceptual stability/instability	not present	not present	present; from stable to unstable; when highly unstable, dream fades
COGNITIVE			
Cognitive Fidelity	relatively constant	widely variable	variable
Affect	baseline	exaggerated	similar to waking
Personality structure	intact	displays degrees of “graceful degradation”	intact, with possible cognitive degradation
Long-term episodic memory formation	intact	weak; may recall last dream prior to waking	intact; somewhat below waking levels
Contextual structure framing conscious operation	waking personality	highly variable; isolated from waking personality	waking personality via lucid dream context
Function of conscious processes	recognize novelty; adapt to regularities	mental recombination: generate conscious novelty via recombination of declarative and perceptual contexts	recognize novelty; adapt to regularities; generate conscious novelty via recombination of declarative and perceptual contexts

Table 3: Comparison of waking, nonlucid and lucid dreams in terms of perceptual and cognitive generator activities.

the multitude of facets of human experience. We hope at least in this we have succeeded.

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