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Such stuff as dreams are made on? Elaborative encoding, the ancient art of memory, and the hippocampus

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Abstract: This article argues that rapid eye movement (REM) dreaming is elaborative encoding for episodic memories. Elaborative encoding in REM can, at least partially, be understood through ancient art of memory (AAOM) principles: visualization, bizarre association, organization, narration, embodiment, and location. These principles render recent memories more distinctive through novel and meaningful association with emotionally salient, remote memories. The AAOM optimizes memory performance, suggesting that its principles may predict aspects of how episodic memory is configured in the brain. Integration and segregation are fundamental organizing principles in the cerebral cortex. Episodic memory networks interconnect profusely within the cortex, creating omnidirectional “landmark” junctions. Memories may be integrated at junctions but segregated along connecting network paths that meet at junctions. Episodic junctions may be instantiated during non-rapid eye movement (NREM) sleep after hippocampal associational function during REM dreams. Hippocampal association involves relating, binding, and integrating episodic memories into a mnemonic compositional whole. This often bizarre, composite image has not been present to the senses; it is not “real” because it hyperassociates several memories. During REM sleep, on the phenomenological level, this composite image is experienced as a dream scene. A dream scene may be instantiated as omnidirectional neocortical junction and retained by the hippocampus as an index. On episodic memory retrieval, an external stimulus (or an internal representation) is matched by the hippocampus against its indices. One or more indices then reference the relevant neocortical junctions from which episodic memories can be retrieved. Episodic junctions reach a processing (rather than conscious) level during normal wake to enable retrieval. If this hypothesis is correct, the stuff of dreams is the stuff of memory.

Keywords: elaborative encoding; episodic memory; hippocampus; neocortical junctions; REM dreams

1. Introduction

The idea that sleep and dreaming complement memory function in wake has a long history (for broad reviews, see Hobson 1999a; 2002; Winson 1986; 1993). More recently, there is interest in the synergistic roles of rapid eye movement (REM) and non-rapid eye movement (NREM) in memory processes (see, e.g., Diekelmann et al. 2009; Ribeiro & Nicolelis 2004; Stickgold 2005; 2009). The relationship, if any, between dreams and memory has remained enigmatic, however. “Why do we need to create an artificial world offline and spend two hours a day in it?” (Hobson 1999a, p. 73).

Aristotle (350 B.C./1996) argued that experiences, like projectiles set in motion during wake, continue as memories in dreams. Freud (1899/1999, p. 12) claimed that “all the material” in dreams derives “in some way” from remembered waking experiences; he also identified the memory sources for dreams (see, e.g., those for “Wolf Man” [Freud 1963, pp. 214–16]). Stickgold (2002) states that, in the absence of external sensory input, memories with derived meanings and symbols must be the source material for dreams. Many have argued that memory sources are key to dream construction (Baylor & Cavallero 2001; Cicogna & Bosinelli 2001; Foulkes 1985; Kramer 2007; Nielsen & Stenstrom 2005). Some contend that

these memory sources reflect emotional concerns (Domhoff 1996; Hartmann 1998; Schredl 2003). Memories are not replayed in dreams (Fosse et al. 2003); instead, memory elements are merged and fused to construct visual scenes (cf. Hartmann 1996; Hobson 1988, pp. 36–38; Walker & Stickgold 2010). The significance (if any) of why memory elements unite in dream image composition remains elusive. This requires explanation in any account of the mnemonic function of dreaming. Stickgold et al. (2001) pinpoint a “frustrating dearth” of evidence on dream construction and its possible functions. The article aims to make a contribution in this area.

Possibly linked to the conflation of memory elements (Cicogna & Bosinelli 2001) is the, often, bizarre nature of dream imagery (Fosse et al. 2004; Hobson 2002; Scarone et al. 2008). McCarley and Hoffman (1981) report that

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67% of REM dreams exhibit bizarreness. Indeed, the word “bizarre” is used to characterize a person/object/place that takes on multiple (apparently inconsistent) elements. Bizarreness is constrained in dreams, however. Bizarre dream characters/objects conform to “bizarreness rules” (Rittenhouse et al. 1994). These rules limit bizarreness to incongruities (inconsistent or fused features of people/objects/places), discontinuities (sudden changes in these features of people/objects/places), and indeterminacy (where the identity of a person/object/place remains explicitly vague). The constrained nature of dream bizarreness excludes many possibilities. For example, typical adult dreams do not feature monsters or people who transmogrify into walking pink blanchmanges (cf. Hobson 2011, p. 163; Rittenhouse et al. 1994). Moreover, most of dream content is not bizarre and conforms to waking expectations (Domhoff 2011; Domhoff & Scheider 2008; Snyder 1970; Snyder et al. 1968). Dreams do not resemble abstract art, for example.

This article argues that the sometimes bizarre (but rule bound) visually associative nature of a dream (along with other dream characteristics) can, at least partially, be understood through the principles underlying what has been termed the “ancient art of memory” (henceforth, AAOM). The article integrates knowledge of the AAOM, from the humanities, into work on dreams and memory in neurobiology and psychology. The AAOM is elaborative encoding in wake engendering a visual composition using imagery (which is often bizarre), association (particularly to place), organization, and narration and forming the basis of all effective memory techniques (see evidence cited later). This efficacy suggests that AAOM principles predict at least some aspects of how declarative memory is configured in the brain. Why might this be?

If the construction of REM dreams can be understood through AAOM principles (see later sections), REM dreaming may be elaborative encoding that results in a visual, hyperassociative, organized, narrative, mnemonic composition, which can integrate a recent memory into remote episodic neuronal assembly networks in the associative cortex (see later arguments). The question then arises of how this integration of recent episodic memories can be accomplished without catastrophic interference (McCloskey & Cohen 1989; Ratcliff 1990) with the content of remote memories. Since Müller and Pilzecker (1900), the traditional answer has been slow consolidation. This answer convinces for semantic memory, where a body of knowledge is being formed but seems less satisfactory for episodic memory, which depends on the ability to differentiate between, and, thus, recall unique events. Even if integration is slow, it is still integration.

Fuster (1999, p. 85) states that a memory is best construed as represented in an associative network or matrix of neurons. For prominent network models, see Anderson (1977), Ballard (1986), Edelman (1987), Feldman (1981), Kohonen (1977), and McClelland and Rumelhart (1985). Fundamental to network structures and processes are nodes/junctions and connections/edges (for a review, see Sporns 2011a, pp. 38–40). With respect to brain networks, definitions of nodes/junction and connections/edges are still problematic; this is significant because definitional choices impact upon the way that networks are understood (Butts 2009; Fornito et al. 2012; Zalesky et al. 2010). Networks can be defined at

micro, meso, and macro levels. At the micro level, nodes/junctions may be said to be constituted by individual neurons; at macro level, decisions are required over the parcellation of grey matter into regional nodes (Zalesky et al. 2010). Neuronal assemblies may represent meso-level phenomena of particular relevance for memory networks (cf. Başar et al. 2000; Miller 1996). At the meso level in episodic memory networks, junction/node and connection/edge are not well understood.

Segregation and integration are fundamental to the organization of the cerebral cortex (Tononi et al. 1994; Zeki 1978; Zeki & Shipp 1988). Buzsáki (2006, p. 65) argues that pattern completion and pattern separation are the basic functions of neuronal networks, expressed though the concepts of integration and differentiation, respectively. Fuster (1999, p. 33) states that segregation and integration characterize memory networks; he uses the concepts of *divergence* and *convergence*. The answer to the problem of how episodic memories are both integrated and segregated in cortical networks may be that a REM dream, composed of associated memory elements, is a junction/node, thus enabling integration at the junction but segregation between the episodic memory representations along the connecting paths/edges that “meet,” and share elements, at a junction.

In support of this hypothesis, the structure of the article is as follows. The next subsection sets out the article’s underlying assumptions about dreaming and memory. The second section describes the AAOM and explains why this constitutes elaborative encoding. The third section presents research from experimental psychology indicating that the principles on which the AAOM is based are mnemonic. This is followed by neurobiological evidence that these principles are expressed during REM dreaming, as a single dream (and its hypothesized memory sources) illustrates. The article then considers how the hypothesis can be tested and concludes with intimations on what this hypothesis implies for sleep stages, focusing particularly on REM dreaming and memory processes.

1.1. Some preliminary clarifications about dreams and memory

Before proceeding to explain the AAOM, some preliminary clarifications are necessary. The hypothesis on the relationship to the AAOM relates to REM (rather than NREM) dreams. The REM sleep stage is most correlated with dreaming mentation (Dement & Kleitman 1957b; Hobson 2002; 2009; Nielson 2003). REM dreams are more animated, characterized by vivid internal perceptions, charged with primary emotions, spatially defined, hyperassociative, and more bizarre than NREM dreams, which are briefer, more literal, thought-like, perseverative, and verbal (for reviews and debates over these distinctions/continuums, see Cavallero et al. 1990; Desseilles et al. 2011a; Foulkes et al. 1989; Hobson 2002; Lavie et al. 1984; Nielson 2003). NREM dreams do not hyperassociate memories (Foulkes 1985), which renders them less comparable (than REM) to the AAOM. As this article is concerned with whether the mnemonic principles of AAOM are isomorphic with dreaming “rules,” the focus is on REM rather than NREM dreams. Stickgold et al. (2001) argue that REM and NREM are characterized by unique

physiology and dream structure; hence, for many purposes, they should be considered separately. This is the position I take in this article also, although see Fosse and Domhoff (2007), who report that early-night REM and late-night NREM dreams cannot be distinguished.

Psychology distinguishes declarative from non-declarative memory and subdivides declarative memory into semantic and episodic/autobiographical. This article relates to *episodic memory*: enduring memories of personally significant past events with contextual place and time underpinnings (Squire 1987; Tulving 1983; 1991). It is not concerned with habitual activities. William James (1890) suggested that association, through activities performed habitually while awake, is the foundation for all memory; thus, the associations that underpin the retention of habitual activities may be formed during wake, also. The article's hypothesis rests on the assumption of shallow encoding of episodic memories in wake. There is considerable evidence that semantic memories are encoded during wake. To avoid an overlong article, I do not review here the vast literature on encoding in wake. The function of episodic memory is understood as oriented to the future rather than the past (Schacter & Addis 2007b; Schacter et al. 2007). The neural substrates for remembering the past and envisaging the future overlap – imagining the future relies on recombining memories of past experiences (Addis et al. 2007; Ellenbogen et al. 2007; Schacter & Addis 2007b; Schacter et al. 2007; Szpunar et al. 2007). Indeed, Conway (2009, p. 2307) proposes replacing “memory system” with “remembering–imagining system.” Imagining depends upon imaging.

Memories are reconstructed on retrieval (Bartlett 1932; Conway & Pleydell-Pearce 2000; Hassabis & Maguire 2007; Neisser 1962; Rubin et al. 2003; Schachtel 1947; Schacter & Addis 2007b; Schacter et al. 1998) not just from different modalities (visual, spatial, motor, language-related, and so on) but from memories that occurred in different time–space contexts (cf. multiple trace theory [Moscovitch & Nadel 1998; Nadel & Moscovitch 1997; Nadel et al. 2000]). *Re-collection* involves the parallel processing of many distributed networks (Fuster 1999, p. 210). Memory flexibility is engendered by sparse (only a fraction of any “whole” memory is represented at any location) and distributed (memories are held over large areas of neuronal space) memory networks (Buzsáki 2006, p. 290; Kanerva 1988). This flexibility implies that memory is robust, but there is no certain memory output for any given input (Fuster 1999, p. 86). Reconstructed memories “bring past experience to bear on present thought and action” (Anderson 1997, p. 20). In doing so, “memory pulls us forward” (Robinson 2005, p. 192). Through this projective process, memory reveals identity – feelings, plans, accomplishments, disappointments, and relationships (cf. Neisser & Hyman 2000). Without the “binding force of memory,” identity would be splintered (Kandel 2006). Identity is expressed through memories of emotional concerns (Archer 2000, p. 10). Personal memories are always emotional. As Freeman (1999, p. 114) points out, “Without emotion, there would be no remembering.”

Against these background assumptions about dreams and memory, the next section explains the principles that underlie the AAOM and are hypothesized to account, largely, for the mnemonic properties of REM dreams.

2. The ancient art of memory in waking consciousness

The AAOM was (and is) exploited in waking consciousness. Consciousness is a contested concept. This article is mainly concerned with two dimensions of consciousness: the phenomenological contents of REM dreaming consciousness, and the neurobiological architecture that makes REM dreaming consciousness possible. (For further elucidation of the way that consciousness is understood in this article, see, for example, Donald [1995] and Metzinger [2003b; 2009].)

In the modern age, the content of waking consciousness is characterized by partial reliance on external memory banks. The clearest example is, of course, the Internet, which partially externalizes semantic and encyclopaedic memories. Consequently, cultural dependence on individual memory has diminished (Donald 1991; 1993). Perhaps related to this is the assumption that individual memory for episodic waking experiences “comes for free”; no special strategies are necessary, such memories occur as a “by-product of perception and comprehension” (Worthen & Hunt 2011, p. 14). This modern notion that memories of waking experiences are formed and retained effortlessly and, thus, not as the result of cognitive, imaginative endeavour, contrasts strongly with the pre-modern view.

In classical antiquity, indeed, right up to the Early Middle Ages, learning the mnemonic craft was central to the education of the social elite (Carruthers & Ziolkowski 2002). Classically, it was well understood that a flexible memory system works best not through learning by rote, nor by memorizing events “as they really are,” but through imaginatively associating the to-be-remembered material in a mental image. Indeed, pre-modern scholars would not have counted anything memorized through rote repetition as a true memory (Carruthers 2008, pp. 22–23). Therefore, as Carruthers argues, the type of memory recognized by modern experimental psychology, as evidenced by the ability to reproduce exactly a list of items, would not have been seen *as memory* by pre-modern scholars. Rote memorization was undertaken in ancient and medieval education, however. “Learning by heart” provided a valuable reiterative foundation upon which a more flexible imaginative memory system could be constructed as it inculcated such habits as dividing up to-be-remembered material, which could then be linked together in a secure order (Carruthers & Ziolkowski 2002, pp. xii–xiv). Flexibility and order were important because the AAOM focused mainly on the encoding of material needed for what were, often, extempore events, such as lectures, disputations, or sermons before live audiences (p. 3).

To the pre-modern mind, flexible memory worked through what I call *imag-ination*. To encode (rather than rote learn) a memory, it was necessary to envision – to form a mental image of – something that was not real, hence *image* plus *imagination*. The mnemonic image was not “real” because it associated several to-be-remembered things. Consequently, a memory was a composite image which had not been present to the senses. Memory and *imag-ination* were as one. Consequently, individual memory was revered: “Ancient and medieval people reserved their awe for memory” (Carruthers 2008, p. 1).

Until quite recently (e.g., Conway's 2009 "remembering-imagining system"), the modern era fostered a view of memory and imagination as polar opposites rather than mutually implicated. To the classical mind, however, memory was not simply concerned with retention but depended crucially upon imaginative composition (Carruthers & Ziolkowski 2002, p. 3). In the AAOM, personally significant events, people, and thoughts are connected in ways which do not replicate how these events, people, and thoughts were actually related in ongoing daily waking experience but how they are meaningfully, emotionally associated from a personal perspective (Bolzoni 2001; Carruthers 2008; Yates 1966). So, historically, memory was seen as a creative process where the to-be-remembered material was made memorable (in contemporary psychological terms, encoded and consolidated in long-term memory) through imaginative composition. The aim of AAOM was to produce memory cues or "chains of association that regenerate memories" (Bolzoni 2001, p. xviii). Carruthers and Ziolkowski stress:

Memory works by association. Its connections are thus individual and particular, not universal....The logic of memory is essentially "arbitrary," in the Latin sense—dependent on one's experiences... desires and above all will....Thus, while the colour "white" may remind me of "snow," it may remind you of "milk" and thus send us along entirely different associative pathways with equal claims to be "true." (Carruthers & Ziolkowski 2002, p. 8)

The pre-modern view that all memory is associative is echoed in current neuroscience by Fuster (1999, p. 2): "Association is an attribute of all memories, at the root of their genesis as well as their evocation." Notably, the more bizarre, dramatic, absurd, or obscene the associative cue the memorizer creates, the more persistent the memory to which the cue has been associated and the easier the process of retrieval (Hughes 1997; Yates 1966).

The visual sense was recognized as the most secure for the art of memory composition (Carruthers & Ziolkowski 2002, pp. 11–12; Yates 1966, p. 19). The AAOM emphasizes that a memory is something that is *looked at* rather than heard or spoken, both as it is committed to mind and when it is recalled (Carruthers 2008, p. 24). To function mnemonically, visual images should be intense and affective; to remember "bitter," for example, the image can portray a person vomiting on a bitter substance (Bradwardine 2002). Although other senses may be used for emphasis—for example, the sensation of taste may be invoked in this image of "bitter"—the visual medium is essential (cf. Carruthers & Ziolkowski 2002, p. 11). A good memory image is charged with primary feelings like fear, desire, elation, or disgust; in contrast, a bad memory composition is anything dull, anything unlikely to command attention (Carruthers 2008, p. 75). The images must be distinctive and, therefore, memorable; if ordinary events occur, they are emotionally heightened through, for example, violence, surprise, or titillation (Carruthers & Ziolkowski 2002, p. 13). If the images take the form of people, these individuals should be well known to the memorizer or famous or, even better, infamous; uninteresting anonymous people do not make for effective cues (cf. Yates 1966, p. 27).

To employ the AAOM, the to-be-remembered material is reorganized. Carruthers and Ziolkowski (2002, p. 4)

comment that "material is first cut up into *divisiones* or distinctions, and then these segments are mentally marked and memorized in a readily recoverable order. Each segment should be 'short' (*brevis*), no larger than what your mental eye can encompass in a single glance or *con-spectus*." The order of the material is of paramount importance so that the *divisiones* can be recalled in sequence, with none omitted in error (p. 4). The number of *divisiones* (compositions or scenes) that can be retained in memory is limitless, but each composition (or scene) should be sparse, composed from not more than about "seven plus or minus two" people and/or objects (p. 9; cf. working memory [Miller 1956]). Crowded, cluttered, or complex scenes do not make good memory images. Also the memory image is timeless—in the sense that rather than referencing the past, the composed image puts the to-be-remembered material in "real time," thereby rendering the image more immediate and, therefore, more effective (Bolzoni 2001, p. 214). If possible, to further command attention, the image should incorporate movement (Bradwardine 2002).

Once an emotionally tagged image is formed, it is associated with a locus, place, or landmark (as a mnemonic technique, this is sometimes termed the *method of loci*). Then another related image is connected to another related landmark and so on (Bolzoni 2001, p. xvii). Suitable landmarks are simple locations easily brought to mind—like a house, a space, a corner, or an arch (Yates 1966, p. 22). The method of loci relies on the creation of a ordered sequence. The located images are not arranged chronologically in time but connected through emotionally charged associations, particularly personal ones related to place (Carruthers 2008, p. 76). For example, sometimes, memory images were placed at landmark locations along routes within familiar buildings (p. 18). Thus, emotional, creative association, and composition in the AAOM depends upon three essential components: images, locations/landmarks, and order (Bolzoni 2001, p. xvi). As the locations/landmarks form an order, the compositional images can be easily recalled as the person who is remembering "passes again" through the places—as if retracing a journey (p. xvii). Using the AAOM, having identified one landmark (or the image it contains), it is possible to move either forwards or backwards as one follows the chain of associations (Carruthers & Ziolkowski 2002, p. xiii; Yates 1966, p. 22). For this reason "images in places" were termed "*agent images*"; to enable retrieval, they engender movement within memory's associational structure (Carruthers 1998, p. 15).

As in modern psychology (cf. "encoding," "storage," and "retrieval"), pre-modern scholars distinguished among "composition," "retention," and "recollection" (Carruthers 2008, p. 23). The "method of loci" locates images in places so that they can be *found* and "re-collected" (for "locational memory," see Carruthers & Ziolkowski 2002, pp. 6–8). To support "re-collection," the AAOM is an art for searching and finding images (Carruthers 2008, p. 23). Indeed, the AAOM is an *ars inveniendi*, a "tool of invention," enabling the discovery and selective recombination of memories (Carruthers 2009). Thus, classically, memory retrieval was understood as a process of reconstruction, just as the modern scholars (discussed earlier) now recognize. This renders the modern term "storage" an unfortunate metaphor, "'storage'...is a curious

intellectual model, for it suggests that our memories are essentially passive impressions of experiences...that can be taken out whole and unchanged" (Carruthers & Ziolkowski 2002, p. 1). This is a point Carruthers emphasizes (1998, p. 8) with regard to the *Ad Herennium* scene described below. The purpose of this image is not to cue some pre-memorized "stored" speech but to enable the defence counsel to recall and return to pertinent issues while she or he extemporizes in response to court proceedings.

Yates (1966), quotes from *Ad Herennium*, a classical art-of-memory text compiled in Rome circa 86–82 B.C. She asks readers to imagine that they are the counsel for the defence in a lawsuit. The case is one of suspected poisoning, and material on the relevant issues is divided up. This first memory image is composed to make the accusation, motive, and presence of witnesses memorable. The further case details would have followed in successive linked images:

The prosecutor has said that the defendant killed a man by poison, has charged that the motive of the crime was to gain an inheritance, and declared that there are many witnesses and accessories to this act. We are forming a memory system about the whole case and we shall wish to put in our first memory locus an image to remind us of the accusation against our client. This is the image. We shall imagine the man in question as lying ill in bed, if we know him personally. If we do not know him, we shall yet take someone to be our invalid, but not a man of the lowest class so that he may come to mind at once. And we shall place the defendant at the bedside, holding in his right hand a cup, in his left, tablets, and on the fourth finger, a ram's testicles. In this way we can have in memory the man who was poisoned, the witnesses and the inheritance. The cup would remind of the poisoning, the tablets of the will or the inheritance, and the testicles of the ram through verbal similarity with testes – of the witnesses. (Yates 1966, pp. 27–28)

This scene illustrates the mnemonic principles of an AAOM composition. All the selected to-be-remembered material is there, yet the scene can be easily encompassed in a single glance, being simple, sparse, organized, and in "real time." Place, as spatial setting (not named geographic location) is clearly defined. The dramatis personae are either known personally to the memorizer or are of interest because of status or fame. In this scene, as described, it is not clear whether there is movement, but to enhance mnemonic effect there should be. Lastly, although the scene as a whole may be relatively commonplace, there is a bizarre, arresting and, in this case, rather disgusting detail to engage primary emotions and ensure distinctive mnemonic resonance.

The principles underlying the AAOM form the basis of all effective mnemonic techniques (see, e.g., Groninger 1971; Luria 1968; Roediger 1980; Wang & Thomas 2000; Wilding & Valentine 1997; Worthen & Hunt 2011). Exceptional memorizers acquire their abilities through assimilating these mnemonic techniques rather than being born with great memories (Ericsson 2003; Maguire et al. 2003). Even if not involved in the action, the mnemonic functioning of imagery is enhanced if the memorizer takes themselves to be present – as an embodied and interested observer. Finally, the memorizer should compose the mnemonic so that the associations are personally meaningful.

2.1. A contemporary illustrative AAOM example

The following mnemonic also illustrates AAOM principles but is more than a tableau; it takes the form of a narrative and, therefore, relies on the method of loci.

Scene 1. I am walking alongside a river. I stop where the river narrows and is shallow. I glance down and see a ham in a net. A rat runs past the ham and crosses the river. Suddenly two bees land on a knot in the net, and then just as suddenly the two bees disappear.

Scene 2. A man wearing leggings, a padded jacket, and a high white collar is approaching me by the river. He shakes my hand. He carries a spear in his other hand.

Scene 3. I'm in a house. It seems to be my house. Through the glass in the front door, I can see a woman standing on the doorstep. I open the door, and she shows me lots of make-up in the case she is holding open.

In this scenario, I am a U.K. high school student who is learning about Shakespeare. I aim to remember: birthplace (Stratford upon Avon, U.K.), life era (Elizabethan), marriage (Anne Hathaway), children (Susanna, Hamnet, and Judith), and most famous works.

These first three scenes result from my division and organization of this to-be-remembered material. They are composed to visualize and memorize birthplace: (St) ratford (narrow, shallow place in the river); Avon (the river and the woman selling cosmetics); Hamnet/Hamlet and most famous line "To (two) be(es) or (k)not to(two) be(es)"; and Shake-spear-e himself. Subsequent scenes would be composed to visualize the other facts and works.

This mnemonic encompasses two aspects of memory that pre-modern scholars distinguished: memory for things, people, events, and ideas (*memoria rerum*); and memory for words (*memoria verborum*) (Bolzoni 2001, p. xvii; Carruthers & Ziolkowski 2002, p. 9; Yates 1966, p. 24). For example, Shakespeare is memorized as a person (the man in leggings), and the word "Shake-spear-(e)" is also being committed to memory. In this respect, the *memoria rerum/memoria verborum* distinction does not only mirror the modern division between episodic and semantic memory, but it also reflects Paivio's (1969; 1970; 1986; 2007) dual coding theory. Paivio (see also Kosslyn 1980; 1996) theorized that objects, events, and people are processed and represented non-verbally in a different subsystem from language (for a counter view that all mental representations are propositional, see, e.g., Pylyshyn 1973; 2002). The image system is specialized for processing spatial and relational information, whereas the verbal system is specialized for sequential information (Paivio 1986, p. 142). In Paivio's view, objects, events, and people are instantiated as mental images in long-term memory, whilst language gives rise to propositions. This view should not be taken as implying that "images" (any more than "words") are actually "stored" in the brain, rather images and words are represented by different neuronal network changes. These instantiated changes can be reactivated. If the word is concrete, on retrieval both a proposition and an image may be activated. Abstract words are difficult to visualize; hence, they are processed only through propositions. Under *dual coding*, Paivio assumes that the non-verbal and verbal systems are functionally independent (one system can be active without the other, or both can be active in parallel). However, the two systems are interconnected so that, in appropriate

conditions, activity in one system can trigger activity in the other. In the AAOM, verbal material can be easily dealt with only if the word is concrete – in the sense that it can be visualized (e.g., Shakespeare). In contrast, visualizing abstractions – that is, the “angst” of “to be(e) or (k)not to be(e)” – is problematic.

Just as in the *Ad Herennium* scene, the division and organization of the material, the associations, and the narrative obscure the actual nature of the to-be-remembered material. This composition cannot be identified immediately as relating to Shakespeare any more than the *Ad Herennium* scene is obviously a mnemonic for a case of poisoning. The “Shakespeare” connections are personally significant and, therefore, arbitrary (e.g., I chose to focus on Shakespeare’s clothes and selected a travelling cosmetic saleswoman to personify the river “Avon”). As someone who is interested in clothes and cosmetics, these are obvious associations to me but are not necessarily so to others. I introduced bizarreness (the ham by the river) and the primary emotion of disgust (a rat runs by the ham). To enhance the mnemonic effect further, I imagine myself to be present and embodied. The route of “river, then the river path, then the house” seems unlikely, but I did once live in a house on a street which had a river running down the middle. I frequently walked by the river on the river path before I entered my house. Hence this route is mnemonic for me.

Another notable aspect is that, although the scenes form an ordered scene narrative, they are not chronological and, therefore, would function just as well if they ran the other way (i.e., the “Avon” scene could have been first). The narrative structure of the Shakespeare mnemonic is dictated by association rather than logical progression. For example, the third scene appears to be bizarrely discontinuous (as defined by Rittenhouse et al. 1994) with the second, but knowledge of the “Avon” link reveals an associational theme. (A river is present in scenes 1 and 2, and the river is, through visual analogy, “named” as Avon in scene 3 – although the word “Avon” never surfaces.)

The AAOM is elaborative encoding that uses the devices of visualization, association (particularly the dramatic and bizarre), organization, narration, embodiment, movement, and location as mnemonics. In psychology, what is the experimental evidence that these devices do function mnemonically?

3. Evidence on mnemonics in psychology

Modern experimental psychology has focused on normal memory processes or memory loss through lesion studies (for early research, see Scoville & Milner 1957). Exploring ways to enhance memory through mnemonics (or elaborative encoding) has been relatively neglected (Maguire et al. 2003; Worthen & Hunt 2011, p. 14). Nevertheless, there is some relevant work.

Early “depth of processing” research demonstrated that richer, elaborative, and more meaningful encodings resulted in better retention as compared with rote rehearsal (Bradshaw & Anderson 1982; Craik & Jacoby 1979; Craik & Lockhart 1972; Craik et al. 1983; Hyde & Jenkins 1973; Mandler 1979; Woodward et al. 1973; Worthen & Hunt 2008). Moreover, the specificity of the encoding determined the effectiveness of retrieval cues (Tulving &

Thomson 1973). For example, my Shakespeare mnemonic would result in “cosmetics” cueing Shakespeare’s birthplace through both converging upon “Avon.” Also, self-generated encodings are better retained than provided ones (Ironsmith & Lutz 1996; Kuo & Hooper 2004).

In terms of the various facets of elaborative encoding, a landmark study on the power of visual imagery vis-à-vis verbal material showed that “the capacity of recognition memory for pictures is almost limitless” (Standing 1973). Shepard (1967) demonstrated that subjects’ recognition of memorized pictures was superior to either words or sentences. A high accuracy for the recollection of pictures was also shown by Nickerson (1965; 1968) and Standing et al. (1970). Richardson (1980, p. 61) concludes, “These results are consistent with the idea that pictorial presentation gives rise to a distinctive and highly efficient means of storing information.” The human capacity to store images is immense; contrary to past assumptions, retained images are also detailed (Brady et al. 2008). Indeed, pictorial detail enhanced rather than diminished retention (Vogt & Magnussen 2007).

Forming associative, interactive mental imagery is particularly potent for memory (Mandler 1979). A series of interacting pictures is remembered better than separate ones (Bower 1970a; Epstein et al. 1960; Richardson 1980, p. 6; Wollen & Lowry 1974). Forming a composite image enhances memory – for example, remembering of the word “lamp” and the number 88 is greatly enhanced by imagining a neon light shaped to form the digits 88 compared with rote rehearsal of the word and number (Bower 1970a; 1972). Spatial interaction that creates simple subject-action-object narratives between the to-be-remembered items is also efficacious (Epstein et al. 1960; Rohwer 1966). For example, remembering of the words “rock” and “bottle” is facilitated by imagining the scene of a rock breaking a bottle. Such examples led Bower (1970b) to suggest that “relational organizing” produces the mnemonic effects of associative imagery. As relational organizing increases, the to-be-remembered phenomena are transformed so that the mnemonic image becomes qualitatively different from the original material (Worthen & Hunt 2011, p. 39).

Early experimental research also demonstrated that vivid, bizarre, or dramatic associative imagery (e.g., a dog with a pipe in its mouth or a crashed plane) is retained better than normal imagery. For example, Standing (1973) calculated that if one million vivid pictures could be presented, 731,400 would be preserved. Later experimental research that used bizarre items in mixed lists (some common items, some bizarre items) and unmixed lists (all items are bizarre) put the mnemonic effect of bizarreness down to distinctiveness (Hunt & Elliott 1980; McDaniel & Einstein 1986; McDaniel et al. 1995; 2000; Worthen 2006). Clearly, if all presented items are bizarre, bizarreness becomes commonplace and loses its distinctiveness. Schmidt (1991) posits that distinctiveness operates at two levels: first within the local context (e.g., a bizarre item within a list of commonplace items) and, second, within a secondary context of prior experience and knowledge (e.g., I have never seen a dog with a pipe in its mouth). At both levels, Hirshman (1988) suggests that bizarreness violates expectations and so results in a startle reaction that triggers focused attention, which, in turn, generates more elaborate encoding during which

the general context for the bizarre object or event is also better encoded, which results in the availability of a richer set of contextual cues for retrieval.

This mnemonic effect is well known for “flashbulb memories” of sensational public events (Brown & Kulik 1977). The gripping drama of a “flashbulb event,” such as the Twin Towers collapse, casts a “light” which enables the incorporation of the commonplace context. Thus, people recollect not just the dramatic event itself but also associated everyday events – what they were doing, where they were, who they were with, and how they felt when they heard the news (Finkenauer et al. 1997). The key mechanism underlying the flashbulb impact is the emotional response to the violation of expectations – the shock and surprise evoked (Hoskins 2009). Emotionally arousing events are better remembered than emotionally neutral ones (Atienza & Cantero 2008; Canli et al. 2000; Dolcos et al. 2004; Kensinger 2004; Sharot et al. 2004).

Marr (1970) remarked that more information has to be stored to remember a random picture than a patterned one; hence, imposing structure on to-be-remembered material aids memory “storage” efficiency. For example, Ericsson et al. (1980) describe how a subject (interested in running) increased his memory span from 7 to 79 digits through chunking the digits and associating the chunks to personally meaningful information – for example, 3,492 was chunked from a list and re-coded as 3 minutes and 49.2 seconds – near the world-record mile time. Order and organization are mnemonic (Bower et al. 1969; Cohen 1963). Both scenes and narratives are organizing schema (Mandler 1984, p. 8). For example, objects organized into a typical room layout are much easier to remember than ones which are randomly placed. Similarly, there is much more accurate recall if events are ordered into a narrative rather than presented as an unrelated series of discrete happenings (p. 89). Indeed, as Mandler (p. 53) argues that, if experience is not narrativized, then memories cannot be retained.

Experimental work on the relationship between embodiment and memory is strangely lacking, although there is increasing interest in embodied cognition in general (see, e.g., Clark 1999; Metzinger 2009; Wilson 2002). Merleau-Ponty’s (1945/2002) seminal work on the embodied mind points out that embodied memories are the most resilient (see also Archer 2000, p. 139). Glenberg (1997, p. 5) argues that embodied memories (as memories of subject-performed actions) are stronger than memories that rely on verbal descriptions; he cites the example that performing the command “open the book” results in better recollection than merely hearing the verbal command. Indeed, if the function of memory is to inform future action (Anderson 1997; Schacter & Addis 2007b), it would seem intuitively likely that embodied action would result in enhanced representations in memory (Benjamin & Bjork 1997).

In the AAOM, the person who is memorizing “looks at” the to-be-remembered images when both encoding and retrieving. These images have to be in recoverable order. Generally, they have been associated with landmarks on well-known routes. In a functional magnetic resonance imaging (fMRI) study on 10 “superior memorizers,” Maguire et al. (2003) found that nine used this “method of loci.” Empirical work has demonstrated that this technique is efficacious (Briggs et al. 1970; Crovitz 1969; De Beni & Cornoldi 1985; Lea 1975; Moè & De Beni 2005;

Roediger 1980; Ross & Lawrence 1968) even when the loci are used repeatedly for different lists of items (Massen & Vaterrodt-Plünnecke 2006). Self-generated loci have been shown to be more effective than ones supplied by others (Moè & De Beni 2005). One memorist used a variant of the method of loci to memorize π to 65,536 digits (Raz et al. 2009).

Along with the evidence (presented in the last section) that the AAOM is the basis of all effective memory techniques (and that memory “champions” employ these techniques rather than being born with exceptional memories), this section has reviewed experimental work in psychology that confirms the mnemonic properties of the AAOM. So there is indicative evidence that the AAOM optimizes memory performance. The next section first briefly reviews current neurobiological work on the relationship between sleep/dreaming and memory and then presents neurobiological evidence that the principles underlying the elaborative encoding of the AAOM (visualization, bizarre connections, organization, narration, embodiment, and place association) are realized in REM dreams.

4. Dreaming and memory in neurobiology

The long-standing idea (see Jenkins & Dallenbach 1924; Marr 1971; Winson 1986) that the “off-line” state of sleep enables memory in some way (or ways) has gained increasing acceptance (Diekelmann & Born 2010; Gais & Born 2004; Squire 2009; Stickgold 2005; 2006; 2009). Recently, Wilhelm et al. (2011) demonstrated that sleep selectively enhances memories expected to be of future relevance. There are still dissenting voices to the sleep-memory link, however (see, e.g., Vertes 2005b; Vertes & Siegel 2005). The most widely accepted theory is that distinct sleep stages (REM, NREM, slow-wave sleep [SWS]) are differentially implicated in memory processes (Diekelmann et al. 2009; Ellenbogen et al. 2007; Manoach et al. 2010; Payne & Nadel 2004; Rauchs et al. 2004; 2005; Ribeiro & Nicolelis 2004; Winson 2004). Paller and Voss (2004) speculate that the complex interplay between different (but interdependent) sleep stages and different (but interdependent) memory processes may be likened to the progression of movements that together constitute a symphony. There is some debate over whether this interplay is best conceptualized as sequential – stressing the orderly succession of NREM and REM stages (Giuditta 1985; Giuditta et al. 1995) – or dual process – emphasizing the differential action of SWS and REM (Plihal & Born 1997; 1999) – or, indeed, whether these two possibilities are actually divergent (for a review, see Rauchs et al. 2005).

There is also conflicting evidence on the interplay between sleep stages and the processing of declarative, emotional memories. For example, after distinguishing between early SWS and late-night REM-rich sleep, Plihal and Born (1997) argue that SWS consolidated declarative memories preferentially. In a later review, however, Ellenbogen et al. (2006, p. 720) conclude that “sleep consolidates emotionally arousing memories and REM sleep provides the unique mechanism.” Consolidation has been conceptualized as occurring on two levels: synaptic, through Hebbian plasticity and long-term potentiation (LTP; Hebb 1949), and system, reflecting the integration of recent with remote memories (see, e.g., Dudai 2004;

Frankland & Bontempi 2005). Drawing on this synaptic/system distinction, Diekelmann and Born (2010) state that SWS supports system consolidation (integration) of declarative memories, whereas REM may be implicated in synaptic consolidation. In a response, Walker and Stickgold (2010) argue that REM may aid integration, a stage described as “beyond consolidation.” Some light may be shed on the various debates over the “consolidation” of emotional declarative memories through distinguishing and defining memory processes more clearly, whilst simultaneously recognizing their mutual interdependence.

Work in psychology conceptualizes declarative memory function as occurring in three stages: encoding–consolidation–retrieval. Research in neurobiology follows this three-fold categorization. All three are hypothetical, indeed, metaphorical concepts. Despite their imprecision, these concepts are important as they serve to link neurobiological with behavioural research. However, neurobiologically informed sleep research has focused overwhelmingly on “consolidation,” which, since Müller and Pilzecker (1900) introduced the concept, has generally been taken to imply progressive “stabilization” as a labile memory trace becomes permanent and resistant to “interference” (see, e.g., Dudai 2002; 2004). This more or less exclusive neurobiological concern with consolidation neglects a possible role for sleep in encoding and retrieval, although see Henevin et al. (1995) for discussion over whether REM sleep may enable further elaboration after initial consolidation; Ribeiro and Nicolelis (2004), who refer to deeper encoding over time; and Mander et al. (2011), who show that NREM spindle oscillations restore episodic encoding abilities. Diekelmann and Born (2010, p. 114) express what appears to be a widely held assumption amongst sleep researchers: “Sleep promotes primarily the consolidation of memory, whereas memory encoding and retrieval take place most effectively during waking.”

The term “consolidation” is rarely clearly defined before it is used (Payne & Nadel 2004). Perhaps in consequence, the concept is expanding out from its original definition. There is now no consensus over what processes should be included under “consolidation” (Stickgold & Walker 2007). Effectively, it has become an umbrella concept. Stickgold and Walker (2007) consider that evolution (following reconsolidation) is an aspect of ongoing consolidation and define consolidation to include processes of enhancement and integration as well as stabilization and destabilization. Diekelmann and Born (2010) include reorganization within their definition of consolidation. Such encompassing uses of “consolidation” may not best aid analysis as they obscure the possible contribution of other memory processes – albeit that all processes may be inter-related. There is no hard and fast distinction between encoding and consolidation – both could result in strengthening. There is, however, a long tradition in psychology of considering encoding to be a process that can be distinguished from consolidation (at least when consolidation is defined as stabilization).

Encoding involves attention, processing, and integration (Craik & Lockhart 1972). Encoding is “shallow” when analysis remains at the perceptual level and “deep” or “elaborate” when the analysis meaningfully integrates features of the to-be-remembered experience with previously “stored” memories (Craik & Tulving 1975). Craik (2002) argues that elaborative encoding works through exploring

meaning, inference, and implications – processes that enhance the distinctiveness of the memory. If distinctiveness is not enhanced, an episodic memory may become impossible to access and retrieve as it is too similar to others (cf. Lockhart et al. 1976). Elaborative encoding also involves the binding together of features of a to-be-remembered experience with aspects of previous meaningfully related ones – resulting in an integrated *and* distinctive memory representation (Tulving 1983). The strength of any memory is largely a function of the extent (or depth) of elaborative encoding (Craik 1983). Tulving et al. (1996) suggest that novelty (i.e., non-habitual, “off script” activities) determines the extent of elaborative encoding, which is the position adopted here also.

If both consolidation (as stabilization) and encoding continue during sleep then, within either the sequential or dual process theories, REM dreaming is an obvious possible candidate for performing elaborative encoding at the system level – as recent memories are associated and integrated with remote ones. Consolidation (as stabilization) could be an automatic process, not entailing an active conscious brain state (see, e.g., Stickgold & Walker 2007), but elaborative encoding would require consciousness to make meaningful associations. Elaborative encoding through REM dreaming may identify meaningful, novel associations that can be physiologically integrated (or “consolidated”) into existing cortical networks as junctions during NREM. High acetylcholine levels during REM sleep with low levels during NREM could be indicative of encoding and consolidation, respectively (Hasselmo & McGaughy 2004).

However, the past characterization (in some quarters) of dreaming as a defective or epiphenomenal form of cognition exhibiting a “random selection of representation stimuli (or associations)” (Sarter & Bruno 2000) or “defective binding” (Kahn et al. 1997) or serving as a useful model for psychosis (Hobson 2004; Limosani et al. 2011b) or schizophrenia (Gottesmann 2006) may have militated against the consideration of a cognitively demanding elaborative encoding function for dreaming. The AAOM is an intelligent and imaginative association of memories, but, as demonstrated earlier, its mnemonic product (hyper-associative mental imagery) obscures the to-be-remembered material. With memory sources masked, and mnemonic processes not identified as such, it would be easy to construe the resultant highly associative mental imagery of the AAOM as defective or epiphenomenal cognition. The next section explores whether REM dreaming may be the archetypal state for the elaborative encoding of emotional declarative memories. If so, the neurobiological substrate for REM dreaming may assist in understanding the broadly comparable but attenuated mnemonic functioning of the AAOM in wake.

With reference to a REM dream (self-identified as such), the next section illustrates how personal memories could be elaboratively encoded (see the Appendix for self-identified memory sources).

4.1. Quicksand dream: Illustration

This dream occurred in November 2003.

4.1.1. Scene 1. I am by the side of a huge structure: a bridge/flyover/bypass is to my right-hand side with a two-lane highway going over it.

4.1.2. Scene 2. Now I am walking along a quiet suburban road of neat houses with open front gardens while approaching a huge bridge. (It seems to be the structure in scene 1 but is now definitely a bridge with a wide, fast-flowing river below it.) But somehow I am also below the structure; it looms above me. Someone is with me, but I can't see him or her. Also, another female person may be behind us, but I can't see her either. Something is a bit wrong – even though the day is sunny and all seems fine. I start to feel uneasy. The last house down by the bridge at the end of the road seems to be under construction. I wonder, will anyone buy it? It's probably going to be too noisy. I think that buying this house may be a mistake. As I approach this last house, I notice how odd it looks – its shape appears rounded but is not clearly delineated. Then I see that something is covering the house. (I think this is maybe why its shape is not the usual one.) But I can't work out what this covering is – maybe it's a vast piece of cloth making the shape of the house more like the bridge. Then I perceive the colour – it's yellow – and I see that the house is covered in sand. I feel afraid.

4.1.3. Scene 3. Suddenly the scene ahead has changed – now I am approaching a beach rather than a river. The view ahead is very enticing. The tide is in. The sun is sparkling on the water. Lots of happy children are playing on the beach, but no adults. Suddenly a bad thing happens. A grown-up appears in the foreground and throws a child out across the sand. The child (now a small white bundle – a baby?) lands on his or her ear and rapidly disappears. Then another child/baby is thrown. I realize that this child/baby, too, may be swallowed up by the sand.

The dream ends as I wake up, terrified.

4.2. Is there neurobiological evidence that REM dreaming may perform an elaborative encoding function?

Using the attributes of the AAOM as the framework, these next subsections present evidence from neurobiology (and sleep research) for correspondences between REM dreaming and elaborative encoding in the following order: hyperassociation; visual complexity, imagination, and emotional arousal; narrativity and embodiment; organization; and movement and place association. Each subsection begins with an illustration from the “Quicksand” dream of the possible correspondence.

4.2.1. Hyperassociation. In scene 2, the bizarre house/bridge under construction on the edge of town, covered in sand and rendered a bad buy because of noise, appears to be a mnemonic composition generated through the hyperassociation of the gist of a recent memory with three remote ones. Hyperassociation ensures that, when retrieved in REM sleep, waking experiences are never replayed in entirety; instead, memory elements from waking experiences merge into a new organized mnemonic representation: the dream scene.

Numerous studies demonstrate that REM dreams incorporate elements of waking experiences (Arkin & Antrobus 1978; Baylor & Cavallero 2001; Cavallero & Cicogna 1993; Cavallero et al. 1990; De Koninck & Koulack 1975; Domhoff & Kamiya 1964; Foulkes 1967; Foulkes & Rechtschaffen 1964; Goodenough et al. 1975; Hall 1966; Karacan et al. 1966; Maquet et al. 2000; Whitman et al.

1962; Witkin & Lewis 1967; and cf. Freud's “day residues”). It has also been noted that memory elements are recombined through association, so they become difficult to distinguish in the dream (Foulkes 1985, pp. 27–32; Hobson 1988; Nielsen & Stenstrom 2005; and cf. Freud's dream “disguise”).

The idea that dreams hyperassociate episodic memories stands in contrast to the limited phenomenological studies that concluded there was a functional dissociation between dreaming and episodic memory (Dement et al. 1965; Fosse et al. 2003; Stickgold et al. 2000). These studies, however, made two critical assumptions about the relationship between dreaming (or, in the case of Stickgold and colleagues, hypnagogic imagery) and episodic memory: First, consolidation (rather than elaborative encoding) was thought to be the memory process of interest; and, second, for consolidation to occur it was thought that episodic memories must be replayed. This article relies on different assumptions: The focus is on elaborative encoding (rather than consolidation), and meaningful emotional association with other memories (rather than replay) is taken as the essence of mnemonic function.

During REM dreaming, deactivation of prefrontal regions, which forge linear-logical associations supporting reasoning (Braun et al. 1997; Maquet 2000; 2005; Maquet et al. 1996) along with increased limbic activity and the heightened activation of the visual associative cortex may enable hyperassociative memory images – that is, visual associations between memories. Concomitant with deactivation of prefrontal regions, suppression of aminergic neuromodulation during the REM sleep state results in less linear-logical cognition and more “fluid reasoning” and “flexible thought” (Hobson & Pace-Schott 2002; Walker et al. 2002). In a review of the evidence, Stickgold et al. (1999) argue that sleep induces changes in memory associations, a suggestion first made by David Hartley (1834). The house/bridge is an example of one of the Rittenhouse et al. (1994) bizarreness categories, “incongruities” (inconsistent or fused features of people/objects/places), engendered through hyperassociation.

Fluid cognitive processes use associations to form novel relationships between phenomena, engendering creative thinking and the ability to solve problems (Walker et al. 2002). Fluid thought enables the identification of analogies (Lee et al. 2007). Seeing analogies relies upon making associations between seemingly disparate phenomena (Esper 1973). Compared to wake, associations have been described as “looser” or “weaker” in REM dreaming (Hartmann 1991; Rittenhouse et al. 1994; Stickgold et al. 1999). The brain ignores predictable associations; instead, novel connections are sought out and strengthened (Stickgold 2003). Stickgold et al. (1999, p. 182) showed that, “contrary to normal pattern of priming, subjects awakened from REM sleep showed greater priming by weak primes than by strong primes....In contrast, strong priming exceeded weak priming in NREM sleep...a shift that we hypothesize underlies the bizarre and hyperassociative character of REM-sleep dreaming.” Forging novel associations (such as would be indicated by weak primes) is integral to both elaborative encoding and retrieval. William James (1890) argued that memory is enhanced though making diverse, non-obvious associations between experiences.

To make any emotionally salient associations between essentially different recent and remote memories, some

novel commonality or pattern has to be detected. In “Quicksand,” this novel commonality is hypothesized to be “fear that defies logical analysis” (see the Appendix). The ability to make and “see” novel associations when connecting up recent and remote memories during REM dreaming may be the reason for the Wagner et al. (2004) finding that sleep (as compared with the same period of wake) more than doubled the ability to have insight into a “hidden” pattern underlying sequences of digits. Similarly, Walker et al. (2002) showed enhanced insight (a 32% increase in the number of anagrams solved) after REM awakenings, as opposed to NREM. And Cai et al. (2009) found that REM, as compared with quiet rest and NREM, enhanced the ability to produce a word that is associated with three test words that seem unrelated. Creativity works through spotting associations or patterns between phenomena that had previously been disconnected or thought to be irrelevant to each other (Martindale 1995). In this process, mental imagery can be highly significant in picturing the analogy. (For several examples of both scientific insight and artistic creativity attributed to sleep, see Maquet & Ruby 2004.) Mazzearello (2000) comments on Kekulé’s insight into the structure of benzene: “Like a snake biting its tail, the circular chain of carbon atoms danced through the dreaming mind of August Kekulé.” At first glance, snakes and carbon atoms seem to have little in common, but in the imaginatively hyperassociative, visual dream world, the analogy was pictured.

4.2.2. Visual complexity, imagination, and emotional arousal. “Quicksand” is purely visual; no other sensory modalities are present. The house/bridge covered in sand is a work of the imagination in the sense that I never walked down a road and saw such a phenomenon. But this scene may be created through memory hyperassociation rendering the dream highly emotionally arousing through the primary instinct of fear, as demonstrated by my awakening.

Since the Aserinsky and Kleitman (1953) and Dement and Kleitman’s (1957b) studies, the intense visual imagery of REM dreaming has been of sustained interest. To what extent do other sensory modalities occur? Data on REM dreams, specifically, are limited. McCarley and Hoffman (1981), after awakening 14 subjects from REM sleep and based on 104 laboratory dream reports, reported a 65% occurrence of an auditory experience, 1% olfactory, 0% pain, 1% gustatory, and 1% tactile. Snyder’s (1970) study was also on REM dreams: From 635 laboratory dream reports, he found a 76% occurrence of an auditory experience, <1% olfactory, 0% pain, 1% gustatory, and 1% tactile. From 3,372 home dream reports (REM and NREM were not distinguished), Zadra et al. (1997) found a 53% occurrence of an auditory experience, 1% of olfactory, 1% of pain, <1% of gustatory, and 0% tactile. Schredl (2010) compared these studies and reported 100% visual modality; auditory occurrences were frequent but sporadic rather than continuous. Consistent with the existence of REM sleep in animals, which do not possess language, a REM dream is a visual rather than a spoken or heard narrative (Winson 2002). Hobson (1988, p. 245) concludes that “no amount of experimental suppression is capable of countering what must be the strongly physiological activation of the visual system in REM sleep.” As noted

earlier, in the AAOM also, while other senses may occasionally be used for emphasis, the visual medium is essential (Carruthers & Ziolkowski 2002, p. 11). As Paivio (1971; 1986) remarks, visual imagery presents a multitude of possibilities for imaginative transformations. The visual sense is the only modality that easily enables hyperassociations: One person/object can assume aspects of the visual characteristics of another; people/objects can be blended; or elements of events that were, in reality, temporally discontinuous can happen together. This visual hyperassociation renders the imagery bizarre, as noted earlier.

As stated earlier, an internally generated AAOM memory composition is something that is mentally “looked at” rather than spoken or heard (Carruthers 2008, p. 24). Using positron emission tomography (PET), Braun et al. (1998) observed that, during REM dreaming, deactivation of the primary visual cortex is correlated with heightened activation of the visual associative cortex. This extrastriate activity was also associated with increased activation of limbic (and paralimbic) regions and reduced activity in frontal associational cortex. They suggested that this pattern may indicate that vivid internally generated visual images are being processed in a closed system, dissociated from external sensory input, as were the composite memory images of pre-modern scholars. This imagery is not static; it has been argued to be sensorimotor in character as it co-ordinates action with perception (Hobson 2002, p. 47; Llinás 2002, p. 1).

However, Nir and Tononi (2010, p. 96) pose the following question: “Are dreams more like perception or imagination?” In a review, they argue that dreams are better seen as a “powerful form of imagination” as the flow of brain activity is backwards, as higher-order cognition is enriched with perceptual and sensory elements, rather than mainly forwards, as in waking perception, when external lower-level sensory stimuli are interpreted and synthesized through higher-order reasoning. Evidence that dreaming relies on visual imagination comes from experimental work. For example, Sprenger et al. (2010) showed that when subjects imagine vivid scenes during dreaming, their REMs were similar to eye movements with open eyes when imagining remembered scenes in wake. In an fMRI study, Hassabis et al. (2007) demonstrated that imagination and episodic memory share some neural substrates. As pointed out earlier, in the AAOM, although memory elements are real, the memory compositions are not real, being rather imaginative phantasmata—in the sense that these composite memory images had not been present to the senses (Carruthers 2008, p. 31). As argued earlier, to enhance mnemonic function, visual images in the AAOM should be intense and affective (Magnus 2002).

Increased activation of limbic and paralimbic regions enables functional interplay between the amygdala and the anterior cingulate cortex, which may account for the emotional intensity and instinctive nature of REM dreaming (Gallagher & Chiba 1996; Maquet et al. 1996; Nofzinger et al. 1997; Wagner et al. 2001). Limbic and paralimbic regions have a key role in elaborating mnemonic traces, particularly in long-term memory (Squire 1987; Zola-Morgan & Squire 1993). The level of activation of the amygdala during the encoding of emotional declarative memories correlates highly with subsequent recall (Canli et al. 2000; McGaugh 2004). Neuroimaging has confirmed the importance of the amygdala in heightened emotional

response and, subsequent, improved retention (Cahill et al. 2004). The amygdala has also been shown to enable emotional intelligence (Bar-On et al. 2003; Brierley et al. 2004). Hence, the increased activation of the amygdala, limbic and paralimbic regions, and anterior cingulate cortex during REM dreaming may support emotionally intelligent elaborative encoding.

4.2.3. Narrativity and embodiment. “Quicksand” follows a story structure where I am embodied in the scenes. I never doubt that the events portrayed are actually unfolding in “real time” before my eyes, as demonstrated by my emotional response – the terror invoked by the events in scene 3.

If memories are retrieved into waking, they are cast into narratives where the audience is the self and/or others. REM dreams are also narrativized – the self is the sole audience. The narrative form is virtually obligatory (Kahn et al. 2000) for the human mind/brain because narratives are our primary mode for meaning-making (Bruner 1990, p. 67; 1991). A narrative is constructed through making associations (Polkinghorne 1988, p. 1). Waking narratives are based on memories, they are “spun from bits and pieces of experience, linking past happenings with present ones” (Kearney 2001, p. 5; cf. Moscovitch & Nadel 1998). REM narratives may mirror waking ones in being constructed from “bits and pieces” of recent and remote memories. The key differences may lie in the connections forged between these “bits and pieces.” In REM, these links will be hyperassociational rather than more linear-logical, as in wake.

At the neurobiological level, the narrative structure of dreams has not been studied extensively, but there is some relevant work. Hobson (2002, pp. 135, 145) concludes that instinct and emotion are the drivers of dream-plot elaboration and that narration depends on the left temporal cortex. The temporal lobe, “the seat of emotion-tinged memory” (Hobson 1999a, p. 152), is selectively activated in REM sleep (Hobson 2002, pp. 135, 145). Cipolli et al. (1998) report that dream narratives are more complex, with greater thematic progression during the REM-rich second half of the night. In contrast, as discussed earlier, Rittenhouse et al. (1994) describe REM dreaming narratives as exhibiting “discontinuities” rather than thematic progression. Using the AAOM as a model, I have already hypothesized that these discontinuities are only logical sequential ones; they make sense in terms of associational thematic dream scene progression. Several studies indicated there is thematic continuity between dream scenes. Cipolli et al. (1998) thought this was demonstrated in the REM-rich second half of the night. Kramer et al. (1964) argued that a night’s dreams were interrelated. Rechtschaffen (1978) considered that dreams demonstrated “thematic coherence.” Globus (1991) argued for “unifying concepts.” Seligman and Yellen (1987) considered that the “principle of adjacency” characterizes dreams (i.e., continuity could be seen between adjacent dream scenes). In a dream-splicing experiment conducted by Stickgold et al. (1994), in which dream reports were cut into parts and then randomly recombined into spliced reports, there was sufficient thematic continuity for judges to distinguish intact from spliced reports. In “Quicksand,” scene 3 is logically discontinuous (another of the bizarreness categories of Rittenhouse et al. 1994) from

scene 2, but there is a thematic continuity in the sand/death association.

Pontine-geniculate-occipital (PGO) waves, which are prevalent during REM dreaming, are probably generated by cholinergic excitation in the presence of aminergic inhibition (Mamelak & Hobson 1989). Jouvet (1967) proposed that PGO waves generate dream images as they project to visual, parietal, and temporal regions. PGO spikes are hard to evoke in waking (Hobson 1999a, p. 168). If they do arise, due to a strong novel unexpected event (e.g., an explosion), they elicit a startle response, which, in turn, focuses attention on the stimulus (Bowker & Morrison 1976). Hobson (1999a, p. 170) suggests that this focussed attention is evoked frequently during REM dreaming in response to the unanticipated precepts (incongruities and plot discontinuities) that are integral to REM narratives. There are two people in the dream whose identity is vague, an example of “indeterminacy,” the Rittenhouse et al. (1994) third bizarreness category. Rendering some phenomena vague may ensure that attention is not deflected from the thematic narrative. Evidence from psychology (e.g., Hirshman 1988, discussed earlier) is that mnemonic effects are enhanced by focussed attention. Kahn et al. (2000) further suggest that PGO waves may help maintain the momentum of REM dreaming narratives.

During dreams, a world appears and, mostly, there is an embodied self at its centre (Llinás 2002; Metzinger 2009, p. 135). Snyder (1970; p. 134) reports that a self appears in around 95% of REM dreams. This self is very agential – in the sense of almost always being active (Llewellyn 2011), although these actions are not under intentional control (Metzinger 2009, p. 135). Tsakiris et al. (2006) showed that motor agency creates a coherent, unified sense of embodiment. As during wake, REM dreamers believe themselves to be the instigators of their actions and, generally, take a first-person perspective on events. Ruby and Decety (2001) demonstrated that the somatosensory cortex is involved in distinguishing the actions of self from those of others and is activated only when taking a first-person perspective. The somatosensory cortex is activated during REM sleep (Maquet et al. 1996). As argued earlier, in the AAOM, if the memorizer imagines herself to generate (or be at least involved in) the action, the mnemonic impact is enhanced (Foer 2011, p. 98). During REM dreams, the deactivation of the pre-frontal cortex precludes “reality testing.” In consequence, the reality of the simulated dream world and the actions of the sensorimotor self within it are not doubted.

4.2.4. Organization. Self-identified (see the Appendix) memory sources for scene 2 of “Quicksand” are a phone call from my eldest son about, *inter alia*, a possible house purchase (a recent memory); a stop to photograph bridges during a U.S. holiday (a remote memory); my childhood fear of quicksand (a very remote memory); and my second son’s hearing problem (a memory of an ongoing concern). If these elements organized through complex cognition in REM dreaming, how does this occur?

REM dreaming is an active conscious state (Aserinsky & Kleitman 1953; Dement & Kleitman 1957b). REM sleep was termed “paradoxical” by Jouvet (1962; 1965) because “intense cerebral activity coincides with muscle atonia” (Jouvet 1999, p. 41). Electroencephalograph recordings demonstrate widespread high-frequency, low-voltage

EEG in both wake and REM sleep (for a review, see Gottesmann 1999). Llinás and Ribary (1993), who found 40-Hz oscillation on the human scalp during REM dreaming, propose that such oscillation induces both visual sensory binding and complex cognition. Crick and Koch (1990) suggest that subjective awareness is linked to 40-Hz oscillations in the relevant neuronal groups. Unitary conscious experience may be engendered through the functional connectivity enabled by 20- to 60-Hz oscillations in the gamma range (Damasio 1990b; Freeman 1975; Singer & Gray 1995). During light NREM, however, although functional connectivity is preserved, neural communication is reduced across the network as a whole (Esser et al. 2009; Massimini et al. 2010; Steriade 2003). In SWS, there is a breakdown of general connectivity (Massimini et al. 2005; Spormaker et al. 2010). Concomitantly, REM is an open system, whereas NREM is a closed consummatory one (Buzsáki 1996; 2006). REM dreaming, like waking, is self-organizing (Kahn et al. 1997; 2000; Tononi 2004; 2008; Tononi & Edelman 1998). Self-organized dynamic states are poised on the boundary between order and chaos (Goodwin 1994). This state of self-organized criticality (Bak 1996) engenders substantive patterning on neural activity (Combs & Krippner 1998). Such patterning enables systems to accomplish complex tasks and evolve in a complex environment (Kauffman 1993, p. 173). The self-organization of REM dreaming differs from that of waking, however, in that external sensory stimuli are gated; 40-Hz oscillations are not reset by external sensory input (Llinás & Paré; 1991; Llinás & Ribary 1993), enabling increased attentiveness to internal cognitive processes (Kahn et al. 2000; Llinás 2002, p. 130). Indeed, Llinás and Paré (1991) conclude that the main electrophysiological difference between wake and REM sleep is “the weight given to sensory afferents in cognitive images; otherwise [they] are fundamentally equivalent brain states.”

Such evidence supports Solms (2003a) argument that dreams are actively constructed through complex cognition. In a similar vein, Revonsuo (2003, p. 91) concludes that “there is no evidence that...essentially random activation could produce the phenomenology and narrative structure of fully developed dreams.” Based on experimental evidence, Walker and Stickgold (2010) suggest that sleep, and REM sleep specifically, engenders “unitized constructs” (see also Cicogna & Bosinelli 2001) through the organization of temporally distinct and seemingly disparate memories. Thus, there are indications that REM dreams self-organize to undertake a complex task. As “REM sleep can be considered as a modified attentive state in which attention is turned away from the sensory input, toward memories” (Llinás & Paré 1991, p. 525), this task could be elaborative encoding, engendering associational (rather than logical) AAOM-like mnemonic images. How may this organization in REM dreams relate to episodic memory networks in the cerebral cortex?

In contextual detail and event/place sequence, episodic memories are unique (cf. Nadel & Moscovitch 1997). For example, I have had many phone calls with my eldest son, but, in its entirety, this phone call was unique. The specificity of episodic memories engenders personal identity (Kandel 2006) but causes an encoding problem because unique, recent, whole, episodic memories lack associative “hooks” to enable integration with other long-term memories. The key to this problem may be to split

any recent whole episodic memory (e.g., the phone call from my son) into “micro-events” and integrate these separately (cf. “multiple trace theory” [Moscovitch & Nadel 1998; Nadel & Moscovitch 1997; Nadel et al. 2000]). These micro-events are analogous to the *divisiones* (or short segments) identified in the AAOM. If only micro-events, rather than whole episodic memories, are taken, then associations can be more readily identified. Elaborative encoding involves memory integration through identifying non-obvious, novel associations between disparate, and therefore distinctive, phenomena. For example, the U.S. bridge incident and the phone call from my eldest son are disparate, but both involved a “house on the edge of town” association. The hearing problem and the house purchase differ, but both have a “concern for son” association. A house that someone had died in and quicksand are distinctive phenomena, but, as I feared death through quicksand as a child, for me, both have a death association. Sand and a U.S. bridge that is partially built are different, but, as sand is a construction material, both share a “construction” association. Over and above these associations, irrational (i.e., defies logical analysis) fear may be the central association that serves to integrate the recent memory of the possible house purchase with the three other recent micro-event memories in scene 2 of “Quicksand.”

If REM dreams are triggered by the requirement to encode and integrate a recent memory in cortical memory networks, all REM dreams would be expected to encompass a recent experience. Freud (1899/1999) referred to “day-residues.” Nielsen and Powell (1992), who reported that “day-residues” appear in 65%–70% of single dream reports, suggest that if several, same-night dreams could be collected and compared to multiple events from the previous day, the hypothesis of 100% incorporation of day-residues may be supported. Aside from day-residues, recent events are also incorporated in dreams following the *dream-lag effect*, defined as a period of up to a week before the dream occurs (see Nielsen & Powell 1988b; 1989). In a review, Nielsen et al. (2004) report that studies, fairly consistently, demonstrate that numbers of dream-lag incorporations are similar in magnitude to day-residue ones. Therefore, although not conclusive, this is strong evidence for the incorporation of recent memories in all dreams. (Research in this area does not distinguish between REM and NREM dreams.)

Figure 1 implies that episodic memories in the cerebral cortex are dispersed as several micro-events. Micro-events from different episodic memories are associated, through elaborative encoding, at junctions. The existence of junctions increases the number of ways that a micro-event can be recalled. For example, quicksand, the U.S. bridge/house, and my second son’s hearing problem could all trigger the memory of my eldest son’s possible house purchase. Memory recall increases directly with the number of ways that an item is associated, cued, or coded (James 1890; Paivio 1971, p. 181; Schacter 2001, p. 68). However, these cues/associations must be distinctive (Schacter 2001, p. 52; cf. earlier discussion on the mnemonic function of “bizarreness”) so that the required item can be brought to mind.

4.2.5. Spatial cognition and place association. “Quicksand” happens somewhere. In scene 2, the events occur as I am

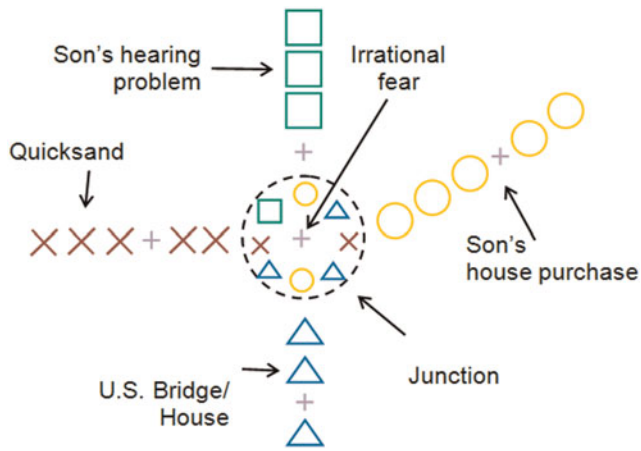


Figure 1. *Schematic representation of a cortical junction and connecting micro-event memories.* A recent memory (my eldest son's possible house purchase) has been elaborately encoded through association with three, seemingly dissociated, remote memories. However, these four share a non-obvious association: irrational fear. A fundamental principle of networks (integration and segregation) enables these episodic memories to be integrated at a junction but otherwise segregated along separate networks. Network reorganization accompanies junction instantiation.

walking along a suburban road approaching a bridge over a river. Scene 3 shifts to a beach.

Dream consciousness creates a convincing illusion of motion through space (Hobson 1999a, p. 171). Fictive movement is convincingly real in REM dreaming. Motor and pre-motor cortices are highly activated (Maquet et al. 2000), and motor output is blocked only through postsynaptic inhibition (Hobson 1999a, p. 183). Movements are frequent and diverse. Neuroimaging shows the activation of motor regions during REM sleep, including primary motor and pre-motor cortices, along with the cerebellum and basal ganglia; this activation is consistent with the motor content of dreams (Desseilles et al. 2011a). As already noted, muscle atonia is present in REM dreams (Jouvet 1962; 1965; 1999). Despite this, the dreaming brain computes the expected consequences of movement (Hobson 1999a, p. 171). McCarley and Hoffman (1981) state that, unlike the waking state where movement is episodic, 79% of REM dreams are characterized by lower-extremity movement, as required for forms of spatial navigation (e.g., walking, running, riding, and turning). Solms (2003a) points out that right-sided lesions of the parieto-temporo-occipital junction result in loss of dreaming along with disruption to spatial cognition, suggesting that normal spatial cognition is critical to dreaming.

In dreams, spatial navigation is virtual but is experienced as realistic (Nielsen & Stenstrom 2005). Navigation during wake is replayed in dream imagery. For example, Wamsley and Stickgold (2010) describe the impact of a skiing arcade game on subsequent dream content as "dramatic." If subjects are trained on a virtual maze navigation task, performance at retest is strongly associated with the task-related dream imagery experienced during an intervening nap; in contrast, waking thoughts about the virtual navigation task in the interval did not predict improvement (Wamsley et al. 2010). Such results are congruent with Cook's (2011) conclusion that the visual imagery of

dreaming and of cinematic scenes both rely upon a similar construction of navigable space. Thus, evidence from a variety of sources strongly supports the inference that spatial navigation abilities characterize human dreaming (for an illustrative spatial navigation dream, see Hobson 2005, pp. 55–57).

In the rat, during spatial exploration of the environment in wake, theta rhythm occurs selectively; in the same animal, theta rhythm is present throughout REM sleep (Vanderwolf 1969; Winson 1972). Spatial memory in rodents can be seen as a simple form of episodic-like memory (Deiana et al. 2011). Buzsáki (2005; 2006, p. 333) suggests that episodic memory in humans may have evolved from neural mechanisms that serve landmark spatial navigation (see also O'Keefe & Nadel 1978; Winson 1986, p. 213). It was argued earlier that there is evidence that, in humans, REM dreaming hyperassociates micro-events from episodic memories. If this is the case, the associations forged in REM dreaming may originally have encoded spatial landmarks but through evolutionary time became episodic also. This would explain the continuing presence of spatial navigation in dreaming. Theta rhythm is present during associative mnemonic processes (Miller 1989; 1991). Concomitantly, theta is necessary for the encoding of information, such as would be required during exploration in a novel environment (Buzsáki 2002; Vertes 2005a). As stated earlier, similar to wake, REM sleep is characterized by fast, low-voltage cortical activity; this is associated with theta rhythm (Jouvet 1969; Winson 2002). Theta and gamma oscillations predict the encoding and retrieval of declarative memories in humans (Osipova et al. 2006). Specifically, Lisman (2005) argues that theta/gamma coding may preserve serial order. The method of loci preserves serial order through associating memories to places. Order preservation would be required in the retrieval of micro-events to reconstruct a whole episodic memory.

If REM dreams are elaborative encoding that transpires at the phenomenological level and, to function mnemonically, dreams must be retained at the neurobiological level, how may this occur? Buzsáki (2006, pp. 285–92) maintains that the hippocampus is a "librarian" for the neocortex, enabling mnemonic navigation in neuronal space. Hyperassociative REM dreams could be retained to constitute the hippocampal index. The hippocampal indexing theory (Hirsh 1974; Teyler & DiScenna 1986; Teyler & Rudy 2007) posits that the hippocampus keeps an index of neocortical loci, which can be used in episodic memory retrieval. The theory is intuitively appealing because cortical networks are autoassociative, meaning that an element can restore the whole memory network (Buzsáki 2006; Kanerva 1988; Kohonen 1988; Marr 1970; Wills et al. 2005). CA3-CA3 is also an autoassociative network that instantiates back projections to the neocortex, enabling "hippocampo-neocortical dialogue" (Buzsáki 1996; Rolls 2007). An efficient hippocampal indexing system would be one in which the index enabled access to several related memories. (Analogously, an index in a book references the several places where related content can be found.) A way for the hippocampus to access related micro-event memories would be to index a series of internal cortical junctions (analogous to spatial navigation by the method of loci, which uses a series of landmarks).

5. The hippocampus

This hypothesis is congruent with the role of the hippocampus. As compared to waking, along with the amygdala, anterior cingulate, motor cortex, parahippocampal cortex, occipito-temporal visual cortex, and medial frontal areas, the hippocampus is preferentially activated in REM dreaming (Desseilles et al. 2011a; Hobson et al. 2003, p. 32). Hippocampal function has been argued to be more attuned to memory for the associations between phenomena than for the phenomena themselves (Eichenbaum & Cohen 2001; Johnson & Chalfonte 1994). Functional imaging data support this view of hippocampal associational function (Davachi 2006; Davachi & Wagner 2002; Giovanello et al. 2004) and indicate that the hippocampal formation may be especially involved in associating elements of episodic memories (Henke et al. 1997). As remote memories are represented in cortical networks, the hypothesis is also consistent with the bidirectionality of “hippocampo-neocortical dialogue” that suggests one function of the hippocampal formation is to modify its (mnemonic) inputs from the neocortex and feed them back (Buzsáki 1996). Theta rhythm during REM may facilitate the transfer of memories from the neocortex to the hippocampus (Buzsáki 1996). As noted earlier, theta is required for encoding (Buzsáki 2002; Vertes 2005a). Elevated levels of acetylcholine during REM may also indicate encoding (Hasselmo & Bower 1993). Consistent with these high levels of acetylcholine, outflow from the hippocampus to the cortex is suppressed (Hobson & Pace-Schott 2002). With output to the cortex inhibited, hippocampal access to remote and recent memories is enhanced (Desseilles et al. 2011a; Hobson & Pace-Schott 2002; Ji & Wilson 2007), as would be required to form associations between them.

Following the elaborative encoding of recent memories with remote ones during REM dreams, the hippocampus may instantiate internal cortical junctions during NREM. During NREM, hippocampo-neocortical dialogue is reversed as there is outflow from the hippocampus to the neocortex (Hobson & Pace-Schott 2002). Evidence suggests that this outflow transfers representations to the neocortex and is associated with spindle activity (Buzsáki 1996; 2006). Research on animals has demonstrated a temporal correlation between cortical spindles and hippocampal sharp-wave/ripple bursts (Siapas & Wilson 1998; Sirota et al. 2003; Wierzynski et al. 2009). Clemens et al. (2007) demonstrated this temporal coupling in humans also. Spindle activity, particularly in stage 2 sleep, is related to improved declarative memory performance (Schabus et al. 2004). Tamminen et al. (2010) showed that spindle activity is associated with the integration of recent memories into cortical networks. Thus, hippocampal sharp waves/ripples and cortical spindles may represent the retention of REM dream scenes as hippocampal indices and the instantiation REM dream scenes as cortical junctions, respectively. Clemens et al. (2006) suggest hippocampal sharp-wave/ripple events and neocortical spindles may involve a matching of specific networks between the two structures. Matching would be required if hippocampal indices and neocortical junctions work together in retrieval. In allocentric spatial maps, junctions are represented by omnidirectional hippocampal place cells (O'Keefe & Dostrovsky 1971; O'Keefe & Nadel 1978), which fire at landmarks, including junctions. During episodic retrieval,

from internal maps, omnidirectional place cells would fire at junctions in episodic cortical networks after matching with hippocampal indices.

5.1. Two questions arising

If hyperassociative dream scenes do encode episodic memories and these scenes are retained as hippocampal indices, these are non-conscious phenomena used, in normal wake, to “search” for memories in cortical networks (cf. the non-conscious “ecphoric” process described by Tulving 1983). Two questions arise from this: First, how does a non-conscious hyperassociative index trigger conscious veridical episodic (i.e., situated in time and place) output? And how is the conscious output constrained to only the relevant episodic memory?

On the first question, non-conscious memory implies that a retained representation of a past episode can impact the way an associated new episode is experienced and so, consequently, on thought and action in relation to the new episode, even if the past episode is not consciously brought to mind. An abundance of experimental and theoretical material attests to the influence of non-conscious (or implicit) memory on consciousness. This article cannot cover all of that. See, for example, Graf and Schacter (1985) for distinctions between explicit and implicit memory and Schacter (1987) for the concept of implicit memory. There is evidence that memory retrieval into normal wake relies on both conscious and non-conscious processes (Jacoby 1991; Rugg et al. 1998; Slotnick & Schacter 2010; Tulving 1983). For episodic memories, which are consciously brought to mind, there is still uncertainty over how these non-conscious influences are physiologically expressed.

Lockhart et al. (1976) suggest that retrieval relies on dual processes. Moscovitch (1989; 1992; 1994) argues that these dual processes are organizational (defined as temporal and spatial specificity), reliant on frontal systems, and associative (dependent upon the medial temporal lobe). In terms of this article's hypothesis, the associative micro-event components of any whole episodic memory are supplied by the dream scene/hippocampal indices, which are non-conscious. This hippocampal index can locate, through parallel processing, cortical junctions from which episodic micro-events can be “read off” to reconstruct a conscious whole episodic memory. For this to occur, the hippocampus must retain the ordering of the micro-events. Drosopoulos et al. (2007) found that sleep strengthens the order of events; they speculate that forward sequencing during sleep accomplishes this. Hippocampal involvement in sequencing of events has been shown in animals and humans (Caplan et al. 2003; Dragoi & Buzsáki 2006; Fortin et al. 2002). Once a memory is retrieved into normal wake, frontal systems add conscious temporal (“when”) and spatial (“where”) specificity to the associative component (Moscovitch 1989; 1992; 1994). There is other support for Moscovitch's proposal. Slotnick and Schacter (2010) present evidence that supports a two-stage retrieval process (non-conscious associational followed by conscious temporal and geographically spatial) in the sense that non-conscious retrieval processes temporarily precede conscious ones. In a review, Freidman (1993) argues that time as “when” is conferred on episodic memories only upon retrieval (see also Schacter 1995, p. 246). During

retrieval in wake, pre-frontal cortical function would enable the reasoning necessary to establish “when” (cf. Fuster 1989; 1999; 2001; 2008). *Source amnesia* (remembering the information but not the time or place that information was acquired) has been noted in patients with frontal lobe lesions who are not otherwise amnesic (Janowsky et al. 1989). Such processes imply *double reconstruction* – that is, episodic memories are reconstructed associatively and then reconstructed in terms of time and place. Consistent with the idea of reconstruction, episodic memory is highly flexible but not always reliable (cf. Damasio 1989; 1990a; 1990b; Meyer & Damasio 2009; Squire et al. 1993) and, in particular, source misattributions are often encountered (Schacter 1995, p. 73; 2001, pp. 93–94). Source misattributions would be expected if, as already argued, reconstruction of the associative components of memory is followed, in wake, by frontal lobe attribution of time–place specificity.

It should be noted that some authors argue against stark conscious/non-conscious or explicit/implicit dichotomies in favour of tripartite schema (see, e.g., Dehaene et al. 2006). In presenting a tripartite schema in relation to memory networks, Fuster (1997; 1999, pp. 292–93) argues that, for any active network, not all parts will be activated to the same degree: At any particular moment in the process of remembering, some network parts would only reach a processing, “P-threshold”; others would attain a sufficient degree of activation, “C-threshold,” to become conscious; whilst yet others would remain inhibited. Parts of a memory network become conscious in wake only when they are required for perception, thought, or action (cf. Fuster 1999, p. 107).

On the second question, if the hippocampus retains indices, for retrieval to occur, a pattern of incoming external stimuli (or an internal representation/composition) would be matched against these indices. There is considerable evidence that the hippocampus performs a match/mismatch function (Hasselmo 2005; Hasselmo et al. 2002; Manns et al. 2007; Mizumori et al. 1999; 2000). For example, if “house on the edge of town” is the incoming pattern of external stimuli (due to, e.g., a conversation about house purchase), the “Quicksand” index and corresponding cortical junction can be accessed. But then how is the “house purchase” episodic micro-event read off? And how is conscious output constrained to that micro-event rather than, for example, the fear of quicksand? As the hippocampus is involved in relational matching, by definition, the incoming stimuli is a pattern which would trigger excitation, through autoassociation, along the “purchasing a house on the edge of town” episodic pathway. This process of serial travel through internal mnemonic space would be analogous to a one-dimensional (“dead reckoning”) journey in the world (see Buzsáki 2006, p. 328). Accordingly, to access the “purchasing a house on the edge of town” episodic element (or conceptual category), the following sequence is hypothesized to occur: After matching with the “Quicksand” index, the “Quicksand” junction becomes activated to the level of processing, but not consciousness, because it is not required for thought or action (see Fuster 1999, mentioned earlier). Conscious activation would then spread along the episodic “house purchase” pathway until the next junction occurs, at which excitation would be inhibited. Meanwhile, activation of the “Quicksand” junction may fall back from processing

to inhibition. (For the self-organizing potential of networks with excitatory and inhibitory elements, see Buzsáki 2006, pp. 62–65.)

6. Summary

In this article, I have argued that the principles underlying the mnemonic functioning of the AAOM are realizable at the neurobiological level in REM sleep. In particular, this last section contends that recent memories are elaboratively encoded with remote ones by the hippocampus. On the phenomenological level, during REM sleep, this elaborative encoding would be experienced as a dream scene, which is retained by the hippocampus as a non-conscious index. The ordering of dream scenes in the whole index may still sometimes reflect a spatial allocentric route (as does the AAOM) but may more often be dictated by emotional and contextual associations (cf. Freud’s method of free association). During NREM, this dream scene may be instantiated as a junction in the cortex. Hippocampal sharp waves/ripples and cortical spindles may represent the retention of hippocampal indices and the instantiation REM dream scenes as neocortical junctions, respectively. A non-conscious junction may constitute a spatial “address” for several non-obviously associated episodic memories, thus engendering “content addressability,” a widely recognized attribute of human memory (see, e.g., Crick & Mitchison 1995; Fuster 1999, p. 86).

Schacter (1992) argues that the distinction between conscious and non-conscious memory raises the question of whether the two occupy separate systems or are different processes that occur within the same system. This hypothesis suggests that non-conscious memory is not a distinct system; its neural correlate finds location at cortical junctions within episodic memory networks, which, in turn, are accessed through hippocampal indices. As demonstrated by Rugg et al. (1998), the neural correlates of conscious and non-conscious memory differ. This hypothesis implies that, in episodic memory networks, episodic memories that can become conscious are represented by connecting pathways, whereas hyperassociative junctions do not, normally, become conscious.

During NREM, loss of functional connectivity significantly impairs intracortical dialogue (Massimini et al. 2005; Steriade 2003). This breakdown of functional cortical connectivity during NREM, even though the cortex remains active (Esser et al. 2009; Massimini et al. 2005), may represent cortical reorganization to enable the instantiation of new junctions. This hypothesis that elaborative encoding of recent and remote memories takes place during REM dreams and the resultant mnemonic composition is instantiated as a junction during NREM sleep is in line with the most widely accepted current theory on the relationship between sleeping and memory – that is, that distinct sleep stages are differentially implicated in memory processes.

As compared to the waking state, REM dreaming is more perceptually vivid and hyperassociative as “analogy replaces analysis” (Hobson 2002, p. 27). REM dreams are also more emotionally intense and more driven by instinct (pp. 26–27). Moreover, also as compared with waking, there is enhanced access to remote memories in the presence of recent ones (Kahn et al. 1997). Although the

AAOM is (and was) practiced in waking consciousness, REM dreaming may provide the most conducive state for the elaborative encoding of personal, emotionally salient memories.

If, however, the dreaming and waking states became de-differentiated (see Llewellyn 2011), hippocampal indices and, hence, hyperassociational junctions may become conscious, thus precipitating psychosis; ultimately, schizophrenia may result as the mnemonic functioning of REM dreaming and the instantiation of junctions, possibly through spindle activity during NREM, are disrupted. Such a conclusion may be supported by studies demonstrating reduced sleep spindle activity in people with schizophrenia (Ferrarelli et al. 2007; 2010) and spindle impairments in early psychosis (Keshavan et al. 2011). If elaborative encoding during REM dreaming is followed by the instantiation of junctions in NREM, all sleep stages are differentially involved in memory processes. Hence, the preservation of differentiation between wake, REM dreaming, and NREM sleep is intimately involved in normal cognitive function.

7. How can this hypothesis be tested?

One approach is to test for memory retention in the absence of dreaming. If dreaming is elaborative encoding, then memory deficits would follow if dreaming ceased or was disrupted over the longer term. How would these deficits be manifested? As argued earlier in this article, the function of episodic memory is oriented to the future rather than the past (Schacter & Addis 2007b, Schacter et al. 2007). Recombining memories of past experiences enables projection into the future (Addis et al. 2007; Ellenbogen et al. 2007; Schacter & Addis 2007b; Szpunar et al. 2007). Memories of non-routine, emotionally salient experiences construct identity, are expressed through concerns, and engender plans for the future. Loss of dreaming would be anticipated to result in loss of identity, loss of emotional concerns, and loss of the ability to plan for the future.

Solms (1997) conducted a study which included patients with either lesions of the parieto-temporo-occipital junction or bilateral lesions of the ventromesial region who reported loss of dreaming. He observed that these patients became “asontaneous, inert and apathetic” (Solms & Turnbull 2002, p. 312). Such conditions would be anticipated where longer-term episodic memory loss has resulted in loss of identity, loss of memory for emotional concerns, and loss of the ability to plan for the future. However, to fully test this hypothesis, it is necessary to investigate episodic memory retention in patients who report loss of dreaming. Episodic memory function, however, is not usually investigated for past life events but is generally tested through word recall and/or recognition after short periods during waking (e.g., the Verbal Paired Associates [VPA] subtest from the Wechsler Memory Scale IV, which is widely used for assessing explicit episodic memory performance; see, e.g., Uttl 2005). Whilst such word tests should relate to the ability to encode and recall moment-to-moment experiences on a short-term basis throughout the day (somewhat confusingly, such short-term retention is considered an aspect of episodic memory; see Squire & Zola 1998), they do

not probe longer-term episodic retention. Evidently, it is difficult to impose experimental control on the ability to encode and retain meaningful subjective experiences (see, e.g., Burgess 2002). If, however, dreaming does perform an elaborative encoding function vis-à-vis enduring episodic memory, it is unlikely to be revealed through such devices as the VPA. (For example, see Genzel et al. [2009], who, on the basis of VPA testing in wake, concluded that awakenings from SWS or REM do not affect sleep-dependent memory consolidation.) Semi-structured interviews (see, e.g., Kopelman et al. 1989) or the Galton-Crovitz technique cueing method (Crovitz & Schiffman 1974; Galton 1879) would be more productive possibilities. Research to date in this area has usually investigated the relationship between episodic memory function and sleep deprivation. For example, when Rauchs et al. (2004) used the What-Where-When task in conjunction with the Remember/Know paradigm, they found that REM sleep deprivation (as compared to SWS deprivation) resulted in subjects having a significantly lower recall for spatial information and giving significantly fewer “remember” responses. However, in a later review (Rauchs et al. 2005), some of the same team concluded that more studies supported SWS for episodic memory consolidation. Such results are difficult to reconcile. The hypothesis I propose here could, however, be considered in this context. If episodic memories are elaboratively encoded during REM dreams and then instantiated as cortical junctions (“system consolidation”) during NREM, both sleep stages are required for episodic retention.

Another possible avenue for testing is to examine whether, when individuals use AAOM techniques in wake, fMRI scans show neurobiological shifts to a more dream-like state. The AAOM relies on generating creative, non-obvious associations, which are narrativized within constructed visual scenes. Two studies provide examples of this type of approach. They are briefly discussed here. Limb and Braun (2008) conducted an fMRI study that compared the neural substrates of learned vis-à-vis improvised musical performance. For improvisation, there was deactivation of the dorso-lateral pre-frontal cortex; they argued this may be linked to “defocused, free-floating attention that permits spontaneous unplanned associations, and sudden insights or realizations” (p. 4). Deactivation of the dorso-lateral pre-frontal cortex is characteristic of dreaming, and, as discussed previously, creative insights have occurred in the dreaming state; therefore, the Limb and Braun study may provide a point of reference for the exploring the neural substrate of the AAOM in wake. Through fMRI, Hassabis et al. (2007) demonstrated that episodic recollection and imagining experiences both rely on complex visual scene construction, which is underpinned by activation in the hippocampus, parahippocampal gyrus, and retrosplenial cortex. The AAOM and dreaming also generate complex scenes; hence, the study by Hassabis et al. also illustrates the type of fMRI study that could provide an evidence base for this article’s hypothesis.

The AAOM is recognized as the most efficacious mnemonic technique in wake. If its use in wake shows similarity to the substrate of dreaming, this indicates that dreaming may be mnemonic. Specificity could be added to these indicative findings by testing for the loss of long-term memory for past events in the absence of dreaming. Thus, these two tests are complementary.

A third avenue is phenomenological. To illustrate this article's hypothesis, I used a dream. Can this approach be codified to form the basis for experimental work? The hypothesis suggests that both recent and remote memories feature in REM dreams. This is a difficulty. Requiring subjects to list all of their recent and remote memories would not be feasible. Subjects could self-identify memory sources for REM dreams, however. Dreams and their memory sources could then be split and judges asked to match them across multiple subjects.

8. Concluding comments

If REM dreaming, NREM sleep, and wake have complementary (or synergistic) memory functions, according to this article's hypothesis, how is this expressed? Elaborative encoding of episodic memories during REM dreaming may be followed by the instantiation of episodic junctions during NREM, as evidenced by spindle activity. There is a relationship between encoding and spindle activity: Bruni et al. (2009) suggest that spindle activity increases after successful encoding, and Mander et al. (2011) show that elaborative encoding abilities are restored after spindle activity. Thus, REM dreaming periodicity may be explained by the requirement for NREM spindle activity to instantiate junctions before further periods of REM. This article's hypothesis is consistent with evidence that hippocampal sharp-wave/ripple bursts and cortical sleep spindle activity are associated with the transfer of representations from the hippocampus to the neocortex (Buzsáki 1996; 2006). The thesis is also congruent with the characterization of REM as an open system and NREM as a closed consummatory one (Buzsáki 1996; 2006), because REM dreaming would actively and consciously forge the visual compositions that are instantiated in NREM. There are indications of a relation between sleep spindles and neural plasticity (Rosanova & Ulrich 2005; Steriade & Timofeev 2003), such as would be required for the instantiation of junctions.

There is growing evidence for the existence of two forms of spindles: slow (≤ 12 -Hz) spindles, which are dominant over frontal regions, and fast (> 12 -Hz) spindles, which are distributed over central and parietal areas (Anderer et al. 2001; De Gennaro & Ferrara 2003). Fast spindles may be associated with transfer of representations from the hippocampus to the neocortex, whereas slow spindles may be related to cortico-cortical coupling or cross-linking in cortical networks (Doran 2003; Mölle et al. 2011). Clearly, the instantiation of cortical junctions in NREM (following hippocampally mediated hyperassociation between memory elements in REM) would involve both the transfer of representations to the cortex and renewed cortico-cortical coupling or cross-linking. Clemens et al. (2005) reported that the numbers of slow spindles, particularly in left fronto-central areas, were highly correlated with overnight verbal memory retention. Clemens et al. (2006) found that overnight visuospatial memory correlated with fast parietal spindles; they noted accordance with the known association between parietal areas and visual imagery. These findings on differential topographical spindle involvement with verbal and visuospatial memory are consistent with Paivio's dual coding theory, as I discussed earlier in this article. Clemens et al.

(2005) also found a correlation between time in NREM sleep and visuospatial memory, as demonstrated by the retention of faces. Such evidence may be consistent with the earlier instantiation of verbal memory junctions through slow spindles and the later instantiation of visuospatial memory junctions through fast parietal spindles after the onset of REM dreaming.

For this article, I hypothesized that elaborative encoding between episodic memory networks takes place during REM dreaming. Encoding also occurs during wake, however. Such encoding may be predominately semantic. Indeed, as discussed earlier in the article, the memory feats achieved through the AAOM in wake are concerned mainly with knowledge. Word-pair learning prior to sleep correlated with recall after sleep, having induced higher spindle activity; the spindle effect was largest during the first 90 minutes of sleep (Gais et al. 2002), as would be consistent with the earlier instantiation of semantic (knowledge based) material. Tamminen et al. (2010) showed that spindle activity was associated with the integration of new semantic knowledge, acquired during wake, with existing neocortical knowledge. Therefore, semantic associations (formed during wake) could be instantiated (or "integrated") as junctions during earlier periods of NREM sleep. Semantic "junctions," however, are likely to take a different form from episodic ones, as is congruent with the existence of two types of spindles. As semantic material forms an integrated body of knowledge, the associations between items are, naturally, multiple and varied (cf. Fuster 1999, p. 216). Associations between items of knowledge can be subsumed into the body of knowledge. In contrast, the hyperassociations wrought between episodic memories through elaborative encoding engender a fabricated visual image. As argued earlier, episodic junctions are non-conscious. One reason for this may be that the material they portray is not real. In contrast, semantic associations are real. Hence, on retrieval, semantic associations can assume a conscious form.

If episodic memories are elaboratively encoded during REM dreams and junctions instantiated during NREM, both of these phenomena suggest robust reasons for memory processes continuing during sleep. The neuro-modulatory regime that supports REM sleep and is hypothesized to enable emotionally charged hyperassociation would be detrimental to any strictly logical thought processes required in wake. The instantiation of junctions would involve prior cortical reorganization. Although junction instantiation would be likely, intermittently, to increase local network connectivity, reorganization would reduce large-scale neural communication; again, these processes would impair waking functionality. SWS is expressed in the first two periods of the sleep cycle, being much reduced (or obliterated) in later epochs. As stated earlier, SWS engenders a breakdown in cortical connectivity (Massimini et al. 2005; Spoormaker et al. 2010) such as would result from cortical network reorganization. In contrast, in NREM (outside of SWS), functional connectivity is preserved or even increased despite the fading of consciousness; this appears counterintuitive (Spoormaker et al. 2011). It is suggested, here, that this counterintuitive finding in light NREM may be engendered by the instantiation of junctions.

As stated earlier, temporal alignment has been demonstrated between cortical spindles and hippocampal sharp-wave/ripple

events (Clemens et al. 2007; Siapas & Wilson 1998; Sirota et al. 2003; Wierzynski et al. 2009). Such alignment may reflect the retention of hippocampal indices and the instantiations of junctions, respectively. During recall, after matching with hippocampal indices, retrieval would be from “places” (i.e., internal cortical junctions). This brain function relies on landmark neural navigation in mnemonic space. The “method of loci” (the mnemonic strategy in wake which works through allocentric place association) mirrors this internal brain functioning. Through composing mnemonic representations and linking them thematically, the hippocampus creates more than an index. The hippocampus has its own ancient story, the stuff that dreams are made on. It begins not “Once upon a time” but “In the first place”

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APPENDIX

A. “Quicksand”: Methodology and memory sources

1. Methodology

The illustrative dream “Quicksand” was self recorded as a text in a dream diary after awakening at home. It was, provisionally, self-identified as a REM dream following comparison with the REM dream characteristics noted earlier. As with any creative human product, there can be no claim that this dream is typical. The dream constitutes a single case study, which is the preferred method when the research is naturalistic and where experimental control over the phenomenon of interest is neither feasible nor desirable (Yin 1991). Clearly, as with a single experiment, generalization is not possible from a single case (Guba & Lincoln 1981). However, both single experiments and single cases facilitate in-depth exploration to engender theoretical propositions that can be tested across further instances (Yin 1991).

Many of the memory sources of dreams are not obvious (Nielsen & Stenstrom 2005), so I adopted a hermeneutic approach to identify them. Hermeneutic inquiry can be applied to any text where associations are not readily apparent and, hence, have to be recovered (Ricoeur 1974, p. 64). I adopted memory sources through hermeneutic processes of projection and modification; such processes replace Popper’s (1959) conjecture and falsification, where the phenomenon under consideration is an open system (Ricoeur 1981, p. 221). The hermeneutic process of recovery is not aimed at identifying the “world behind the text” or the hidden intention of the author but the “world in front of the text” – defined as “all those things the author could be aware of and (by design or by default) was not” (Bauman 1978, p. 229). Where the text is a dream (or dream report), Bauman’s proposition implies that “downstream” memory sources have not been intentionally disguised by the dreamer (cf. Freud) but that the design of the “upstream” highly associative mnemonic process of dream construction has, by default (not design), obscured the recent and remote memories which constitute the dream.

Any hermeneutic endeavour produces findings that are essentially open in nature (Giddens 1984, pp. 284–85; 1993, pp. 168–70) in the sense that they can always be challenged, extended, or reassessed. Clearly, this is the case with the identification of the memory sources of dreams. As in the recall of any memory, the process is reconstructive (Bartlett 1932; Conway & Pleydell-Pearce 2000; Hassabis & Maguire 2007; Neisser 1962; Rubin et al. 2003; Schachtel 1947; Schacter & Addis 2007; Schacter et al. 1998). Hence, the reconstructed memory sources for

“Quicksand” remain open to revision or addition. I report the dream only at this point.

2. The memory sources of “Quicksand”

Scenes 1 and 2 of “Quicksand” seem to associate elements of four memories: one recent (at the time of the dream) and three remote. One (remote) memory is dominant, two (recent and remote) feature quite strongly, and another (remote) is only peripherally present. These four memories seem to coalesce through association to the imagery of scene 2; for the sake of brevity, I will mainly discuss this scene.

First, the *recent memory*: At the time of the dream, my eldest son was planning to buy his first house and phoned me inter alia about his house purchase plans. He had been to see one on the edge of an old housing estate adjacent to a “good” part of town. The house was empty, the previous occupant, an elderly woman, having died in it. I feared this house might be “unlucky” but didn’t voice this concern; I didn’t want to appear irrational. But I still hoped he wouldn’t buy the house.

Second, the *dominant remote memory*: In 2002, I had a working holiday driving around upstate New York with my then-partner, N, and his sister. N is interested in bridges and loves to stop and photograph examples. One day driving along a highway we pulled up next to an impressive sight – a massive new bridge under construction immediately next to an elegant, graceful, but collapsing old bridge. Both stretched out over a wide, fast-flowing river. N was keen to take photos, but access wasn’t easy. We glanced behind us and saw several small houses bordering a bend in the river. N hit on the idea of driving along this road: If anyone were out in their garden, he would beg permission to take photos. It proved more difficult than expected to locate this place because, actually, the road was on the edge of a small housing estate, but, eventually, we found the right place. But unfortunately – even on this sunny afternoon – no one was in their garden. But N wasn’t to be thwarted. We got out of the car and walked along the road. N decided to knock on the door of the house that looked the most promising, being closest to the bridge. I argued against this; it was lunchtime and people were probably eating. In my view, they would be annoyed at being disturbed.

But I was proved quite wrong. The woman who answered the door was delighted that we wanted to photograph the bridge from her garden. She declared the locals were tremendously proud of both the bridges, old and new. N’s sister and I spent some time in this woman’s garden, conversing with her as N took photos. He then persuaded us to stay for just a few more minutes – from here, N saw that we could get right up under where the new bridge was being constructed, where more great photos would be attainable. So we left the garden and found this place right under where the massive new concrete bridge was being built. As N and his sister were happily shooting away, I suddenly started to get a bad feeling: The new bridge from right up close looked “dead” to me – cold, hard, concrete, looming overhead. I thought the old bridge was actually far preferable. How could a new thing – something under construction – look so horrible? And the spot where we were standing was lonely – a kind of no-man’s land. I wanted to move on to more pleasant things and escape this sudden irrational fear.

The *third and most remote memory*: When I was a small child (I do not remember the exact time/place context), my mother warned me against wandering off across beaches. She said children can die if they stray. “Quicksand” can suddenly swallow them up. In my childish imagination, I saw this “quick”-sand as very fine, soft, and sparkly – attractive but so fine that children (especially small ones) could quickly slip through and be engulfed. I loved being by the sea and playing on the beach. That something as delightful as a bright, sandy seashore should harbour a dreadful quicksand death trap seemed unbelievable, but my mother said it was true. This remote “Quicksand” memory has a subordinate role in scene 2 (the cloth-shroud-death-sand association to the house)

but assumes a central role in scene 3 (not discussed here for reasons of brevity).

Lastly, *another peripheral association*: At the time of the dream, my second son had a long-standing and worrying problem with his hearing. As a result, he found noisy surroundings intolerable. In scene 2, the house is under construction. (Actually, in the U.S. holiday, it was the bridge, not the house, that was under construction.) The new bridge was being constructed from concrete. Sand is a component of concrete. When I stood below the new bridge, I experienced the irrational fear that I described earlier. From the perspective of my second son, the U.K./U.S. house would be a bad buy because construction work would render it too noisy. As with the sand theme, this “damaged hearing/ear” theme continues into scene 3 as the baby/child lands on his/her ear before disappearing into the sand.

From the perspective of waking consciousness, these four memories are dissociated. A stop to photograph bridges during a holiday, a phone call from my eldest son about a possible house purchase, quicksand, and my second son’s hearing problem seem to have little in common. But associations can be identified. The first is place – the first two memories feature a house positioned “on the edge of town.” The second is an emotion – fear. During the stop to photograph bridges, under the new bridge I experienced a fear that I told myself was irrational. Similarly, on hearing about the house in which someone had died, I felt a fear that I tried to dismiss as illogical. My childish fear of quicksand was confused; it focused on the “wrong” type of sand. My son’s hearing problem was worrying, but, at the time of the dream, the cause was unknown despite rational investigation. So these four fears shared a common feature – they defied logical analysis. Fear seems to drive the dream plot so that in scene 2 the feared object is the house/bridge under construction. Someone had died in the house – this association engenders the cloth-shroud association. The construction association seems to elicit both “sand” and “noisy,” which then associate to quicksand (which I feared as a child) and my second son’s hearing problem, about which, at the time of the dream, I was fearful. Thus, scene 2 creates a nexus of associations initiated by place/fear.

Open Peer Commentary

The analogy between dreams and the ancient art of memory is tempting but superficial

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Abstract: Although the analogy between dreams and ancient mnemotechniques is tempting because they share several phenomenological characteristics, this analogy is superficial at a closer look. Unlike mnemotechnically encoded material, rapid eye movement (REM) dreams are inherently difficult to remember, do not usually allow conscious subsequent retrieval of all interconnected elements, and have been found to support subsequent episodic memory in only rare cases.

First, we would like to emphasize that we do agree with the author on several points of her theory: During dreams, fragments of both recent and remote experiences reappear, in

particular emotionally relevant ones; the seemingly bizarre links between these dream elements may actually be explained by idiosyncratic semantic networks (which can be revealed, for example, through psychoanalysis or other techniques); and there is good evidence that rapid eye movement (REM) sleep supports subsequent memory retrieval of emotional events (e.g., Nishida et al. 2009). Furthermore, on a phenomenological level, dreams do share several characteristics with ancient art of memory (AAOM) mnemotechniques: Both are hyperassociative – that is, they connect individual contents through rich networks of links (which for mnemotechniques increases the number of cues which make these contents accessible) – and these associations may appear random and bizarre on the first sight but actually serve a hidden logic.

Despite this apparent similarity between dreams and mnemotechniques, we argue that dreams are unlikely to function as effective mnemotechniques. The ultimate goal of mnemotechniques is to improve memory, but dream memory is deficient compared with memory for waking experiences (Hobson et al. 2000). Not only are dreams remembered rarely, but dream memories also typically contain much less detail than does memory for experiences acquired during waking state. This may be due to various psychological factors, including the apparent strangeness of dreaming experience (which impedes subsequent recall; see Bartlett 1932), as well as due to physiological factors such as the low level of functional EEG connectivity in brain regions that are crucial for declarative memory (Fell et al. 2003). A mnemotechnique that sets individual memory contents into a framework that is inherently difficult to remember is paradoxical. (Imagine a device for motor control that renders your movements random and uncontrollable.)

It could be argued that while dreams themselves are difficult to remember, they support the consolidation of their constituents; in principle, an efficient mnemotechnique does not require that the entire connection of various items be remembered, but at least that the individual items within this connection can be easily accessed and therefore better remembered. Indeed, this seems to be what the author has in mind when she hypothesizes that “[i]f hyperassociative dream scenes do encode episodic memories and these scenes are retained as hippocampal indices, these are non-conscious phenomena used, in normal wake, to ‘search’ for memories in cortical networks” (sect. 5.1, para. 1). Thus, the idea is that dreams trigger subsequent retrieval of parts of the episodes that are retained in them through nonconscious processes. Even if this is the case, the parallel to mnemotechniques is at best remote – mnemotechniques are used to support conscious recall of entire fictitious or real memory episodes, not to trigger memory unconsciously for individual constituents of these episodes.

But leaving this aside for now, what is the empirical evidence for a role of dreams in episodic memory consolidation? It is well established that non-REM (NREM) sleep (Plihal & Born 1997) and NREM mentations (Wamsley & Stickgold 2010) support later retrieval of declarative memories. REM sleep appears to play a more prominent role for subsequent memory of emotional memories (Wagner et al. 2001) and procedural memories (Plihal & Born 1997), although evidence is mixed in this respect because a recent study suggests that pharmacological reductions of REM sleep facilitate the consolidation of motor sequences (Rasch et al. 2009). Evidence for a role of REM dreams in the support of later retrieval of episodic memories is extremely scarce (Cipolli et al. 2005; Fiss et al. 1977).

Finally, the physiological order of REM sleep and NREM sleep is inconsistent with the proposed model. The author suggests that “elaborative encoding of episodic memories during REM dreaming may be followed by the instantiation of episodic junctions during NREM” (sect. 8, para. 1). However, REM sleep usually follows NREM sleep – the first REM episode usually occurs at the end of the first sleep cycle, and generally there is more REM sleep in the second half of night and more NREM sleep

in the first half of night. Thus, the physiological order of REM sleep and NREM sleep would rather suggest another sequence of processes: Consolidation and integration of episodic memories via the formation of semantic network connections probably already occurs during NREM sleep, and these connections may later be activated (and, possibly, more thoroughly integrated) during REM sleep (Diekelmann & Born 2010).

To summarize, the analogy between REM dreams and AAOM mnemotechniques is convincing at only a superficial phenomenological level but is odd, at a closer look, for several reasons: Unlike mnemotechnically encoded material, REM dreams (1) are inherently difficult to remember, (2) do usually not allow conscious subsequent retrieval of all interconnected elements, and (3) have been found to support subsequent episodic memory in only rare cases. Furthermore, the physiological order of REM sleep and NREM sleep suggests that REM sleep supports, if anything, a secondary consolidation or integration step.

Some Renaissance, Baroque, and contemporary cultural elaborations of the art of memory

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Abstract: The target article addresses historical and present-day mnemotechnics as a practice. It also deserves scrutiny as culture writ small. For would-be Hermetic adepts of the Renaissance and Baroque, the ancient art of memory (AAOM) provided both an iconography and a projective-test vision of possibilities. In contemporary fiction, Memory Palaces become a metaphor for the workings of mind, of culture, and of information technology.

To dream is to coordinate the objects we viewed while awake and to weave a story, or a series of stories, out of them. We see the image of a sphinx and the image of a drugstore, and then we invent a drugstore that is changed into a sphinx.

—Jorge Luis Borges, *Other inquisitions* 1937–1952 (1964b, p. 21)

A king's mouth gapes monstrously wide as he prepares to bite off another man's head, despite remonstrations from a scholarly winged onlooker. In an otherwise-deserted courtyard, beside a blazing hearth, a Roman legionary raises his sword against a giant egg. Another scholar points over-sized compasses towards a geometrical figure inscribed on an external wall where the plaster is crumbling from the brickwork. Despite the grotesquerie, these images are neither dreams nor Surrealist collages, coming instead from the Baroque alchemy tradition (Klossowski de Rola 1997). No resource of engraving has been spared to lend each scene an illusory realism and bolster it with circumstantial detail of stage set and costume. Schematic outlines would convey the same concepts but would not imprint the reader's psyche.

Alchemy illustrations were not mnemonic per se but represented an elaboration or repurposing of the ancient art of memory (AAOM). They exemplify a proto-scientific conviction that the hidden rules governing the operations of the universe are knowable, and to understand and internalise these rules is to control them. To Hermetic/Cabalistic thinkers such as Bruno and Camillo, the AAOM provided precisely the tools they sought for internalising the principles they had discerned (Yates 1966). Thus the techniques for translating information into memorable imagery flourished through the 1600s.

One manifestation of this conviction was the humanist enthusiasm for Egyptian hieroglyphs (Iverson 1993). We meet them,

for instance, filtered through the AAOM, in the dream-narrative *Hypnerotomachia Poliphilia* (Colonna 1499/2005). The *Hieroglyphics* of Horapollon acquired oneiric illustrations in which disembodied eyeballs and hands drift like hot-air balloons above Northern Renaissance landscapes (Anon. 1543/1551/1993). Unconstrained by mundane translations, scholars could regard hieroglyphs as a cosmic source code, with esoteric symbols that mirror the key constructs of reality.

Alchemical diagrams were part of a broader “emblemata” tradition of imprinting the mind with moral precepts allegorised into memorable pictorial terms. The results have been compared to “flashcards for the insane.” The intention, broadly didactic, became explicitly mnemonic in the *Ars Memoranda* and *Rationarium Evangelistarum* (Anon. ca. 1470/2002). Here the Evangelistic gospels were compressed into 15 images with details designed to evoke episodes from the narrative. A flying lion, an awl piercing its leg, might juggle hieroglyphs and brandish a small donkey while a goat bursts, *Alien*-style, from its chest.

The classical AAOM emphasises the structuring of knowledge into manageable bundles. Each “bundle” is encoded as a striking tableau in which memorable characters engage in activities or display attributes that simultaneously store the information and enhance the heraldic vividness of the scene. Llewellyn proposes that the parallels with the imagery encountered in dream are the product of convergent evolution rather than coincidence. In dream, to ensure wide linkage and avoid new memories from merging with older ones, the hyper-associative “indexing” process avoids the most obvious associations while it weaves links between recent experience and earlier memories. In the AAOM, incongruities and *bizarrie* are a strategy for memorability. The difference is that dream incongruities are seldom apparent at the time. The juxtapositions and indeterminacy may be not just impossible but *unrepresentable* – purely verbal combinations that cannot translate into visual terms – yet we blithely accept them. House and bridge co-exist as in quantum mechanics. Bats eat cats as easily as the converse; ants conjoin with elephants (Colonna 1499/2005). Dreams may bring the conviction that we are experiencing visual percepts, but instead they seem to be a spread of activation across neural networks through which abstract, ungrounded symbols interact.

A second key element of the AAOM is the Method of Loci. Each tableau is associated with one specific location along a familiar route – one niche within a cathedral, perhaps, internalised by repeated visits – both distinguishing the tableaux and enumerating them so that bundles can be recalled without omissions. Retrieval becomes a kinaesthetic metaphor of mentally retracing the route through embodied experience. This mental/architectural filing system has parallels with the collective external memory of information technology, instantiated as the cyberspace of science fiction. It is not surprising, then, that contemporary literary uses of the AAOM focus on the Method of Loci. In Watson (1990), the titular aliens are mnemonic adepts whose abilities reshape reality: one by one, as they commit the details of Earth's architectural highlights to memory, buildings disappear.

To provide a framework or armature for organising later material, loci must be rote-learned. Fiction often abandons this necessity as a tribute to the power of creative imagination. The Memory Palace employed by Hannibal Lecter to organise his lifetime of learning has no counterpart in the tangible world (in which “it would rival the Topkapi Palace in Istanbul for size and complexity”; Harris 1999). The Bureaucrat's palace (Stanwick 1991) is mobile, fractal, telescopic: Stanwick is using the tropes of the AAOM to describe a virtual-reality software interface and see it anew in the reflection of antiquity. One might invoke Borges (1964a). What are the Garden of Forking Paths, the labyrinth of Ibn Hakkan al-Bokhari, and the Library of Babel, if not Memory Palaces? The House of Asterion has 14 pools, 14 mangers, 14 courtyard loci.

Conversely, the role of the grotesque tableau has dwindled. It may be that drama, absurdity, emotional arousal, and the extremes

of beauty and rank have lost their impact for a modern audience. Again, there are precedents in the Baroque AAOM. In Camillo's Memory Theatre and Bruno's mnemonic wheels, the fusions were latent rather than overt. These were attempts to systematise and personify the neo-Platonic principles of reality in an exhaustive, combinatorial generation of juxtapositions. Bruno has now attained a literary apotheosis: in one reviewer's estimate, he "probably appears in more science fiction novels than anyone else." As for the Memory Theatre, in Fuentes (1977) it became a metaphor for culture itself.

Dreams are made of memories, but maybe not for memory

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Abstract: Llewellyn's claim that rapid eye movement (REM) dream imagery may be related to the processes involved in memory consolidation during sleep is plausible. However, whereas there is voluntary and deliberate intention behind the construction of images in the ancient art of memory (AAOM) method, there is a lack of intentionality in producing dream images. The memory for dreams is also fragile, and dependent on encoding once awake.

Llewellyn claims very plausibly that dream imagery may be related to the processes involved in memory consolidation during sleep. She cites many of the reviews and original works in this field, to which may now be added claims that also during wake there is offline memory reprocessing (e.g., Peigneux et al. 2006) involving spontaneous thought processes (daydreams) and the brain's default network (Wang et al. 2009).

Llewellyn refers to the dream-lag effect as indicative of sleep-dependent memory consolidation (Nielsen et al. 2004). This effect refers to a 5- to 7-day delayed incorporation of waking sources into dreams, which follows the more well known immediate incorporations (day residues) from the previous day. Llewellyn is correct to point out that a mnemonic function for rapid eye movement sleep would be supported by evidence that the dream-lag effect is specific to REM rather than non-rapid eye movement (NREM) sleep. A recent study has indeed shown the specificity of the dream-lag effect to REM sleep rather than N2 sleep (Blagrove et al. 2011a).

However, in supporting a systems approach to the memory consolidation function for REM sleep, the author does not counter the claim for slow-wave sleep having this function, with REM sleep having instead a synaptic function. In addition, that N2 and spindles may be associated with memory enhancement and integration for declarative memory (e.g., Tamminen et al. 2010) does raise questions for claims of the involvement of REM sleep or REM dreams in declarative memory consolidation.

There are additional problems with Llewellyn's proposal in the analogy between REM dream characteristics and the bizarre, narrative, hyperassociative, embodied, spatial characteristics of the ancient art of memory (AAOM) method. The analogy fails when it comes to the voluntary and deliberate intention behind the construction of images in the AAOM method compared with the lack of effort/intentionality/choice in producing dream images. Llewellyn cites evidence that "self-generated encodings are better

retained than provided ones" (sect. 3, para. 2), and yet dreams are precisely "provided" to us. Indeed, even in lucid dreams, much of the dream content arises independently of the dreamer's volition. The memory sources of dreams are generally unknown to us during sleep or even after waking. The emotional response to the violation of expectancies is cited by Llewellyn as a component of AAOM, and yet in dreams bizarreness is often not recognised as such. It is unclear why the author wants to analogise the processes of dream bizarreness to AAOM, which has connotations of rote learning, and the method of loci even more so, rather than towards the more creative meeting between two memories, as proposed by many, with Palombo (1978) being an early example, to Stickgold and Walker (2013), or the more therapeutic views of narrative discontinuities causing changes in self-perception after waking (Kuiken 1995).

To test her model, the author proposes several approaches. First, she states that "Loss of dreaming would be anticipated to result in loss of identity, loss of emotional concerns, and loss of the ability to plan for the future." This is similar to Jouvett's (1991) hypothesis on the role of paradoxical sleep (REM sleep) in psychological individuation. The negative correlation between alexithymia and dream recall frequency (Nielsen et al. 1997) can be explained by this model (but also by others).

Secondly, she proposes to test for memory retention in the absence of dreaming. Several studies have already tested memory retention in the absence of dream recall (Göder et al. 2011; Solms 1997) and by comparing subjects with high-frequency and low-frequency dream recall (for reviews, see Blagrove & Pace-Schott 2010; Ruby 2011), but little relationship with memory abilities has been found. However, again one cannot be sure that low-frequency dream recallers dream less than high-frequency dream recallers. The literature on REM sleep suppression may thus be relevant, although unclear. For example, Göder et al. (2011) found no negative effects of a decrease in REM sleep on memory performance in patients taking antidepressants, whereas Watts et al. (2012) found that antidepressant suppression of REM sleep impairs hippocampus-dependent learning in rats.

Thirdly, the author rightly proposes to investigate phenomenologically the relationship between immediate and delayed incorporation of waking life events into REM dream content. In a recent study Blagrove et al. (2011b) did investigate the incorporation of recent events into dreams, although sleep stage on awakening was not known. However, regarding Llewellyn's proposal that judges could attempt to match memory sources and dreams, that study indeed found this to be possible for day-residue incorporations, but not for delayed incorporations. The authors suggested that delayed incorporations may involve metaphorical or personal knowledge such that independent judges cannot identify source material in the way the person who had the dream can do.

Llewellyn's placing of Wamsley et al.'s (2010) finding that dream content is related to improved performance on a spatial learning task overlooks the possibility that the dream imagery is not related to any memory processing during sleep, but is instead related to concerns about pre-sleep task performance – that is, the dream reflects an emotional concern rather than a cognitive function. Such an argument could lead to an epiphenomenal view of dreaming (Blagrove 2011). Nevertheless, a memory-consolidation function for REM sleep can still be supported by relating dream content to a higher-level learning of social interaction and interpersonal experiences as supported by Nielsen and Lara-Carrasco's (2007) character self-interaction model of dream content.

However, counting against REM dreams having some lasting elaborative encoding effect is the fragility of memory for dreams. Eichenlaub et al. (2013) have found that high-frequency dream recallers show double the amount of intrasleep wakefulness compared with low-frequency dream recallers, indicating that dreams are only recalled if encoded during wakefulness.

Furthermore, randomly presented sounds were found to elicit different brain responses in high-frequency and low-frequency recallers during both wakefulness and sleep, with the higher brain reactivity in high recallers hypothesised to contribute to the higher frequency of dream reports by increasing intrasleep wakefulness. Further justification is thus needed for the claim that unremembered dreams have any consequent effects. Dreams may thus be made of memories, but without having a memory-consolidation function.

Composition and replay of mnemonic sequences: The contributions of REM and slow-wave sleep to episodic memory

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Abstract: We propose that rapid eye movement (REM) and slow-wave sleep contribute differently to the formation of episodic memories. REM sleep is important for building up invariant object representations that eventually recur to gamma-band oscillations in the neocortex. In contrast, slow-wave sleep is more directly involved in the consolidation of episodic memories through replay of sequential neural activity in hippocampal place cells.

“The stuff of dreams is the stuff of memory,” Llewellyn argues (target article, abstract), and “REM dreaming may provide the most conducive state for the elaborative encoding of personal, emotionally salient memories” (sect. 6, para. 4). She thus postulates two intimate relations between dream and memory: (1) a content relation – the contents of dreams are constitutive for, if not identical with, the contents of memories; and (2) a causal relation – REM dream provides the main causal mechanism for memory consolidation. The formation of memories, as Llewellyn suggests, can be divided into three steps: (1) the composition of multiple elements into scenes, (2) the association of (emotionally tagged) scenes with loci, and (3) the ordering of scenes on the basis of ordered sequences of loci.

In the following, we propose prominent candidates for the neurobiological mechanisms that might underlie the three-step model, thus putting it on a firmer physiological foundation. At the same time, these very mechanisms lead us to question the evidence for the intimacy – especially of the causal relation between REM dream and memory.

Gamma-band (30–80-Hz) oscillation has been postulated as a vital mechanism for the object-related binding of distributed neuronal feature representations (Gray et al. 1989; Singer & Gray 1995; for a review, see Singer 1999). There is evidence that gamma-band oscillation is constitutively involved in conscious awareness (Engel et al. 1999). Crucially, gamma-band oscillation is present in REM sleep and moreover characteristically distinguishes REM sleep from non-REM sleep (Llinás & Ribary 1993). It has been found in the hippocampus of the rat and the rabbit (Bragin et al. 1995; Stumpf 1965). As we have shown in neural network simulations (Maye & Werning 2004; Werning 2003b; 2005a; 2005b; 2012), gamma-band oscillation may subserve the generation of nonsymbolic, but still compositional, object representations. From this point of view, it seems indeed plausible that a composition of multiple features into objects takes place in REM sleep (Fig. 1a[A]) – for the integration of features into events, see Werning (2003a). This supports step 1 of the three-step model.

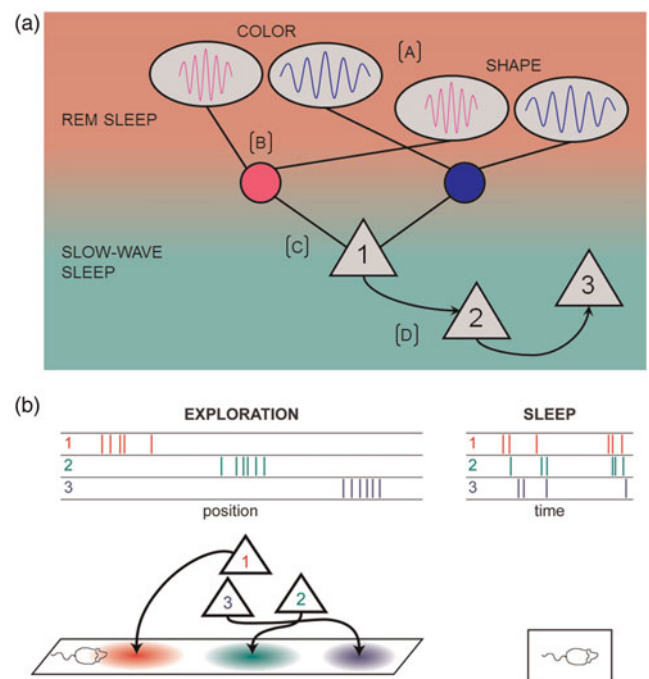


Figure 1 (Cheng & Werning). **1a:** The contribution of REM and slow-wave sleep to the formation of episodic memories. (A) Objects are temporarily represented by neural synchronization between distributed neural feature representations. (B) Invariant object representations are generated. (C) Various objects are integrated into scenes at particular places. (D) Places are ordered in sequence. **1b:** During active exploration of an environment, place cells are activated sequentially based on the locations of their place fields. The same cells become active in a similar order during subsequent slow-wave sleep in the absence of external inputs.

Place cells in the hippocampus of rodents fire action potentials only when the animal is located in a circumscribed location (Cheng & Frank 2011; O’Keefe and Dostrovsky 1971). Similar cells have been observed in the human hippocampus navigating a virtual reality environment (Ekstrom et al 2003). It seems reasonable to assume that hippocampal cells provide the neural basis for the representation of spatial locations required in step 2 of the three-step model (Fig. 1a[C]). The link between the hippocampus and the three-step model is further underscored by the fact that the hippocampus is also essential for episodic memory formation in humans (Scoville & Milner 1957).

Two more properties of place cells provide a tantalizing link to step 3 of the three-step model (Fig. 1a[D]). First, place cells’ spiking is sequentially ordered during active behavior controlled by a 6- to 10-Hz oscillation (Gupta et al. 2012). Second, during quiescence or sleep, the same place cells are reactivated in the same sequence as shown in Figure 1b (Diba & Buzsaki 2007; Lee & Wilson 2002; for a review, see Buhry et al. 2011), and there are hints that these replay events occur during REM sleep (Louie & Wilson 2001). Replay is generally accompanied by sharp-wave/ripple (SWR) events, and we have found that SWR-related activity is enhanced when animals learn about novel spaces (Cheng & Frank 2008). We therefore fully agree with Llewellyn that the hippocampus is probably intimately involved in the storage and retrieval of episodic memories.

However, unlike Llewellyn, we believe that the experimental evidence suggests that slow-wave sleep (SWS) is important for consolidation of episodic memories, but REM sleep is not. First, in human studies, REM sleep improves procedural skills learned before (Fischer et al. 2002; Karni et al. 1994) but has little influence on episodic memories (Gais & Born 2004).

Second, SWS is important to consolidate declarative memories (Gais & Born 2004; Fosse et al. 2003; Tucker et al. 2006). Third, the aforementioned neural sequences occur predominantly during SWS and the finding of sequential reactivation in REM sleep (Louie & Wilson 2001) has not been replicated by any other study.

Instead, we would suggest that a possible mechanism that links REM sleep to the formation of episodic memories might be the generation of invariant object representations. Cells representing objects in a way that is invariant with regard to particular features and independent of particular contexts were found in the hippocampus (Quiroga et al. 2005). Those representations might be regarded as rigid designators of objects (Kripke 1980) because they make objects cognitively accessible across times and independently of the detailed descriptive information in any particular context. These invariant object representations (“grandmother” cells/assemblies) exist alongside compositionally generated object representations in the neocortex bound by gamma-band oscillations. These two representational formats might interact with each other during REM sleep (Fig. 1a[B]), forging the appropriate synaptic connections between hippocampus and neocortex. For episodic memory, invariant representations provide a compression mechanism that avoids the need to store detailed sensory information. This is beneficial because, on the one hand, the storage capacity of the hippocampus is limited (cf. Palm & Sommer 1992), and, on the other, much of the detailed context-bound information processed in the neocortex is irrelevant for memory.

We thus concede that there might be an intimate content relation between REM dreaming and episodic memory because both essentially involve invariant object representations. However, the causal relation between REM dreaming and memory consolidation might be less intimate than Llewellyn assumes.

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Such stuff as NREM dreams are made on?

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Abstract: The question that we deal with in this commentary is the need to clarify the synergistic role of different non-rapid eye movement (NREM) sleep stages (stages 2 and 3–4) with REM and while awake in elaborative encoding of episodic memory. If the assumption is that there is isomorphism between neuronal and cognitive networks, then more detailed analysis of NREM sleep and dreams is absolutely necessary.

Sue Llewellyn’s target article proposes the striking hypothesis that rapid eye movement (REM) dreaming shares some similarities with mnemonic processes underlying old mnemonic techniques (ancient art of memory [AAOM]) in elaborative encoding of episodic memory.

The idea that memory could benefit from the synergistic action of waking and sleeping is suggestive and probably true. Nevertheless, several points need to be clarified regarding the synergistic role of the different sleep stages and dreams (REM and non-rapid eye movement [NREM]) in the elaborative encoding of episodic memory. The neurobiological underpinnings of REM sleep and some specific NREM sleep stages (stage 2, slow-wave sleep [SWS]) are well documented and understood, thanks to the physiological, psychophysiological, and neurological literature of the

past few decades. On the other hand, empirical data about dreaming and dreams are scant and inconsistent.

With regard to REM dreams, if we consider dream reports collected at night (with the exception of the first REM), we agree with the majority of authors who define REM dreams as characterized by vivid perception, frequent bizarre associations, narrative structure, self-embodiment, and location. In that case, the hypothesis that these characteristics of REM dreams could be similar to devices underlying the AAOM is very suggestive. In fact, it could explain a mnemonic function of REM dreaming – that is, the elaborative encoding of recent memories with emotional distinctive remote episodes though hyperassociative activity, visual imaging, and bizarre links among objects, places, people, and so on, similarly to AAOM.

The argument is based also on neurobiological evidence associated with REM and NREM sleep. That this isomorphism between neurobiological and cognitive networks (Stickgold et al. 2001) is related to NREM sleep, though, is an overall questionably strong assumption. NREM sleep cannot be considered a unique type of sleep, although there are important differences in biological characteristics between early stage 2, stage 2 during sleep, stage 2 near the end of sleep, and SWS. Llewellyn seems to collapse neurobiological aspects of different NREM sleep stages and NREM generic dream characteristics (thoughtlike, brief, trivial) into a unique, comprehensive concept of NREM.

This reasoning is supported by neurobiological data showing that the associative areas involved in information processing are similarly activated in REM and NREM (all of the stages), whereas differences are found in the hippocampal and parahippocampal regions, which are primarily involved in memory systems and in the emotional participation in dreams.

On the other hand, the analysis of the dreams at night and the comparison between mental activity at sleep onset (NREM stage 2), in NREM stage 2 at night, in NREM SWS, and in the REM shows many similarities. Our experimental data (Cavallero et al. 1992; Cicogna et al. 1992; 1998) showed that NREM and REM dream reports cannot be distinguished if the dream reports’ length is the same (the quantitative difference is predominant). Moreover, NREM dream reports collected near awakening are frequently difficult to distinguish from early-night REM dreams (Cicogna et al. 1998; Fosse & Domhoff 2007). That could suggest the engagement of a unique cognitive system involved in dream generation, irrespective of EEG sleep stage (as Foulkes [1985] proposed in his model). In accordance with Solms (2000), dreams occur all night. Therefore, it seems reasonable to state that dreaming does not depend exclusively on REM physiology. Dreaming depends on a complex functional system involving regions of forebrain (parieto-temporo-occipital carriage, mesial frontal white matter, limbic system, and associative visual areas). Central Nervous System (CNS) activation certainly modulates cognitive processes quantitatively but not necessarily qualitatively. The dream generation could use the same cognitive mechanisms in every sleep stage. The qualitative differences could be an epiphenomenon of the quantitative ones. This is our speculative hypothesis, based on empirical data, but we hope that further data will better clarify and explain the NREM–REM “dialogue.”

According to Llewellyn, the interplay between NREM and REM is the instantiation during NREM sleep of internal cortical junctions by the hippocampus, retained as indices. The instantiation of junctions enables the elaborative encoding of recent and remote emotional episodic memories during REM dream generation. The author emphasizes that the different sleep stages are distinct but integrative in memory and dream processes. This hypothesis is interesting and suggestive because, like our hypothesis, it enables one to disregard models that reserve an exclusive role for REM sleep in dream generation (see Stickgold et al. 2001).

However, Llewellyn assigns much importance to the role of cortical spindle activity in the formation of cortical junctions, so

the role of slow-wave sleep remains an open question. In this model, the function of SWS is unclear in the absence of electrophysiological features (spindle activity, sharp waves) considered critical to the instantiation of cortical junctions.

Concluding it is the role of SWS–NREM sleep is not persuasive. It requires much explanation inside the dream generation processes either from a physiological or a cognitive perspective. We understand the good intentions aimed at finding a synergy among all the different levels of vigilance (REM–NREM sleep–wakefulness) in encoding episodic memory and in REM dream generation. Moreover, we think that the empirical data do not allow the determination of a persuasive integration of neurophysiological and cognitive characteristics of NREM sleep stages.

Finally an interesting question that could be addressed by future research regards the dream recall of the dream episodes encoded. If we assume the “state dependence effect” on episodic mnemonic processes (see encoding specificity principle, Tulving & Thompson 1973), fragments of dreams might be retrieved and used as a base of implicit knowledge for new dream generation. In this way, elaborative encoding during sleep could make accessible what is not available to waking awareness.

Such stuff as psychoses are made on?

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Abstract: In her target article, Sue Llewellyn concludes that an unconstrained form of consciousness is necessary for the elaboration of meaningful associations. Unlike the author’s view that dedifferentiation of memory encoding processes across wakefulness and sleep determines schizophrenia, our proposal suggests this mechanism could reflect a common neurobiological substrate for psychosis across several different diagnostic domains.

Sue Llewellyn suggests that visual imaginative processes akin to those employed in the ancient art of memory (AAOM) underlie all effective mnemonic techniques. Developing this observation, she argues that an unconstrained form of consciousness is necessary for the elaboration of meaningful associations and that the hyperassociative form of visual imagery observed in dreams could reflect the brain’s attempt to process emotionally relevant stimuli encountered in wakefulness. In her view, psychosis would emerge if hyperassociational junctions rose to consciousness, possibly through disruptions of spindle activity during non-rapid eye movement (NREM) sleep. Abnormal slow-wave sleep architecture and impaired memory consolidation processes have been linked to the development of psychosis, but the relationship between these phenomena remains largely unknown (Ferrarelli et al. 2007; Keshavan et al. 2011; Manoach et al. 2010; Seeck-Hirschner et al. 2010).

The striking similarity between dreams and psychosis sparked the interest of many enquirers of the mind throughout history, at least since Aristotle suggested that “the faculty by which, in waking hours, we are subject to illusion when affected by disease, is identical with that which produces illusory effects in sleep” (Aristotle 350 B.C./1941). In both conditions, subjective experience produced by endogenous neural activity is uncritically interpreted as originating in the external environment (Feinberg 2011). Whereas in healthy subjects the transition from sleep to wakefulness rapidly restores adequate contact with the environment, psychotic patients seemingly experience a continuous loss of touch with reality. Delirious states of consciousness that are traditionally distinguished from so-called functional psychoses for

the presence of a recognizable organic cause have been observed to most closely resemble dreams (Hobson 2004). However, several authors have suggested that the progression of knowledge on the neurobiological bases of dream production could shed light on all psychotic disorders, including schizophrenia (D’Agostino et al. 2012; Feinberg 2011; Gottesmann 2006; Perogamvros & Schwartz 2012).

Psychosis and dreaming: A common generator? Deficits in source monitoring and aberrant assignment of significance to irrelevant stimuli are often implicated in current attempts to explain the pathogenesis of psychosis (Corlett et al. 2010; Fletcher & Frith 2009; Howes & Kapur 2009). According to these theories, hyperactivity of the mesocorticolimbic dopaminergic system determines abnormal interpretations of subjective experiences by failing to direct attention appropriately to both internal and external stimuli. Whereas hallucinations are hypothesized to derive directly from such dysfunction, delusions are thought to reflect the brain’s cognitive effort ultimately to make sense of one’s puzzling experience.

The same neural circuitry is strongly linked to the encoding and expression of emotionally salient learning and memory formation in healthy subjects (Laviolette 2007). Activation of this system and associated limbic structures during REM sleep has been hypothesized to determine prioritization of contents that are reprocessed in dreams (Perogamvros & Schwartz 2012). Recent accounts of delusion formation also imply the role of glutamate-dependent synaptic plasticity, whereby incoming information is continuously interpreted on the basis of prior representations because of aberrant prediction error signaling (Corlett et al. 2010). According to this mechanism of hierarchical Bayesian learning, dreams analogously arise when “sensory firing is not constrained by top-down prior information and inferences are accepted without question owing to an attenuation of the prediction-error signal from lower to higher levels” (Fletcher & Frith 2009, p. 52).

In this perspective, both dreams and psychosis depend on a loss of inferential reasoning. Whereas in sleep this loss could serve the function of sustaining elaborative encoding proposed by Llewellyn, in wakefulness it appears to determine a maladaptive circuit of continuous reinforcement of prior mnemonic traces. A genetically based susceptibility to hyperassociative mnemonic encoding during wakefulness could explain the classic positive dimensions of disorganized thought, delusions, and hallucinations that define psychosis. Unlike Llewellyn’s view that schizophrenia itself could depend on a dedifferentiation of memory encoding processes in wakefulness and sleep, we suggest this mechanism could reflect a shared neurobiological substrate between dreams and psychotic symptoms found across several different clinical diagnoses.

Bizarreness as a loss of logical constraint. This new theory aims to explain the primarily visual nature of dreams and other well-known peculiarities of this form of consciousness, such as bizarreness. This phenomenon is thought to reflect the spontaneous activity of the brain as a closed system in the absence of environmental inputs and voluntary self-regulation mechanisms (Antrobus 1991; Mamelak & Hobson 1989; Rechtschaffen 1978). Indeed, deactivation of the prefrontal cortices – which is also commonly observed during cognitive tasks in schizophrenic patients – is a distinguishing feature of REM sleep, when dream bizarreness is known to reach its peak. Bizarreness can be viewed as a loosening of the formal structure of cognition, suggesting the brain is physiologically prone to the loss of constraint applied by logical reasoning and environmental inputs during wakefulness. Bizarre cognition has recently been shown to clearly differentiate dream and fantasy narratives in healthy subjects but not in acutely psychotic subjects belonging to different diagnostic domains (Limosani et al. 2011a). In psychiatry, the correlation of specific brain abnormalities to classic psychopathological symptoms remains elusive, and most research into the neurobiology of psychiatric disorders focuses on a syndromic level. Research into specific transnosographic abnormalities such as the loss of inferential reasoning that accompanies patients’

uncritical acceptance of abnormal thoughts and perceptions could hold new promise. Future studies on the neurofunctional correlates of dream bizarreness may help to shed light on such loss, which appears to be crucial for what is commonly described as psychotic patients' loss of touch with reality.

Don't count your chickens before they're hatched: Elaborative encoding in REM dreaming in face of the physiology of sleep stages

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Abstract: Llewellyn suggests that episodic memories undergo “elaborative encoding” during rapid eye movement (REM) dreams, generating novel associations between recent and remote memories that are then instantiated during non-REM (NREM) sleep. This hypothesis conflicts with our knowledge of the physiology of NREM and then REM sleep stages and their ordered succession. Moreover, associations during sleep might also involve the extraction of hidden patterns rather than de novo associations.

It has been proposed that mental experience in sleep, such as dreaming activity, both reflects and contributes to the off-line consolidation of recent episodic memories (e.g. Cipolli et al. 2004; De Koninck et al. 1990; Fiss et al. 1977; Wamsley & Stickgold 2011). However, the mechanisms underlying a beneficial effect of sleep on memory consolidation through dreaming remain largely unknown. Llewellyn proposes that rapid eye movement (REM) dreaming supports the “elaborate encoding” of episodic memories, eventually leading to the emergence of novel commonalities or associations between recent and remote memories that are then instantiated as “junctions” and consolidated during non-REM (NREM) sleep. We found Llewellyn's hypothesis sensible in considering synergetic roles for REM and NREM sleep in memory consolidation processes. Indeed, animal studies (Giuditta et al. 1995) and human studies (Ficca et al. 2000) suggest that information processing through consecutive iterations of NREM-REM sleep cycles plays a pivotal role in the off-line consolidation of recent memories.

In this respect, and as acknowledged by Llewellyn, several authors already ascribed complementary roles to the main sleep states. For instance, it was proposed that recent memories are protected against retroactive interference during NREM sleep and then consolidated during REM sleep (Scrima 1982) or at the molecular level that NREM slow-wave sleep (SWS) promotes post-acquisition processes of neuronal reverberation, whereas transcriptional events necessary for long-term memory consolidation are sparked during the subsequent REM sleep. Hence, converging data support the hypothesis of sequential processes of memory consolidation during sleep (Giuditta et al. 1995). More generally, the selection of adaptive memory traces and the weakening of nonadaptive ones may predominate during NREM sleep, the selected memory traces being then consolidated during the immediately ensuing REM sleep episode.

Besides differences in conceptualizations, most proposals converge to suggest that the succession of cerebral states

corresponding to a typical sleep cycle (i.e., NREM followed by REM sleep) influences the consolidation of recently learned information in long-term memory. In contrast with this prevailing view, Llewellyn argues that episodic memories are first processed during REM sleep and then consolidated during NREM sleep. This position raises several questions that would need to be addressed.

First, if it is true that episodic memories are elaborately encoded during REM dreaming and then consolidated as “junctions” during NREM sleep, it logically entails that REM sleep-dependent memory processes would take place *before* those occurring during NREM sleep—that is, in the opposite order of sleep states within a cycle, which also assumes that the first NREM episode within a night of sleep might not play any role in the processing of memories. However, such a hypothesis is invalidated by the abundant literature ascribing a major role to the first NREM sleep episode in memory consolidation (e.g., Gais et al. 2000; Plihal & Born 1997; 1999; Yaroush et al. 1971). Second, and within the continuity of the previous argument, the first sleep cycles in a night are proportionally the richer in NREM (SWS) sleep, whereas the last sleep cycles are the richer in REM sleep. Therefore, consolidation according to Llewellyn would predominantly occur during the first part of the night, whereas elaborative encoding would take place in the second half, again leading to the same logical contradiction.

Notwithstanding sleep physiology, we also found Llewellyn's proposal incongruent with the chronobiological characteristics of dreams production. Indeed, dream contents change as the night progresses: REM sleep mentation is more vivid, more emotional, and bizarre later in the night (Agargun & Cartwright 2003; Fosse et al. 2004; Verdone 1965; Wamsley et al. 2007). Because Llewellyn envisions these features of dream contents as reflections of elaborative encoding processes, elaborative encoding should occur during late REM sleep, thus leaving little time for NREM sleep processes to instantiate the so-called junctions.

Taken together, these elements question the roles attributed by Llewellyn to NREM and REM sleep states. While the succession of sleep stages may not be mandatory for memory consolidation processes (e.g., Scrima 1982), this interplay should be conceptualized and grounded in physiology whenever the differential actions of NREM and REM sleep follow an orderly sequence, as it is the case in Llewellyn's proposal.

Another key concept in Llewellyn's proposal is that novel associations between recent and remote memories are generated through dreaming activity during REM sleep. The evidence presented to us in support of this hypothesis is questionable. Indeed, Llewellyn mostly relies on studies by Wagner et al. (2004) and Walker et al. (2002) to infer a REM dreaming-related ability to create novel associative patterns. However, REM sleep was not specifically tested in the study by Wagner et al. (2004), only the effect of a complete night of sleep deprivation. Furthermore, although Walker et al. (2002) found an association between REM sleep and improved ability in solving anagrams, the implicit rules extracted after a night of sleep were actually already present at encoding (also in Wagner et al. 2004). Therefore, it is disputable whether these studies support the creation of de novo associations during sleep rather than the simple extraction of hidden patterns. Although activation of dopaminergic circuits during REM sleep may indeed favor dreaming and unusual associations (Perogamvros & Schwartz 2012), it is probably more appropriate considering Wagner's and Walker's studies to suggest that (possibly REM) sleep facilitates insight into hidden rules, a process that leads to the construction of novel, higher-level schemas (Walker & Stickgold 2010).

To conclude, Llewellyn's proposal has merits in proposing a synergetic role of sleep stages in memory processes. However, the proposal is also counterintuitive, considering the chronobiology of dreams and the architecture of sleep both within and between sleep cycles over the course of the night. It also

remains disputable whether and how elaborative encoding processes would generate novel associations during sleep.

Dream and emotion regulation: Insight from the ancient art of memory

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Abstract: During dreaming, as well as during wakefulness, elaborative encoding, indexing and ancient art of memory (AAOM) techniques, such as the method of loci, may coincide with emotion regulation. These techniques shed light on the link between dreaming and emotional catharsis, post-traumatic stress disorder, supermemorization during sleep as opposed to wakefulness, and the developmental role of rapid eye movement (REM) sleep in children.

Llewellyn's thorough description of rapid eye movement (REM) dreaming as elaborative encoding for episodic memories provides a convincing argument for the value of the ancient art of memory (AAOM) principles. Our commentary presents a complementary aspect of the dream, arguing that it is not solely "the stuff of memory," but also that of emotion regulation. Although her arguments lack an explicit link to the role of emotion in dreaming, Llewellyn does indirectly provide methods for understanding the process and purpose of emotion regulation in REM dreaming, which we explore in this commentary.

The psychological models of dreaming suggest that dreams are constructed from one's emotional history and serve partly to regulate emotions, because the dreamer is forced to look, feel, and reprocess emotional memory. During a dream, the activation of the medial prefrontal cortex would play a role in the attribution of thoughts and emotions to oneself and to characters and situations of the dream, while the deactivation of the inferior parietal regions would enable the dreamer to experience the dream in the first- and third-person perspectives. This offline role-playing would facilitate the resolution of internal conflict, which some assimilate to an emotional catharsis (Desseilles et al. 2010; 2011a; 2011b; 2012).

During lucid dreams, as in the *method of loci*, the dreamer constructs the dream scene and participates in the action while simultaneously being an observer. The role of the dream scene could, in certain cases, be a task of memory, memorization, recollection, and association. As an Aristotelian catharsis (Desseilles et al. 2011a), this theater-like staging could enable the dreamer to gain an outside perspective on certain behaviors, preoccupations, and problems present during wakefulness. Once lucid dreamers sufficiently identify, they could engage in mechanisms of regulation (functional or dysfunctional) of emotions, such a reappraisal, suppression, or rumination, without having to await wakefulness, as do nonlucid dreamers when they engage in the conscious regulation of emotions based on memories of dreams. The capacity of lucid dreamers to modify the course of their dreams could impact Llewellyn's theory, since she hypothesizes that following the elaborative encoding of recent memories with remote ones during REM dreams, the hippocampus may instantiate internal cortical junctions during non-REM sleep. Lucid dreamers could perhaps control elaborative encoding and thus change the quality of indexing, modifying the associations that could be recovered during wakefulness. The method of loci would therefore facilitate the regulation of emotions through an Aristotelian catharsis during the lucid dream (Zadra & Pihl 1997) by acting

directly on the mnemonic composition and hippocampal indexes. This *online* aspect of mnemonic composition would suggest that the use of the method of loci during wakefulness (enabling a first- or third-person perspective), whether or not combined with the induction of a lucidity during dreams (Stumbrys et al. 2012), could enable the dreamer subsequently to modulate more efficiently the emotional content associated with memories. The nonlucid dream would also play a cathartic role in emotion regulation, with REM sleep reducing the brain's reactivity to waking emotional experiences, simultaneously decreasing the intensity of previous affective experiences and diminishing subjective emotionality on the subsequent day (van der Helm et al. 2011b).

Emotion regulation could also emerge from indexing, which enables a more practical and rapid return of detailed material and facilitates the processing of new material through its anchoring to remote memories. Unsuccessful indexing would therefore lead to a more difficult return to remote memories, which is what Llewellyn suggests, and to poor processing of the material, which would linger freely. The work of bonding and indexing is particularly important in traumatic memory and post-traumatic stress disorder (PTSD), where the hypermemory of a traumatic event is present as much in dreams as in wakefulness. The recurrence of dreams linked to the traumatic event suggests that elaborative encoding and indexing are deficient. In fact, emotional hypersensitivity and endangerment of the self could inhibit elaborative encoding through hyperassociations to other memory episodes, leading to an absence of bonding. The traumatic memory episode remaining isolated and unassociated would thus not be indexed, reduced, and processed. The linking of the traumatic event would need to be carried out during wakefulness, for example by using imagery rehearsal therapy (Harb et al. 2012), so as potentially to modify both elaborative encoding and indexing. In the context of PTSD, Roisin (2003; 2010) considers the exhortation of the desire to live as an essential action in the psychological growth of individuals having suffered a traumatic experience. When this desire resurfaces, post-traumatic symptoms disappear. Roisin therefore seems to link desire to elaborative encoding during wakefulness. Through its emotional salience, desire, like the dream, would contribute to emotional regulation.

Llewellyn's article suggests that we all have supermemorizer talents in our sleep, but not necessarily when awake. Explicit memorization that is largely superior to normal can be accompanied by emotional or social difficulties, like Asperger's syndrome of the autism spectrum (as in Daniel Tammet (Baron-Cohen et al. 2007)), or like savant syndrome (as in Kim Peek (Treffert & Christensen 2005)). Moreover, memorizers and individuals with Asperger's syndrome would not think of these AAOM rules (Tammet 2007) because they do not explicitly use them. Rather, the rules would function autonomously during wakefulness, as they do during sleep in the general population. Perhaps forgetting most of our dreams would serve to preserve our mental *resources* for surrounding stimuli during wakefulness, so as to not be distracted by our inner world. Therefore, could forgetting our dreams be necessary to our cognitive and emotional balance? If the AAOM enables the regulation of emotions through catharsis or indexing, should it remain predominantly nonconscious so as not to hinder social relations?

In addition to remaining at a level of implicit memorization, the use of the AAOM during REM sleep should increase with the quantity of information that confronts the individual. We could imagine that children highly exposed to new information would require increased processing in order to strengthen anchoring and increase their ability to remember. As we know that REM sleep is more predominant in infants (Marcus et al. 2008), we could propose a developmental perspective on the necessity of assimilating a varying quantity of *episodes* (episodic memory) to retrieve. Thus, in addition to forgetting, the increase of anchoring in infants could be necessary to their cognitive and emotional development, particularly in the context of social relationships.

“They who dream by day”: Parallels between Openness to Experience and dreaming

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Abstract: Individuals high in the personality trait Openness to Experience appear to engage spontaneously (during wake) in processes of elaborative encoding similar to those Llewellyn identifies in both dreaming and the ancient art of memory (AAOM). Links between Openness and dreaming support the hypothesis that dreaming is part of a larger process of cognitive exploration that facilitates adaptation to new experiences.

Based on parallels between the hyperassociative phenomenology of rapid eye movement (REM) dreaming (henceforth *dreaming*) and the ancient art of memory (AAOM), Llewellyn theorizes that the function of dreaming is to facilitate elaborative encoding of memories. The AAOM provides a fascinating source of inspiration for theories of dreaming, but it is an optional cognitive technology, taught to many educated people hundreds of years ago but rarely seen today; this raises the question of the existence of more common waking states related to dreaming. We believe a more ubiquitous parallel exists between dreaming and waking, and that elaborative-encoding processes akin to those of dreaming commonly occur spontaneously during wake in the segment of the population high in the personality trait Openness to Experience.

Edgar Allan Poe (1848/1975, p. 649) described creativity by noting, “They who dream by day are cognizant of many things which escape those who dream only by night,” and this epigram provides a good description of Openness, which is one of the five major dimensions of human personality and encompasses traits related to imagination, creativity, and perceptual sensitivity (John et al. 2008). Properly speaking, Openness is half of that major dimension, which is now often labeled *Openness/Intellect*, and describes variation in a general tendency toward cognitive exploration (DeYoung, *in press*; DeYoung et al. 2012).

Openness/Intellect reflects the ability and tendency to seek, detect, comprehend, appreciate, and use information. Whereas the *Intellect* half of this dimension describes engagement with abstract, semantic information, *Openness* describes engagement with sensory and episodic information. Although Openness and Intellect vary together on average, one may find people high in Openness but low in Intellect, and vice versa.

What are the links between Openness and dreaming? First, a simple observation: Openness is the one major personality trait that predicts the tendency to report more dreams and more vivid dreams (Watson 2003). The other links are psychological and neurobiological. Dreaming is “close to imagination” (Nir & Tononi 2010, p. 97), and *Imagination* has been proposed as an alternative label for Openness, which encompasses fantasy proneness (Saucier 1992). Llewellyn proposes that dreaming is an imaginative mnemonic process that identifies associations of recently encoded memories with older memories. Further, these associations are often remote, based on emotional and motivational similarity, or on analogies between specific elements of the memories, rather than on logical connections. Openness strongly predicts the ability to identify remote associations in wake and to engage in *divergent thinking*, the generation of many unusual and creative solutions to problems like “What are all the uses you can think of for a brick?” (McCrae 1987; Silvia et al. 2008; 2009). Both dreaming and Openness appear to facilitate elaborative encoding and thinking outside the box.

These psychological similarities between dreaming and Openness may stem from neurobiological similarities. In REM, the balance of neuromodulators in the brain is dramatically different than in wake. Serotonin, which stabilizes information processing (Spoont 1992), and norepinephrine, crucial for defensive reaction to unexpected events (Yu & Dayan 2005), are almost entirely

suppressed, whereas acetylcholine, centrally involved in learning and neural plasticity, is elevated. In wake, acetylcholine levels are elevated in environments characterized by “expected uncertainty,” in which the organism can predict the utility of learning (Yu & Dayan 2005). Finally, dopamine is not reduced in REM, although its concentration shifts from cortex to striatum, and evidence suggests it is actually necessary for dreaming (Solms 2000). Dopamine potentiates cognitive flexibility and exploration, consistent with the hypothesis that dreaming is a form of cognitive exploration (Peterson & DeYoung 2000). Acetylcholine and dopamine, the two neurotransmitters that appear to play a key role in dreaming, have both been linked empirically and theoretically to Openness (DeYoung et al. 2011; Grazioplene et al. 2013). We are not hypothesizing that people with high levels of Openness have the same dramatically altered balance of neuromodulators seen in dreaming. However, individual variation occurs in all neuromodulators, and we are hypothesizing that the waking neuromodulator balance in those high in Openness is more similar to that of dreaming than it is in those low in Openness. In addition to similarity in neurotransmitters linked to dreaming and Openness, there is also similarity in larger brain systems. Dreaming engages the brain’s so-called default mode network (DMN), which appears to be crucial for all forms of episodic simulation (memory, imagination, perspective-taking), and Openness and divergent thinking are both associated with heightened connectivity in the DMN (Adelstein et al. 2011; Takeuchi et al. 2012).

In one regard, we believe the parallel between dreaming and AAOM may be misleading. The purpose of the AAOM is to improve recall rather than to gain new understanding, and Llewellyn suggests that dreaming shares this purpose. However, she also notes that “elaborative encoding works through exploring meaning, inference, and implications,” and that novelty “determines the extent of elaborative encoding” (sect. 4, para. 5). We believe that the function of this exploration is not simply to improve recall, but to discover potentially useful patterns in experience that had not been grasped previously. (Note that these discoveries need not become conscious to be useful, although both the facilitation of insight by REM [Cai et al. 2009; Wagner et al. 2004] and the prevalence of dream interpretation suggest that they may sometimes become conscious.) Dreaming is likely to be part of the general process of cognitive exploration that facilitates human adaptation to novelty (Peterson & DeYoung 2000). Openness/Intellect reflects individual variation in that process during wake. Llewellyn states that mnemonic connections in dreaming “will be hyperassociational rather than more linear-logical, as in wake” (sect. 4.2.3, para. 2), but not all associations formed in wake are linear-logical. Hyperassociational phenomenology, milder than but directly analogous to dreaming, is a normal experience for those high in Openness. Openness is associated with some increase in risk for psychosis, but nonetheless seems to be adaptive, in part because it facilitates creativity (DeYoung et al. 2012). In dreaming, the brain appears to give free rein to hyperassociative elaborative encoding. In wake, this exploratory mnemonic process is not silenced but merely subordinated, and its degree of subordination varies with Openness.

A hippocampal indexing model of memory retrieval based on state trajectory reconstruction

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Abstract: A method is proposed where static patterns or snapshots of cortical activity that could be stored as hyperassociative indices in hippocampus can subsequently be retrieved and reinjected into the neocortex in order to enable neocortex to then proceed to unfold the corresponding sequence, thus implementing an index-based sequence memory storage and retrieval capability.

A central aspect of the target article is the neocortical junction that is encoded in the hippocampus as an index. Hyperassociative rapid eye movement (REM) dreams could be retained to constitute the hippocampal index. During memory retrieval, elicitation of the appropriate index from the hippocampus by internal or external stimuli enables the subsequent retrieval of cortical content using the index. In the elaboration of this proposal, section 5.1 poses two questions: “How does a non-conscious hyperassociative index trigger conscious veridical episodic (i.e., situated in time and place) output? And how is the conscious output constrained to only the relevant episodic memory?” (para. 1).

Llewellyn then provides a descriptive account of how the hippocampus and neocortex interact to achieve this. However, the functional implementation of such a mechanism is not specified. We can consider an analysis of the functional description of this REM-based hippocampal indexing, and the subsequent memory retrieval, in the concrete context of implemented recurrent network models of cortex that we traditionally have employed in sensorimotor sequence learning (Dominey 1995) and in language processing (Dominey & Ramus 2000; Hinaut & Dominey 2013). In this context, static patterns or snapshots of cortical activity that can be stored as hyperassociative indices in hippocampus can subsequently be retrieved and reinjected into the neocortex to enable neocortex to then unfold the corresponding sequence, thus implementing an index-based sequence memory storage and retrieval capability. This is potentially interesting because it provides a form of validation (if successful) of a mechanism that is provided only as a possible solution in the target article. Such an analysis suggests that the index is not a cortical locus or set of loci, but rather a snapshot of the cortical state at that time which can be used, as stated in the target text, as a cue for retrieval in an auto-associative memory. Before addressing the two questions posed earlier, we can first consider these issues: What is the nature of the neocortical junction, and how can it be used in memory retrieval? This first poses the question of what the nature of a conscious memory is.

Memories will tend to implicate the semantic system, which has been demonstrated to encompass a broadly extended network of distributed cortical areas (Binder & Desai 2011; Binder et al. 2009). In this context, the activation necessary to invoke a memory could involve a fairly massive activation of a large distribution of the neocortex. It has been suggested that the hippocampus integrates distributed cortical activity, fusing this coactivation into a memory trace, and that over time the cortex can become independent of hippocampus, with prefrontal cortex taking over the role of integration for more mature memories (Frankland & Bontempi 2005). This suggests the hippocampus would be able to re-instantiate a prior state of cortical activation. Once this state of activation is instantiated, the cortex would then play out the corresponding memory.

We have modeled cortex as a dynamic system of leaky integrator neurons with local recurrent connections (Dominey 1995; Hinaut & Dominey 2013). Such networks have interesting dynamics. In particular, the internal state follows a trajectory such that if the system is put into a state along an existing trajectory, then the system will tend to follow that trajectory from the given state as a point of departure. Based on this property, the state of activation of cortex could be stored as an index by the hippocampus and then reinjected into the cortex. In such conditions, the cortex would then continue in the appropriate trajectory from that point onward, thus “replaying” the corresponding dynamic memory trace. Importantly, such systems display some robustness to noise, but also a form of degraded behavior: if the injected

pattern deviates sufficiently from the intended pattern, then the resulting trajectory will deviate from the intended trajectory. This implies that the pattern of activity that is played into the cortex from the hippocampus should be as accurate and complete as possible.

In other words, if a specific memory is to be recalled, then it should be indexed in the most specific manner possible. This suggests, as indicated by Llewellyn, that hippocampus keeps an index of multiple loci that can be used in episodic memory retrieval. If sufficient loci are activated, then the cortex will enter into a state from which a dynamic trajectory will then unfold.

This trajectory can be considered to correspond to the narrativization of experience into a linear sequence. The question that remains, with respect to junctions, is if a trajectory proceeds through a junction, how can the system ensure that it does not deviate onto a different trajectory that traverses that junction? That is, how is the system constrained to recall only the intended or relevant episodic memory? From the perspective of the dynamic systems and recurrent network models that we manipulate, the more that the pattern of cortical activity—entrained by the hippocampal index—is complete and corresponds to the memory to be recalled, the more that the resulting trajectory of cortical activity will correspond to the unfolding of the corresponding episodic memory.

This comment thus advocates the characterization of the cortex as a dynamic system, with state trajectories that can be “replayed” by putting cortex into a past state via hippocampal inputs. This provides a mechanism that is consistent with Llewellyn’s proposal and provides potential responses to the questions: “How does a non-conscious hyperassociative index trigger conscious veridical episodic (i.e., situated in time and place) output? And how is the conscious output constrained to only the relevant episodic memory?”

Mnemonic expertise during wakefulness and sleep

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Abstract: We studied the world’s most distinguished experts in the use of mnemonic techniques: the top participants of the World Memory Championships. They neither feel the use of mnemonics to be dreamlike, nor does their REM sleep differ from mnemonic-naïve control subjects. Besides these empirical data, also theoretical considerations contradict an isomorphism between features of REM sleep dreaming and mnemonic principles.

Mnemonic techniques have been valued since ancient times but have lost attention dramatically for decades. Llewellyn’s target article on a possible role of mnemonic principles (ancient art of memory [AAOM]) acting during rapid eye movement (REM) sleep to aid episodic memory processing is therefore a timely and important endeavor. Here we aim to demonstrate that one promising way to test these ideas is to study users of mnemonic techniques, both novices—that is, naïve subjects who have been systematically taught mnemonic strategies—and experts who have trained the use of mnemonics for several years. One group of subjects provides a unique opportunity in this regard: Participants of the annual World Memory Championships regularly demonstrate their mastery in mnemonic techniques by

memorizing astonishingly large amounts of information (Maguire et al. 2003). During the last two years, we studied the world's most successful memory athletes, who all credited their performance to deliberate training in mnemonics.

A simple qualitative test of the REM-AAOM hypothesis is the question of whether the application of mnemonics actually feels like dreaming: If REM sleep dreaming implements or is isomorphic to mnemonic principles, the use of mnemonics should feel dreamlike during wakefulness. This should be true in particular for the more experienced users of mnemonics. We asked 34 mnemonic experts (aged 32.1 ± 11.3 years, 12 female) in the top 100 memory-sports-world rankings and 37 mnemonic novices (aged 24.4 ± 4.9 years, 9 female) who participated in an introductory course in mnemonic techniques whether they felt the application of mnemonics to be dreamlike, on scale of 1 (totally dreamlike) to 7 (not dreamlike at all). Neither group felt the application of mnemonics to be very dreamlike, with the mnemonic experts' ratings being even slightly (though nonsignificantly) shifted more to the nondreamlike side of the scale (4.9 ± 1.5 vs. 4.5 ± 1.5 , $t = 1.1$, $p > 0.2$).

A test on the neurophysiological level is to compare the REM sleep of mnemonic experts and control subjects naive to mnemonics. If an essential function of REM sleep is to apply mnemonics on recent memory traces, then it should differ depending on how much information was learned before sleep and whether this information was already encoded mnemonically or without the use of mnemonics. We investigated 16 mnemonic experts (aged 27.1 ± 9.5 years, 6 female) in the top 50 of the memory-sports-world rankings with polysomnography, both after a day without memory-related activity and after an intense learning session of several hours during which they applied mnemonics on a broad variety of declarative information, and compared them with closely matched controls (aged 27.4 ± 8.5 years, 6 female) without any experience in mnemonic techniques (Dresler et al. 2012).

Despite a huge difference in mnemonic expertise and memory load, we did not find a significant difference in REM sleep duration between the groups ($F=1.5$, $p > 0.2$) or between the learning conditions ($F=0.4$, $p > 0.5$) and no interaction effects ($F=0.9$, $p > 0.3$). Since REM density has been proposed to be implicated in memory processing and to provide a marker of learning potential (Smith et al. 2004), we also analyzed this variable, but also did not find a differences between the groups ($F = 1.0$, $p > 0.3$) or conditions ($F = 0.2$, $p > 0.6$) and no interaction effects ($F = 0.2$, $p > 0.6$). For details, see Tables 1 and 2.

The results of both tests with mnemonic experts do not support the REM-AAOM hypothesis. In our view, this is no surprise, since despite several intuitively convincing similarities between REM sleep dreaming and mnemonic techniques, the two also manifest essential differences. One important aspect of mnemonics, like the method of loci, is to provide a systematic structure that reliably helps to retrieve the complete set of to-be-remembered information. However, REM sleep dreams, with their frequent discontinuities and indeterminacies, do not provide such systematic structure, but rather consist of a chaotic progression of only loosely related elements.

An essential function of mnemonics is to provide easily accessible retrieval cues that help to recollect less accessible information. Mnemonic retrieval cues associated with new information during REM sleep, however, are hard to access after awakening, because

Table 1 (Dresler & Konrad). *Time spent in REM sleep, given as mean minutes \pm standard deviation*

	Mnemonic experts	Controls
Nonlearning condition	92.1 \pm 24.8	93.6 \pm 16.4
Learning condition	84.2 \pm 22.5	95.4 \pm 18.4

Table 2 (Dresler & Konrad). *REM density, given as mean count of rapid eye movements per minute of REM sleep \pm standard deviation*

	Mnemonic experts	Controls
Nonlearning condition	4.7 \pm 1.2	4.3 \pm 1.6
Learning condition	4.5 \pm 1.2	4.3 \pm 1.2

of dream amnesia. According to the REM-AAOM hypothesis, somehow they do their job anyway – just on a nonconscious processing level. The mnemonic mechanism seems to be somehow inverted here: During wakefulness, mnemonics provide easily accessible retrieval cues to activate otherwise inaccessible memories, whereas during sleep the REM-AAOM hypothesis presumes them to provide inaccessible retrieval cues that in most cases do not even reach a conscious level when the corresponding memory traces are successfully retrieved. We find this hardly convincing.

Another problem of the REM-AAOM hypothesis is its focus on episodic memories: Defining properties of episodic memories already include several mnemonic features like representation in the form of visual images, having a personal perspective, being represented in given order, or being recollectively experienced when accessed (Conway 2009). Even though some of the mnemonic experts that we studied reported that sometimes they would encode also proper episodes mnemonically (e.g., if completeness of details is important), typical applications of mnemonics are discrete or abstract sets of information without episodic structure – for example, telephone numbers or shopping lists. Roughly speaking, mnemonics transform such unrelated bits of information into episodelike structures – for example, imagined stories or mentally travelled routes.

The REM-AAOM hypothesis hence faces a dilemma: Either it proposes that REM sleep mnemonically reprocesses only information that is already episodically structured – in which case the application of mnemonics loses much of its strength – or it widens its focus on declarative memory in general, including also information without proper episodic structure – although for these kinds of stimuli, several studies were unable to find an essential role for REM sleep in memory processing (e.g., Dresler et al. 2011; Genzel et al. 2009; 2012; Rasch et al. 2009).

In conclusion, both empirical data and theoretical considerations contradict the REM-AAOM hypothesis. The world's leading mnemonics users do not feel the application of mnemonics to be dreamlike, and their REM sleep does not differ from mnemonics-naïve controls. The REM-AAOM hypothesis focuses on information that normally does not need to be encoded mnemonically, and that is proposed to be encoded mnemonically in a cognitive environment that is not well suited for the application of mnemonics.

Beware of being captured by an analogy: Dreams are like many things

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Abstract: Classic traditions have linked dreams to memory (e.g., “dreaming is another kind of remembering” [Freud 1918/1955]) and

modern notions like *implicit memory* subsume dreaming by definition. Llewellyn develops the more specific thesis that rapid eye movement (REM) dreams, because of their similarities to mnemonic techniques, have the *function* of elaboratively encoding episodic memories. This proposal is premature, requiring exigent testing. Other analogs of dreams, for example, jokes, do not invoke function but do contribute to dream science.

I would like to raise the question of whether attempts, like the target article's, to spell out the *function* of dreams tend to be premature just-so stories that show insufficient deference to the *null hypothesis* at the beginning and a neglect of *falsifiability* at the end. In this case, in particular, an analogy – ancient mnemonic techniques – is shown to bear similarities to consolidation processes presumed to be implemented by rapid eye movement (REM) dreaming. My question is whether the mnemonic analogy can serve as a scientific model that both informs and delimits the REM-function hypothesis of dreaming. Actually, dreams are like many things, including aphasia, subliminal perception, hysterical symptoms, schizophrenia, jokes, daydreams, poetry, Bartlettian and Freudian reconstruction, and, yes, also mnemonic techniques.

Llewellyn does not try sufficiently to test out her proposals against modern research findings in dream psychology (an admittedly sparse corpus, in view of the massive neglect of the subject of dreams by cognitive psychology for decades). Still, some specific research-based questions come to mind. How does the mnemonic analogy bear on the important modern finding – glancingly alluded to in her article (sect. 4.2.4, para. 5) of a U-shaped function describing the incorporation of awake experiences in dreams over, roughly, a one-week window (with maximal dream incorporation occurring a day or two after awake experiences – the *day-residue effect* – and about a week after the awake experiences) (e.g., Blagrove et al. 2011a; Nielsen & Powell 1988a; Nielsen et al. 2004). Or, how would the mnemonic hypothesis handle individual differences in the speed with which significant life events are reflected in dreams – for example, an amputation being reflected almost immediately in the dream images of the self in about one-third of patients, weeks or months later in another one-third, and not at all in still another one-third (Brugger 2008; Mulder et al. 2008). Or, how would the mnemonics-dream analogy deal with the finding that REM and dreams can be doubly dissociated such that dreams can occur without REM and REM can occur without dreams (Nir & Tononi 2010; Solms 2003a; Solms & Turnbull 2002)? Obviously, the dream-mnemonics hypothesis needs some serious testing (as Llewellyn would agree; see sect. 7).

It is relevant to consider where other dream analogs lead scientifically. Freud's *On aphasia* (1891/1953), which appeared only a few years before Freud was obliged to abandon neuroscience and become a psychologist, is an especially powerful model for dreams and other twilight phenomena. It prefigures Freud's central psychological contributions, including his work with Joseph Breuer, *Studies on hysteria* (1895/1955), in which, it might be noted, a *memory theory* of hysterical symptoms is proposed ("symptoms are mainly reminiscences"), and a *memory therapy* is developed for recovering the latent content of body memories (procedural memories, symptoms) into conscious recall. Within a few years, Freud generalized this hypermnestic therapy to dreams, which according to him are "hypermnesic" and which are subject, like hysterical symptoms, to interpretation in which surface semantic contents ("manifest contents," "the façade") are interpreted for deeper semantic contents ("latent contents," "hidden meanings") (Erdelyi 1985; 2012; under review; Freud 1900/1953).

Many of the aphasia phenomena observed in the neurological clinic are clearly not memory consolidation techniques but outright failures of normal memory. For example, "fusions" (Freud 1891/1953, p. 22) of different elements (within few years to be known in psychoanalysis as *condensations*) are often obtained – for example, *Vutter* for *Vater* (father) [and] *Mutter* (mother) – along with *displacements* of meaning (e.g., *pencil* is rendered as

pen, or *Berlin* as *Potsdam*). Also, target items that are inaccessible to *declarative memory* sometimes appear as *procedural enactments* (e.g., *cutting motions* for the inaccessible word *scissors* [Werner 1956, p. 349]). It is unlikely that memory errors of this sort have the function of consolidating memories; on the contrary, these errors, as in dreams, probably arise from memory *defects* resulting from *resource insufficiency* (Erdelyi 2012; under review). The very same kinds of errors are found in subliminal perception (Bartlett 1932; Erdelyi 1996; 2012; under review; Fisher 1988; Pötz 1917; Werner 1956).

Jokes, on which Freud (1905/1958) published a monograph only a few years after the *Interpretation of dreams*, are usually ignored in both the psychoanalytic and experimental literatures but actually provide a powerful methodological and theoretical tool for the understanding of twilight phenomena. Freud himself thought of jokes as significantly homologous to dreams – the *dream-work* distortions (*omissions*, *hints* and *allusions*, *displacements*, *condensations*, *plastic* [imagistic] *representation*, *dramatization* [behavioral or procedural enactments], and *symbolization*) are the same in jokes, in which context he called them the *joke-work*. *Primary-process* cognition (e.g., hyperassociativity and wishful thinking; failures of logic, of reality testing, and of linear time; the coexistence of opposites; concretistic representation; and the absence of morality) are prevalent in dreams and in jokes (also, in schizophrenic thinking). Through jokes, a "psychophysics of the third ear" can be implemented that proves jokes – and dreams by extension – are not "transparent": Sensitivity to latent contents, which may increase over time with effort, can be precisely measured (e.g., through the sensitivity index, *d'*) and marked individual differences demonstrated. (Some of us are more insightful to latent contents than are others [e.g., Bergstein & Erdelyi 2008].) Jokes, also, have powerful methodological implications for mainstream content-analytic approaches to dream meanings. For example, jokes *prove* that we can reliably count meanings in the manifest content and miss the meaning that counts in the latent content (by not "getting" the joke). The joke-dream analogy has not, however, been parlayed into a ludic-function hypothesis of dreaming.

My basic point, in conclusion, is not to cast doubt on the surface resemblances between mnemonic techniques and dreams but to raise questions about what new scientific contribution this particular analogy offers for the understanding of dreams. The mnemonic analogy need not be parlayed, and perhaps should not be parlayed without exigent testing, into a mnemonic theory of dreams.

The seahorse, the almond, and the night-mare: Elaborative encoding during sleep-paralysis hallucinations?

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Abstract: Llewellyn's proposal that rapid eye movement (REM) dreaming reflects elaborative encoding mediated by the hippocampus ("seahorse") offers an interesting perspective for understanding hallucinations accompanying sleep paralysis (SP; "night-mare"). SP arises from anomalous intrusion of REM processes into waking consciousness, including threat-detection systems mediated by the amygdala ("almond"). Unique aspects of SP hallucinations offer additional prospects for investigation of Llewellyn's theory of elaborative encoding.

Sleep paralysis (SP) involves temporary immobility at sleep onset or offset, while individuals are awake and aware of their

surroundings (American Academy of Sleep Medicine 2001; Hishikawa 1976). SP arises from anomalous intrusion of REM-related motor inhibition and hallucinoid imagery into waking consciousness (Hishikawa & Shimizu 1995; Takeuchi et al. 1992). Across diverse samples and measures, SP hallucinations reliably fit three factors (Cheyne & Girard 2004; 2007): An ominous felt presence forms a core intruder experience, accompanied by multisensory hallucinations. *Incubus* experiences instantiate the intruder as perched on the chest, suffocating the experiencer or committing physical or sexual assault. *Vestibular-motor* experiences comprise illusory movement, vestibular sensations, and more blissful out-of-body phenomena. Despite the history reviewed by Llewellyn that supports contributions of memory to dreaming, SP hallucinations are generally modeled as epiphenomena of REM-induced activation of amygdala and emotional brain, sensory, and associational posterior brain regions, with reduced prefrontal monitoring (Cheyne & Girard 2007; 2009). Llewellyn offers an interesting perspective that SP hallucinations might also reflect elaborative encoding.

SP experiences appear to be consistent with the mnemonic principles applied by Llewellyn to REM dreaming: dramatic/bizarre association, visual complexity, imagination, emotional arousal, narrative, embodiment, organization, movement, and spatial association. Nonetheless, note that SP hallucinations and dreams diverge in some ways. Although dream reports and SP hallucinations are primarily visual and auditory, the latter involve more substantial tactile, physiological, and vestibular-motor experiences. Whereas dream imagery is entirely endogenous, unconstrained by sensory input, SP hallucinations present a unique interface between perception, imagination, and expression of internal representations (Girard et al. 2007). Half of SP experiencers maintain their ability to open their eyes and perceive their surroundings. Hallucinations overlaid on this environment are perceived with a vivid sense of external reality. SP hallucinations are also distinguished as more terrifying, vivid, complex, and multisensory than other forms of hypnagogic imagery (Cheyne et al. 1999). The potential to test memory for aspects of the real environment and how these are integrated with memory for hallucinatory experiences offers an interesting prospect for investigation. It would also be interesting to code and compare SP narratives with reports of dreams and waking episodic memories.

Novel binding of episodic memories to form hyperassociative dream scenes depends on an underlying commonality. As in Llewellyn's example, fear provides such an overarching theme for dream narrative and is especially common and extreme during SP episodes (Sharpless et al. 2010). Cheyne and Girard (2007) proposed that a threatening felt presence forms a core delusion from which SP hallucinations elaborate. Experiencers often rate the terror of intruder and incubus hallucinations "off the scale." This fear is thought to arise from REM activation of the amygdala and extended threat-activated vigilance system in the context of waking consciousness while experiencing ominous hallucinations, helplessly paralyzed, typically supine in the dark. Cheyne and Girard (2007) suggest that REM initiation of this vigilance system also offers a model for thematic organization of dreams more generally. Incorporating Llewellyn's proposal, it might be worthwhile to consider the amygdala's role in emotional enhancement of recollection (Sharot et al. 2004) and that, via the hippocampus (Sharot et al. 2007), fear might serve an integrative mnemonic function.

Llewellyn proposes that encoding of recent memories is enhanced via hyperassociations with emotionally salient remote memories. Aspects of SP have been associated with a history of trauma (Abrams et al. 2008) and, in at least one case, related to remote memory of childhood abuse (McNally & Clancy 2005). Such cases may provide insight into the nature of hyperassociative binding. Although core elements are consistent, incubus assaults take various culturally specific instantiations such as old-hag attacks, alien abductions, spirits, and demons (Cheyne et al. 1999), sometimes with fatal consequences (Adler 2011).

Llewellyn differentiates nonconscious episodic hyperassociations bound during REM from conscious semantic associations formed in waking and NREM sleep. The unique mix of REM and waking in SP may evoke not only episodic associations, but integrate semantic representations. SP narratives might then reflect a product of elaborative encoding of prior experiences and instantiations of culturally relevant schema. It might be informative to explore the extent to which SP experiences are guided by cultural fables and, conversely, whether elaborative encoding during SP shapes memories that influence cultural accounts.

What individual and contextual factors give rise to the threatening intruder versus blissful vestibular-motor experiences? How do personal encounters and navigational experience relate to dreaming and SP associations involving persons and places? Llewellyn reminds that self-identity relies on coherent autobiographical memory. Whereas dreams involve first-person perspective from an embodied, agential self, vestibular-motor hallucinations include out-of-body experiences. Perhaps elaborative encoding of movement-related memories in the form of typically nonconscious hyperassociations during anomalous waking paralysis challenges the continuity of body and "self." Spatial attributes of intruder and vestibular-motor hallucinations have been linked to intrinsic biases in sensory and motor function (Girard & Cheyne 2004; Girard et al. 2007). These findings suggest that place associations might not relate solely to hyperassociations with remembered places, but depend in part on individual differences in sensorimotor functions.

Given the conscious state during SP episodes and ability of individuals to recall their experiences vividly, future research should probe relations between the waking "night-mare" and episodic memories. Elaborative encoding predicts that cuing this associative network should enhance retrieval of linked memories. On the other hand, disruption of normal differentiation between waking and stages of sleep can impair memory and cognition (Terzaghi et al. 2012). Although SP is considered common among cognitively intact individuals, relations between SP and cognitive abilities lack systematic study. Whereas Llewellyn highlights the hippocampus and binding of recent and remote memories, the cognitive domains involved are also implicated in more extended brain networks supporting not only memory of the past but also episodic simulation of imagined future events (Addis et al. 2009). Thus, processes underlying elaborative encoding might function not only to strengthen episodic memory, but also to create novel imaginative scenarios for adaptive activation and honing of neural systems, such as those involved in threat detection (Boyer & Bergstrom 2011).

Ontological significance of the dream world

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Abstract: Sometimes while sleeping we find ourselves thrown amidst an authentic, albeit bizarre, world. The process of integration by means of which memory elements might be fabricated into a seamless world indistinguishable from the world of waking life is not explained by Llewellyn, who focuses instead on the elaborative encoding of memories. Ontological implications of the sometimes indiscernibility of wake and dream worlds are considered.

Some dreams are thought-like, whereas some are foggy and vague, but sometimes dream worlds are so vivid, so authentic, that on waking we have to reason out that "it was only a dream." We may find ourselves while dreaming thrown amidst a sometimes fantastic yet utterly real world. ("Thrownness" is the sheer finding oneself always already amidst some world or other

[Heidegger 1999].) That it only “seems to be real” is something we add in retrospect.

Llewellyn tells us, as did Freud (1899/1999) more than a century ago, that “the stuff of dreams is the stuff of memory” (abstract) and that hyperassociated memories (cf. Freud’s “primary process”) are integrated into compositional wholes that have never been present to the senses. (Freud, too, called his dream theory “compositional.”) Memory elements are “merged and fused to construct visual scenes” (sect. 1, para. 2), which are experienced as realistic.

Hyperassociations wrought between episodic memories through elaborative encoding engender a fabricated visual image. (sect. 8, para. 3)

This often bizarre, composite [dream] image has not been present to the senses; it is not “real” because it hyperassociates several memories. (abstract, para. 2)

That the bizarre composite image is not real is a detached assessment made by a judicious waking self, not by a dream self frantically running for his life from a dream tiger! As Llewellyn states regarding her quicksand dream, “I never doubt that the events portrayed are actually unfolding in ‘real time’ before my eyes” (sect. 4.2.3, para. 1).

But how a relating, binding, integrating, compositing, merging, fusing, constructing, engendering, fabricating, synthesizing process might work on a mishmash of elaboratively encoded memories so as to hoist an *authentic seamless world at times indistinguishable from the world of waking life* is left unexplained by Llewellyn. To the deconstructive eye, the very proliferation of such terms, all applied by Llewellyn to basically the same idea, signals something awry in her argument: an emphasis on the cognitive at the expense of the perceptual.

Since some dream content is easily seen as a revival of memory traces, the lacuna in the argument is easily passed over. The sun sparkling on the water, children playing on the beach...these she has likely seen previously, and it seems plausible that this part of the dream could be merely revived and composited memory images...but then a grown-up throws a child across the sand; the child lands on his or her ear and disappears into the sand; another child/baby is thrown...so vividly real is the quicksand that Llewellyn wakes up terrified! Surely Llewellyn has never seen such a specific scene in the past. How might one’s thrownness amidst an authentic, unique, unified world during dreaming be achieved from a set of episodic disparate memory traces, whatever their hyperassociation?

That world thrownness during dreaming (which may even be consciously created in the case of “lucid dreaming” [LaBerge 1985] can be indiscernible from that of waking should give us pause: Indiscernibles demand the same explanation. If the dreamer can find herself thrown amidst an authentic world when sensory informing is shut down, then this raises the most peculiar and frightening possibility that there is no world actually out there in waking either, despite our always finding ourselves already amidst one. Both waking and dreaming worlds might be continually created *de novo*, a “formative creativity” (Globus 1987), rather than transformative of sensory inputs and memory traces.

If world thrownness is a formative construction, this need not start us down a slippery slope to a God-dependent idealism along Berkeleyan solipsistic lines (Foster 1982) or to an idealistic Borgesian metaphysics (Borges 1998). I have proposed instead a species of monadology in which physical reality is strictly quantum *at all scales*, an “abground” (Heidegger 1999) closed to observation, whereas the presencing world is a “dis-closure” constituted by living dissipative brains operating with quantum degrees of freedom (Globus 2003; 2009) under the logic of quantum thermofield brain dynamics (Vitiello 1995; 2001).

The dream world, I suggest, is not a cognitive compositing by a rapid eye movement (REM)-sleepy *bricoleur* using the hyperassociated memory trace materials at hand, not a transformative creation but an episodic formative process out of the “unknowable and unspeakable” (Bell 1987) abground of the quantum realm.

The wake world, too, is a dis-closure, but with the added benefit of an input operator on the disclosive process. In that the fantastic dream world is so ephemeral and quickly forgotten, we take it to be cognitive play and miss its profound significance. The dream is *via regia* to ontology.

A three-legged stool needs a stronger third leg

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Abstract: Whereas the target article stresses the neurobiology and psychology of dreams, this commentary emphasizes that the role of dreams in emotional integration and adaptation contributes to a fuller understanding of dreaming and memory. The dream presented in the target article is used, within the constraints of space, as a possible example of a broader approach to dream material.

The target article is a remarkably scholarly, comprehensive discussion of memory research (see the lengthy list of references) and its relation to rapid eye movement (REM) sleep. Llewellyn uses as an organizing principle the ancient art of memory (AAOM) – the way our ancestors supported memory before the age of print and the Internet. Significant memory was not just learning by rote but an active process requiring creative activity. Llewellyn likens the activity in REM sleep to AAOM. She accepts the idea that dreaming is mainly a phenomenon associated with REM sleep and proposes that dreams represent a vivid example of AAOM in action. She bases her arguments on her extensive review of “neurobiology and psychology” (sect. 1, para. 4), which has clearly supported the role of REM sleep in memory organization. The point of this commentary is to suggest that neurobiology and psychology are two long and strong legs of a three-legged stool, but that to fully understand the role of REM sleep and dreaming a third leg must be equally strong.

This third leg, I would contend, is the information that has been accumulated from our clinical and research work with human subjects’ dreams. Although Llewellyn touches on research on human subjects dreams, this information as presented in the target article lacks the emphasis and depth of the other two legs. Early studies of REM sleep and memory proposed that REM sleep was involved in memory consolidation (Greenberg 1970). This turned out to be accurate, to some degree, but it also eventually proved to be more complicated than just consolidation (Greenberg et al. 1970). Some types of memory seemed to be REM dependent while others didn’t.

Llewellyn uses the semantic-versus-episodic distinction. Greenberg & Pearlman (1974) prefer Seligman’s (1970) prepared-versus-unprepared-learning formulation as an effort to explain why word-list or one-trial learning do not seem to require REM sleep whereas more complicated tasks for animals and emotionally adaptive requirements for humans are REM dependent (Greenberg & Pearlman 1974). This formulation about differences in types of information that require REM sleep points to the idea that, as the author and many earlier writers (Breger et al. 1971; French & Fromm 1964; Greenberg & Pearlman 1975) suggest, there is an “integration of recent memories with remote parts of associative memories or networks.” More important is the nature of such memories. Llewellyn refers to literature suggesting that the emotional dimension is important in the memories. Llewellyn does not really spell out the actual nature of this emotional dimension, however, and I would like to remind readers of some research that makes this clearer. Llewellyn points to Freud’s statement that dreams have images from the previous day’s experience. However, Freud (1900) talked about these images as indifferent. It would seem

that this is one place where Freud did not really get it (Greenberg & Pearlman 1978). French and Fromm (1964) pointed to dreams and their manifest content as containing important images related to the patient's "focal conflict." We (Greenberg & Pearlman 1978) demonstrated how in Freud's own classical "Specimen dream," where he again talks about indifferent day residue, he misses the very emotionally important day residue. That dream, in the manifest content, actually portrays an event – a failed operation on a patient – that was so very important to Freud's self-esteem. We also presented findings from the sleep lab for a patient in psychoanalysis (Greenberg & Pearlman 1975). Again the manifest images relate to emotionally significant issues for the patient. The results of our studies (Greenberg et al. 1992) suggest that what is in the dream is emotionally significant and that what is emotionally significant from waking life is what appears in the dream.

If one considers these findings meaningful, then the statement "frustrating dearth" of evidence on dream construction and its possible functions" (sect. 1, para. 2) is missing the point. Only in the world of nonclinical research can one miss the connection (bridge) between the clearly demonstrated and pretty much accepted role of REM sleep in memory and the idea that the kind of memories integrated in human dreams are mainly connected with the organization of emotionally meaningful and active issues with which the dreamer has been struggling while awake and continues to try to resolve during dreaming. Dreams show clearly how the dreamer sometimes succeeds in integrating and resolving the waking issues or at other times fails to integrate and has nightmares or repetitive dreams that fail to show any resolution (Greenberg et al. 1992). These ideas build on the early and much more cognitive proposals about REM sleep and memory consolidation. An example of how this might be approached can be considered in relation to the "Quicksand" dream in the target article. This is presented as an example of a way to think about dreams and the day residue rather than a considered demonstration of the emotional salience of the dream.

One should approach a dream within the context of its occurrence. In this case, Llewellyn has chosen to present the dream in the context of proposing an important, elaborate framework for understanding the operation of memory functions in dreams. Her effort is impressive both in the amount of literature she has mastered and in the quality of her ideas. I do not think it is any stretch to suggest that this effort has been a major preoccupation and concern of hers (only she can confirm this) and that one might wonder how this might show up in the dream. Because of space limitations, I can only suggest that one might think about her efforts to create a new *bridge* in our thinking about dreams and perhaps her fear, as she struggled with this enormous effort, that she might fail and be swallowed by the quicksand – or, put another way, will anyone buy her new theoretical house? The story in the dream and her associations certainly encompass great hopes and great fears.

This commentary is a very sketchy presentation of ideas about a fuller approach to the understanding of dreams, which might be added to Llewellyn's extremely thorough and well-presented discussion. I hope these ideas will make the third leg as substantial as those of neurobiology and cognitive psychology.

The ancient art of memory

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Abstract: Revision of Freud's theory requires a new way of seeking dream meaning. With the idea of elaborative encoding, Sue Llewellyn has

provided a method of dream interpretation that takes into account both modern sleep science and the ancient art of memory. Her synthesis is elegant and compelling. But is her hypothesis testable?

Why are dreams strange? Why are they so difficult to remember? And what is their function? We still do not really know the answers to these fundamental questions, which Sue Llewellyn addresses in her provocative article on dreaming as elaborative encoding. Besides being a forceful reminder of the ancient art of memory, I appreciate the effort to tie this tradition to modern science in an integrative way. For me, the approach links quantitative studies of dream bizarreness (Hobson et al. 1987), the neurophysiology of rapid eye movement (REM) sleep (Hobson et al. 2000), and the experimental study of sleep and memory (Stickgold et al. 2001).

In essence, Llewellyn is telling us that dreams are bizarre because their content is scrambled by the altered physiology of REM sleep (low aminergic, high cholinergic tone), which allows fragments of the dream to be reordered to facilitate the efficient storage of emotional salient information. This theory is capital because it allows us to retain the idea that dreams are, somehow, meaningful while setting aside the unlikely suggestion of Freud that the function of dreaming is to disguise and conceal unacceptable wishes to protect consciousness (Hobson and McCarley 1977; McCarley and Hobson 1977).

Llewellyn's elaborative encoding theory of is more compatible with the completely opposite view that REM sleep and dreaming are positive collaborators that shape and update waking consciousness (Hobson 2009). My own theory of REM dreams as protoconsciousness is not entirely independent of the idea of elaborative encoding. In fact, the two ideas are not only theoretical cohesive but mutually enhancing by providing a theoretical mechanism by which diurnal waking experience could be integrated with what I take to be the evolutionary memory by which the genome creates REM as an epigenetic program of virtual reality for the fetal brain.

So the good news is theoretical coherence of an entirely novel sort. The bad news regards testability. For elaborative encoding to be more than literary window dressing, it is essential to propose experimental tests to prove it wrong, and I must confess that I do not see how this can be done. Anecdotal self-analysis will not do here. We must not tolerate neo-Freudianism, no matter how brilliant. Will Sue Llewellyn, the experimentalist, please stand up?

REM sleep and dreaming functions beyond reductionism

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Abstract: Brain activation patterns and mental, electrophysiological, and neurobiological features of rapid eye movement (REM) sleep suggest more functions than only elaborative encoding. Hence, the periodic occurrence of REM sleep episodes and dreaming may be regarded as a recurrent adaptive interference, which incorporates recent memories into a broader vital context comprising emotions, basic needs and individual genetic traits.

The target article makes a parallel between rapid eye movement (REM) sleep dreaming and principles of the ancient art of memory (AAOM), thus proposing a role for REM sleep dreaming state in elaborative encoding of episodic memories. First, in the target article, Llewellyn argues that REM sleep dreaming renders recent memories more distinctive through novel and meaningful associations with emotionally salient and remote

memories. Second, Llewellyn goes on to predict how recent episodic memories are further configured in the brain through dreaming imagery. This concept further challenges the enigmatic nature of REM sleep and its dreaming. Similar to previous theories of sleep, the inevitable reductionism inherent in the concept of the target article leaves unresolved questions. The critical issue for milestone hypotheses for REM sleep dreaming is therefore to avoid as much as possible “surprise,” “free energy” costs, or redundant “prediction errors,” as posited by another recent concept, according to which REM sleep dreaming and phenomenology may subserve basic adaptive functions beyond memory reprocessing such as free energy minimization (Hobson & Friston 2012, p. 87).

Even if the AAOM principles are regarded as a focus in the cognitive domain in the context of already existing more fundamental theories of REM sleep (e.g., Hobson 2009; Hobson et al. 2000; Jouvet 1998), there is still experimentally driven and fact-based information that needs to be reconciled.

Recent human studies indicate that REM sleep electroencephalographic (EEG) signatures are not merely associated with memory encoding and consolidation. Whereas theta (5- to 7-Hz) REM sleep electroencephalographic (EEG) activity has been associated with both dream recall from REM sleep (Marzano et al. 2011) and consolidation of only emotional memory (Nishida et al. 2009), gamma (more than 25- to 30-Hz) REM sleep EEG activity has been assumed to be associated with affective mental states (Marshall et al. 2011; van der Helm et al. 2011b). Hence, frequency-specific EEG activities of human REM sleep (Cantero et al. 2003; Llinás & Ribary 1993) may support its functions dissimilarly. A recent rodent study indicates that theta oscillations during REM sleep may produce synaptic downscaling in the hippocampus (Grosmark et al. 2012). Along with the observed association between human theta EEG rhythm and successful dream recall in REM sleep (Marzano et al. 2011), this finding conforms well with either the kind of elaborative encoding proposed in the target article or the need for room to minimize the free energy (Hobson & Friston 2012). Yet, specifically regarding the target article's concept, a possibility remains that sleep-dependent memory reprocessing may be an epiphenomenon of more basic functions of both non-REM sleep (Tononi & Cirelli 2006) and REM sleep (Hobson & Friston 2012).

Sleep studies of human insight have demonstrated that whereas early-night slow-wave sleep (SWS) and its EEG signatures support the transformation of implicit knowledge into explicit insight to a hidden regularity in a complex generation task, late-night REM sleep preserves only the previously generated implicit knowledge without engaging specific REM sleep EEG signatures (Yordanova et al. 2008; 2012). These results show that only SWS and its EEG signatures may be linked to successful human heuristic creativity and do not suggest memory reconstruction during REM sleep.

Critically, nearly all psychiatric disorders are characterized by a REM sleep overdrive, yet these psychiatric conditions can not be linked to successful memory formation (Benca et al. 1992; Walker 2010). Further, it has been shown that augmented REM sleep in children with attention-deficit/hyperactivity disorder is associated with the core psychiatric symptoms of inattention and hyperactivity/impulsivity, whereas the greater amount of REM sleep in normally developing children is associated with better performance intelligence (Kirov et al. 2007; 2011). These findings suggest at least a bidirectional role of REM sleep, depending on presence or absence of psychopathology.

From a developmental perspective, infants experience much more REM sleep, which decreases through childhood and adolescence, than adults (Roffwarg et al. 1966). Thus, considering that REM sleep neurobiology and the corresponding dream generation are tightly coupled (Stickgold et al. 2001), explanations are needed for the following: (1) What memory sources may create the presumably enormous dreaming during infancy and early

childhood? (2) What cognitive and/or adaptive functions does such dreaming subserve? (3) How does this risky homeostatic state (e.g., Hobson & Friston 2012) predominant during early development relate to evolutionary advantages? (4) What kind of memory processes may be subserved by REM sleep dreams incorporated in nightmares, a common feature of both normal ontogenesis and developmental psychopathology (Brand & Kirov 2011; Kirov & Brand 2011)? Although it has been assumed that REM sleep subserves brain maturation during ontogenesis through internally generated and genetically grounded stimulation of neuronal assemblies (Marks et al. 1995), this assumption mandates experimental updates by applying new paradigms accounting for REM sleep hypotheses such as genetic programming (Jouvet 1998), threat simulation (Revonsuo 2000), and protoconsciousness (simple awareness of perception and emotions provided by genetic equipment ensuring generation of a virtual world) or Bayesian learning and inference (Hobson 2009; Hobson & Friston 2012).

Human REM sleep occurs periodically, thus distinguishing sleep cycles from one another, with the frequency and duration of REM sleep periods increasing progressively across overnight sleep (Broughton 1987). These temporal dynamics of REM sleep and dreaming can not be readily linked to the concept of elaborative encoding through the AAOM principles forwarded in the target article. Instead, it seems more relevant that in combination with concomitant neuroendocrine (Steiger 2002, 2007) and cardiorespiratory processes (Gastaut & Broughton 1964), the temporal dynamics of REM sleep and dreaming could supply vitally important homeostatic functions together with many cognitive adaptive processes.

I argue that the periodic occurrence of REM sleep and its dreaming may be regarded as a recurrent adaptive interference that may incorporate previously encoded and consolidated memories into a broader vital context comprising residuals of hypotheses testing, related emotions, basic needs, and individual genetic traits.

The spaces left over between REM sleep, dreaming, hippocampal formation, and episodic autobiographical memory

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Abstract: It is argued that Llewellyn's hypothesis about the lack of rapid eye movement (REM)-sleep dreaming leading to loss of personal identity and deficits in episodic memory, affectivity, and prospection is insufficiently grounded because it does not integrate data from neurodevelopmental studies and makes reference to an outdated definition of episodic memory.

The assumptions about relations between sleep and memory have changed considerably since Moruzzi and Magoun (1949) proposed that sleep reinstates the function of synapses. About a decade ago, the biological significance of dreams was downplayed by some authors, who called them “spandrels of sleep” (e.g., Flanagan 2000). Llewellyn's target article confirms a new impetus in sleep research, suggesting that Freud's wish to develop a scientific theory for “the interpretation of dreams” might not be a “lost dream” (Freud 1900). By emphasizing elaborative encoding (as opposed to consolidation) and a major role of rapid eye movement

(REM) sleep (as opposed to non-REM [NREM] sleep or slow-wave sleep) in the formation of episodic memories, Llewellyn is partly in opposition to other frameworks (Diekelmann et al. 2009; Stickgold & Walker 2007). Recently, for instance, Hahn et al. (2012) demonstrated that entorhinal layer III may be a mediator for memory consolidation during slow-wave sleep. Although Llewellyn reviews an impressive amount of data, she neither elaborates on several established findings nor comments on the association between REM sleep, dreaming, and episodic memory in special populations, such as children.

Young children seem to have at least the same amount of REM sleep as adults (Davis et al. 2004; Siegel 2011). However, developmental data show that the episodic memory system emerges only later in life (Fivush 2011; Willoughby et al. 2012). Furthermore, motor-perceptual skills – which probably are acquired very early in life – also seem to bear relationships with both NREM and REM sleep (Rauchs et al. 2005). One question that subsequently arises is why infants (and many mammalian species) have so much REM sleep but do not have episodic memory (Tulving 2005). Children's dream recall was found to increase significantly after age 7, correlating with mental imagery ability and visuospatial skills (Nir & Tononi 2010) rather than other intellectual capacities. These abilities are subserved by neural substrates that comprise extrahippocampal areas.

Llewellyn puts special weight on the relationship between REM-sleep dreaming, hippocampus, and episodic memory. Her focus on the hippocampus is justified, mirroring that of other researchers. However, during the first years of life, the hippocampal formation – one of the crucial brain regions for the formation (or “indexing,” as Llewellyn writes [sect. 4.2.5, para. 5]) of episodic memories – is still immature (Josselyn & Frankland 2012), whereas semantic memories can already be formed via parahippocampal areas (e.g., Vargha-Khadem et al. 1997). Parahippocampal cortex, which receives a diverse gamut of synthesized sensory-specific in addition to multimodal cortical information (Nieuwenhuys et al. 2008), was also shown to be engaged in REM sleep (as Llewellyn also remarks). Activation of the parahippocampal region was furthermore found in relation to place perception (Kanwisher 2010) and processing of scenes and landmarks (Piefer et al. 2005). The amygdala is also activated during REM sleep and plays roles in different phases of episodic mnemonic memory processing (encoding, consolidation, and retrieval) (Ally et al. 2012; Markowitsch & Staniloiu 2011a).

Paraphrasing Llewellyn, we ought to say that the term *episodic memory* is rarely precisely defined before it is used. This is also the case in target article. The various ways the term is currently employed in the literature constitute a source of confusion for empirical data interpretation. Llewellyn herself points to data “difficult to reconcile” (sect 7, para. 2), implying that the relation between REM sleep and episodic memory may depend on the conceptualization of episodic memory and testing paradigms employed. Llewellyn's definition of episodic memory – “enduring memories of personally significant past events with contextual place and time underpinnings (Squire 1987; Tulving 1983; 1991)” (sect. 1.1, para. 2) – is itself outdated (Markowitsch & Staniloiu 2011b; 2012; Tulving 2005). As Szpunar and McDermott (2008) remark, episodic memory has been an “evolving concept.” Tulving, who coined the construct *episodic memory*, used to emphasize the refinements in its conceptualization by giving a date for his most recent definition (e.g., Schacter & Tulving 1994). Whereas a few decades ago the term *episodic* could be applied to describe memory for laboratory stimuli with a specific embedding in time and place, currently the episodic memory system is viewed as equivalent to the episodic autobiographical memory system. In 2005, Tulving's definition of episodic memory comprised 17 lines, ending with this sentence: “The essence of episodic memory lies in the conjunction of three concepts – self, autonoetic awareness, and subjective time” (p. 9). This definition deviates considerably from previous ones

and from those still in use in some literature – for example, “What–Where–When” tasks (sect. 7, para. 2), to which Llewellyn refers with respect to the findings of Rauchs et al. (2004). It has been observed that specific details, pertaining to “what, where, when,” may be produced by some individuals without true first-person reexperiencing (Markowitsch et al. 1997) that is essential for *strictly episodic memories (events)* (Eustache & Desgranges 2008; Viard et al. 2012). On the other hand, there are individuals who judge their recalled material with a high confidence as representing true reexperiencing while delivering few episodic details (Levine et al. 2009). This may reflect impoverished narrative abilities or that having several similar episodic events may reduce the memory strength for them, leading to *semanticization* (Cermak 1984).

We concur with Llewellyn's reservation about using Verbal Paired Associates tests to uncover the relationship between REM sleep and episodic memory because they do not match the current understanding of episodic autobiographical memory. Furthermore, LePort and colleagues (2012) found that individuals with highly superior autobiographical memory did not perform significantly better on the Verbal Paired Associates test than did controls. Since 2005, several authors have increased the sophistication of their testing paradigms for episodic autobiographical memory (e.g., Levine et al. 2009). It seems therefore plausible that by employing testing paradigms that tap into the more recent definition by Tulving (2005), the contribution of slow-wave sleep to episodic memory will be viewed from a different perspective.

In conclusion, the link between REM sleep and strict episodic memory (as defined currently) is far from being unequivocal. Also, the contribution of NREM sleep to strict episodic(-autobiographical) memory needs further exploration. How different stages of sleep support the likely interactive processing within different memory systems remains a topic for future research (Dew & Cabeza 2011).

The secret is at the crossways: Hodotopic organization and nonlinear dynamics of brain neural networks

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Abstract: By integrating the classic psychological principles of ancient art of memory (AAOM) with the most recent paradigms in cognitive neuroscience (i.e., the concepts of hodotopic organization and nonlinear dynamics of brain neural networks), Llewellyn provides an up-to-date model of the complex psychological relationships between memory, imagination, and dreams in accordance with current state-of-the-art principles in neuroscience.

In the target article, Sue Llewellyn proposes that rapid eye movement (REM) dreaming is able to encode new episodic memories through several cognitive processes that enhance the likelihood of information retrieval by providing strong associations with other remote and emotionally salient memories.

After such presentation, one great question arises: Is there any biological basis to support that the proposed connective patterns actually occur in a deeper physiological level at the neural networks involved in long-term memory encoding and dreaming (such as the mesial temporal structures and the limbic networks), or is this just another purely speculative description (according to Llewellyn, based on the ancient art of memory [AAOM] principles) about some possible structural pattern in the relationships

between remote emotionally salient information, the phenomenology of dreaming, and the acquisition of new memories? The answer to such concern is actually one of the most decisive factors in predicting the long-term implications of any theoretical model in psychology. For example, very few people would deny that Freud's id/ego/superego scheme of the human psyche represented a relatively rational description of the relations between human desires, fears, and personal decisions (De Sousa 2011). Nevertheless, the fact that the topological structure of Freud's theoretical model bore no resemblance to the actual hierarchical structure of the underlying biological systems at any level rendered such a scheme a simple speculative description of the observed psychological phenomena with limited scientific applications.

Interestingly, a short appraisal about the contemporary understanding of the relationships between structure and function in the human brain (Bressler & Tognoli 2006; Damoiseaux & Greicius 2009; Horwitz & Braun 2004; McIntosh 2000) reveals that the vast majority of the current neuroscience literature has departed from a static *localizationist* approach (Berker et al. 1986; Von Economo 1930; Wernicke 1970), in which each different eloquent area of the brain is deemed to be responsible for a specific function (a paradigm clearly illustrated by the classic Brodmann's cortical maps; Pearce 2005), to a dynamic *connectionist* approach (McClelland et al. 2010), in which actual information is not spatially located at specific brain regions but rather can be traced to specific patterns of connections among distant clusters of neurons (Seung 2009). In fact, Llewellyn's proposal closely follows the current *hodotopic model* of brain functions (De Benedictis & Duffau 2011), according to which the human brain would operate based on the activity of a plastic network of cortical functional epicenters (topical organization) connected by both short-local and large-scale white-matter fibers (hodological organization). In such a framework, not only memories, but a variety of other higher cognitive functions (such as language, attention, memory, and decision making), would emerge from the dynamic interaction between parallel streams of information flowing between highly interconnected neuronal clusters (Litwin-Kumar & Doiron 2012) organized in a widely distributed circuit modulated by key central nodes. Such parallel processing and local recurrent activity would, therefore, give rise to neuroplasticity and enable the encoding of new information as the overall patterns in the strength of the intrinsic connections of such network change over time (Polack & Contreras 2012; Turrigiano & Nelson 2004). This new paradigm for understanding brain functions has led to an amazing and challenging mapping task (the so-called Human Connectome Project), which compares in complexity to (and, according to some authors, even exceeds) that of mapping the human genome (Sporns 2011b; Toga et al. 2012).

From a theoretical standpoint, modeling this type of information processing has required a new set of mathematical and conceptual tools that involve fuzzy logic and probabilistic outcomes (Brainerd & Reyna 2001) (instead of the classic Boolean logic with its two-valued deterministic outcomes), as well as nonlinear (chaotic) dynamic systems and stochastic processes (Afraimovich et al. 2011), instead of classic linear functions. According to such models, the complexity of higher cognitive functions would emerge not by data processing involving hierarchical trees of propositional calculus (with a branching trend of information from specific to general categories in progressive logical order), but rather by a comparative pattern analysis of the different features of the sensorial input performed by parallel, distributed, and interconnected networks (McClelland & Rogers 2003). It has already been shown that nonlinear (chaotic) dynamics can be successfully used to describe, represent, and model several cognitive and neural functions (Korn & Faure 2003), such as neurons' single-cell firing patterns (Huber et al. 2000), neural network

synchronization (Elbert et al. 1994), autonomic nervous system response to systemic physiological stimuli (Magrans et al. 2010), electroencephalographic analysis (Abásolo et al. 2007), synchronic pattern and noise modulation in adaptive motor control in the cerebellum (Tokuda et al. 2010), and even higher cognitive processes (Aiello 2012) and complex psychiatric disorders (Uhlhaas & Singer 2012).

By combining the classic psychological AAOM principles (visualization, bizarre association, organization, narration, embodiment, and location) with the most recent findings in the neuroscience of memory and emotions, Llewellyn has demonstrated that, unlike the Freudian psyche model, such principles are solidly grounded on the neurobiology of memory and dreaming. The advantages of such compatible framework go far beyond the simple desire for interdisciplinary uniformity regarding the conceptual structures (as well as an universally accepted nomenclature) employed in the study of dreams and memory by both psychology and neuroscience. Indeed, if a psychological model survives such a compatibility test, that means its theoretical structure is universally valid and can, therefore, be successfully applied also to the formulation of scoring systems that can then be used in very practical clinical studies involving, for example, frontline neurosurgical interventional trials for a wide range of neurological conditions affecting memory (such as Alzheimer's disease and other forms of dementia; Laxton & Lozano 2012; Laxton et al. 2010).

In summary, there is nothing new in stating the apparently obvious fact (which has been clearly noticed and properly described since early antiquity; Harrisson 2010) that there seems to be a close connection between human dreams, imagination, and memory. The great trump and uniqueness of Llewellyn's article is having analyzed such a close relationship on the basis of two leading-edge paradigms in neuroscience: the concepts of hodotopic organization and the nonlinear dynamics of brain neural networks.

The method of loci (MoL) and memory consolidation: Dreaming is not MoL-like

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Abstract: Certain *method of loci* (MoL) prerequisites – familiar, coherently ordered locations – should appear during dreaming if the latter is, in fact, elaborative memory encoding as hypothesized by Llewellyn. A review of the literature suggests that dreamed locations are neither familiar nor coherently ordered and thus unsuitable for facilitating memory in this sense. This conclusion converges with other evidence that episodic memory is dependent upon non-rapid eye movement (NREM), rather than REM, sleep.

Llewellyn proposes a bold hypothesis about rapid eye movement (REM) dream function – that it elaboratively encodes episodic memories in a manner akin to classical mnemonic techniques. This work comes at a time when there is an upswing in interest (Smith 2010; Wamsley & Stickgold 2011) in how dreaming participates in the well-established memory functions of sleep (Diekelmann & Born 2010; Walker & Stickgold 2010). It may thus have heuristic value for this renewed line of inquiry. Nonetheless, her hypothesis is complex, freely mixing phenomenological and neurophysiological assumptions, and it remains speculative and untested. In this commentary, I consider whether dreamed location imagery possesses the qualities necessary to enhance memory as Llewellyn claims.

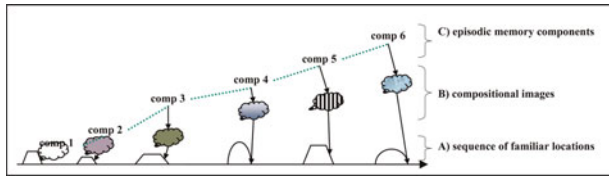


Figure 1 (Nielsen). Encoding of an episodic memory with the classical *method of loci* technique. The individual draws upon (A) a familiar sequence of locations, such as a building or path with a known order. To each unique location, the individual associates (B) a distinctive compositional image that substitutes for (C) a component of the to-be-remembered episode. To recall the memory, the individual mentally “revisits” the locations and “retrieves” the image/component “placed” there. Because the location sequence is familiar, images linked to it can be accessed in any order. Distinctiveness of the compositional images derives from, for example, their visual vividness, bizarreness, or emotion. Dream imagery only rarely depicts familiar, coherently ordered sequences of locations but may at times fulfill the requirement of distinctiveness (see the text).

Invention of the ancient art of memory (AAOM) is attributed to Greek poet Simonides of Ceos (556–468 BCE), who developed the *method of loci* (MoL; Fig. 1) after purportedly identifying the remains of comrades crushed in a temple collapse solely from his memory of where they were sitting before he fortuitously left the building. The MoL became common in Greek oral traditions and remains among the most effective mnemonic techniques (Massen et al. 2009; Verhaeghen & Kliegl 2000). The MoL facilitates memory for both abstract and concrete material (Wang & Thomas 2000), is especially effective with serially ordered material (e.g., episodic memories) and is most effective when the imagined pathways used are self-generated versus other-generated (Bellezza & Reddy 1978). It is a favored technique of mnemonists, as shown in a study of highly trained subjects, 90% of whom spontaneously used the MoL to complete study tasks (Maguire et al. 2003). Some findings even suggest that the MoL is effective without using bizarre or atypical composite imagery; the latter have no effect on memory if the imagery employed is sufficiently concrete, lively, and emotional (Persensky & Senter 1970; Senter & Hoffman 1976).

Given the centrality of the MoL technique to memory enhancement, a critical question for Llewellyn’s hypothesis is: *Does dreaming portray coherently ordered, familiar locations like those required for the MoL?*

Evidence supports the view that it does *not*, that dream locations are neither familiar nor coherently ordered. First, subjects rate dream locations as familiar only infrequently. In one study (119 dreams, 331 locations), they indicated that only 35.5% of dream locations were either exact or slightly modified replications of previously experienced locations (Dorus et al. 1971). This value is lower than for characters (51.7%) or activities/interactions (39.1%) but parallels the 33.7% of dream settings that subjects in a normative study ($N = 200$) described as familiar (Hall & van de Castle 1966). The latter value is an overestimate because familiarity scoring included famous settings that subjects may never have visited. Accordingly, another study estimates that familiar settings are the least frequent episodic memory element (17%) that subjects link to their dreams; less frequent even than themes, emotions, characters, or actions (Fosse et al. 2003).

Second, a lack of location ordering is suggested by the finding that dream locations are clearly the most frequent temporally discontinuous element (12.8%); they suddenly and unexpectedly appear, disappear, or transform (Revonsuo & Salmivalli 1995). Other elements, such as persons, objects, or actions, are discontinuous only 1.5%–4.8% of the time. A second study (Rittenhouse et al. 1994) found discontinuities of location (10%) to be second only to discontinuities of plot (14%). Beyond such apparent

discontinuity, however, successive dream locations may not be linked in any coherent sense (see example below). A dream protagonist might traverse several locations that are not logically connected and yet not notice this discontinuity.

Thus, the relative paucity of location familiarity and coherent ordering does not necessarily entail that dreams themselves are incoherent, but only that their coherence may be based on other qualities, such as emotion, narrative structure, or protagonist activity. Ambulatory motor activity, in particular, is prevalent in dream content (McCarley & Hobson 1977) and sustains a sense of story continuity, even though the scenes through which movement occurs change frequently and unexpectedly. For example, one short dream (Hobson & McCarley 1977) illustrating continuous motor activity also belies an absence of location continuity; in quick succession the dreamer reported: “sitting in front of a piano,” “walking around an amusement park,” “watching a band,” “walking up some steps,” “near rocks in the water,” and “filling a hole up with marble slabs” (p. 117). This array seems too disparate and incoherent to support MoL-like memory enhancement.

It could be argued that since even fictitious MoL locations are mnemonically effective (Yates 1966), so too are the novel, fictitious locations of dreams. In fact, fictitious “virtual environments” are as effective for improving memory as is a standard, familiar MoL setting (Legge et al. 2012). However, the latter finding was for stimuli that were encoded immediately after exposure to the virtual environment, when memory for the environment had not yet dissipated. No testing of longer-term consolidation was undertaken, and it is doubtful that it could have occurred if the virtual environments were not also committed to memory as required by the MoL. Dream settings, though perhaps similarly “virtual,” are also not typically highly memorized.

It could also be argued that MoL familiarity and coherence requirements need not be based upon geographic or architectural locations to be effective. As Llewellyn’s “lawsuit” example illustrates, a well-structured tableau containing very closely spaced locations may be effective; dream imagery may be much like this. Note, however, that such closely spaced MoL landmarks are less effective than are distantly spaced landmarks, such as one’s route to work (Massen et al. 2009). Nonetheless, this argument implies that dream locations may be irrelevant to dreaming’s memory function; the essential ingredient may be the formation of composite dream images.

In conclusion, research on the question of dreaming’s MoL-like quality suggests that dreams do not fulfill certain basic requirements; locations are neither familiar nor coherently ordered and thus may not facilitate episodic memory. This conclusion dovetails with most, but not all (cf. Griessenberger et al. 2012; Rauchs et al. 2004) evidence that either sleep does not consolidate episodic memory (Aly & Moscovitch 2010; Inostroza et al. 2013) or that episodic memory depends upon non-rapid eye movement (NREM), rather than REM, sleep (Daurat et al. 2007; Drosopoulos et al. 2005; Scullin 2012; van der Helm et al. 2011a).

Dreams, mnemonics, and tuning for criticality

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Abstract: According to the tuning-for-criticality theory, the essential role of sleep is to protect the brain from super-critical behaviour. Here we

argue that this protective role determines the content of dreams and any apparent relationship to the art of memory is secondary to this.

It is widely believed that memory consolidation is the purpose of sleep. However, as detailed in the target article, the description of this process that emerges from experiment is confusing and complex. Mindful that complex phenomenology is commonly the attribute of a secondary purpose, we proposed (Pearlmutter & Houghton 2009) that sleep has a different primary purpose – tuning for criticality – and that the link with memory consolidation is secondary. Memory consolidation may occur during sleep, it may even occur preferentially during sleep, but it is not the essential purpose of sleep.

The obvious goals of learning, rapid responses to stimuli, and prolonged retention of short-term memories are, from a network dynamics point of view, attributes of near-critical systems. Thus, it is likely that, during learning, neuronal circuits become increasingly critical and approach super-critical behaviour – behaviour that would involve runaway oscillations and constitute a pathological disruption of normal brain function. Thus, the optimisation of behaviour during learning requires a mechanism for preventing the brain from straying into a parameter region where it could be stimulated into pathological oscillations, and learning can occur only if there is a margin of safety around the current state of the brain.

In the tuning-for-criticality theory the purpose of sleep is to establish this margin of error. Thus, during sleep there is a synaptic plasticity regime which is different from the one which supports learning during wakefulness, and this works to move the brain away from criticality. In this way the sleep-work cycle tunes the brain so that it is close to criticality and optimised to respond to likely stimuli, but safe from the uncontrolled behaviour associated with super-criticality.

According to this proposal, the role of dreams is to stimulate the brain in a manner that mimics awake cognition as part of a search for self-reinforcing loops. Dreams are therefore a guess, based on recent and distant memories, of possible future stimuli. The target article describes the attributes of dreams. Dreams are emotionally salient and sometimes shocking or disgusting, they are associated with pontine-geniculate-occipital waves, they are narrative but the narrative is fragmentary, they contain incongruities, and the identities of people in them are often fused or indeterminate. Dreams are largely visual, with snatches of auditory sensation but almost no olfactory, gustatory, or tactile content. They are often characterised by the illusion of movement and spatial navigation. The target article points to this as a congruence between the form of the classic mnemonic and dreams, though it does not elaborate on what cognitive or biochemical mechanism related to this congruence would act to improve the efficacy of the mnemonic. We contend, however, that these are all attributes which dreams might be expected to have if they are a mechanism the brain uses to cast around for neuronal circuits in which potential stimuli could evoke runaway oscillations.

Pontine-geniculate-occipital waves arise only in wakefulness in response to unexpected events and are believed to focus attention, heightening responses. Emotionally salient, disgusting, and shocking dream content is likely to provoke stronger neuronal responses. Because the brain responds to temporally integrated stimuli, the exploratory simulated environment produced by dreams needs a narrative structure, but for this purpose, the narrative may be fragmented and discontinuous. The dream world need not be wholly specific; fused and indeterminate aspects of dream content seem unlikely to reduce its capacity to evoke responses indicative of potentially harmful self-reinforcing loops. The visual, auditory, and ambulatory character of dreams reflects the timescales and stimulus types most pertinent to everyday learning and common threats. In short, the nature of dream content is consistent with a tuning-for-criticality function of sleep. The pertinence of dream content means that similar content is likely to be memorable and this might explain the utility of this type of content in mnemonics.

Learning for behavioural optimisation is a key objective of cognition and content salient to this objective is likely to be both memorable and provocative. It may be this, rather than a direct functional link, that relates the art of memory and the nature of dreams. Alternatively, we might speculate that the random activity involved in dreaming first evolved to avoid criticality and that the availability of random narratives based partly on recent memories encouraged the development of learning strategies which make strong use of these narratives through a sort of hashing algorithm. In this light, we would view mnemonic consolidation as a particularly apt secondary purpose of sleep, in that it makes use not only of physical quiescence but also exploits the computational processes already present in tuning for criticality.

Mnemonic consolidation may avoid waste by utilizing the dream content that was generated, at some metabolic expense, to locate potentially super-critical neuronal circuits. However, we believe that there is no evidence to suggest that memory processes like consolidation and mnemonic association can occur only during sleep. Sleep is such an extreme and hazardous adaptation it seems unlikely it evolved to serve a function, like mnemonic association, that could also be performed while awake.

From Freud to acetylcholine: Does the AAOM suffice to construct a dream?

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Abstract: Toward illuminating the structure of Llewellyn's dream theory, I compare it in formal terms to Freud's dream theory. An alternative to both of these dream machines, grounded in the distribution of cholinergic activation in the central nervous system, is presented. It is suggested that neither "high" nor "low" dream theory is sufficient to account for the properties of dreams.

Llewellyn's is an attractive hypothesis, engagingly presented. In structure – not, of course, in substance – it is like Freud's dream theory. Freud's dream machine exercises a set of operations – the components of the *dream work* – that, when applied unconsciously in waking, produce a neurotic symptom. Llewellyn's dream machine exercises a set of operations – the components of the ancient art of memory (AAOM) – that, when applied deliberately in waking, elaboratively encode an episodic memory.

Both dream generators account ingeniously for the peculiarities of dream experience, and both achieve an explicit aim. By condensation, displacement, "consideration of representability," and secondary revision, a Freudian dream expresses a forbidden Oedipal wish (Freud 1900/1981). A Llewellynian dream – by association, organization, narration, embodiment, movement, and location – encodes the to-be-remembered material. In both cases the latent dream is obscured – in Freud's model by cunning, in order to evade the "psychic censorship," and in Llewellyn's (she has no use for a calculating homunculus) by guileless neural processes, in order to realize what I shall call the AAOM-in-REM. These formal likenesses entail another. Against the school of "bottom-up" dream construction, Llewellyn's theory, like Freud's, is a "high" theory: an explicitly "top-down" machine.

What if – both on the neural axis and in regard to imaginative complexity – dreaming is neither a "high" nor a "low" process, but an egalitarian one? A case in point is what might be called Llewellyn's telencephalocentric treatment of levels of acetylcholine (ACh) in waking and in sleep. Table 1 lists and describes the main cholinergic neural groups in the central nervous system. It is fair to ask, can the AAOM-in-REM accommodate the realities of ACh-in-REM, from hindbrain to forebrain? (In Table 1, cell

Table 1 (Porte). *Cholinergic cell groups activated in rapid eye movement (REM) sleep*

Location	Selected projection targets	Selected functions
Ch1 Medial septal nucleus		Hippocampal theta EEG Locomotion / idiothethesis
Ch2 Diagonal band of Broca, vertical limb	Dentate gyrus, Ca3, Ca1, Subiculum, entorhinal cortex	Memory for place and context Modulation of place cell activity (e.g., by speed and turning direction) Memory for time (MacDonald et al. 2011)
Ch3 Diagonal band of Broca, horizontal limb	Olfactory bulb	Odor perception and discrimination Olfactory spatial map (Jacobs 2012)
Ch4 Nucleus basalis of Meynert	Neocortex Sectors of amygdala Sectors of thalamus	Activation / gamma rhythm Visuospatial attention Feature binding (Botly & De Rosa 2012)
Ch5 Pedunculo-pontine tegmental nucleus	Thalamus Cholinergic nuclei of the reticular formation Superior colliculus, intermediate layers Dopamine neurons: Substantia nigra pars compacta Ventral tegmental area	Thalamocortical activation Hippocampal theta EEG Locomotion Ponto-geniculo-occipital waves Rapid eye movement Gaze movement Vestibular experience Reward processing and acquisition
Ch6 Laterodorsal tegmental nucleus	Similar to Ch5 projections Branching projections to dopamine neurons and thalamus	Similar to Ch5 functions Alarm vocalization (not found in Ch5) (Brudzynski et al. 2011)
Ch7 Medial habenula	Interpeduncular nucleus	Flight response to frightening stimuli Modification of fear response (Stephenson-Jones et al. 2012) Landmark navigation / path integration
Ch8 Parabrachial nucleus	Separate and branching projections to amygdala and superior colliculus	Superior colliculus motor output Extra-geniculostriate visual inputs to amygdala (Threat response before consciousness of threat?)

EEG: Electroencephalogram

groups are designated by accepted nomenclature [Wainer & Mesulam 1990]; citation is provided only for recent claims concerning function.)

Indisputably in REM sleep – if you will, in *Table 1-in-REM* – neural excitation is high in each of the cell groups Ch1–Ch8. Also indisputably, REM sleep and the neural distribution Ch1–Ch8 are highly (and probably inseparably) conserved across species. A sufficient theory of human dreaming must incorporate those facts. *Table 1-in-REM* can do so.

But can *Table 1-in-REM* account, as Freud's and Llewellyn's models may seem to do, for the properties of dreams? Pending the outcome of that question's empirical investigation, I

propose a tentative answer, or at least a prologue to an answer: By analogy to the cholinergic retinal wave of early neural development, in REM sleep or its prototype in at least all vertebrate species, "waves" of excitation sweep over the entire cholinergic central axis. These waves, like retinal ones, propagate stochastically but acquire coherent structure. Thus a "dream wave" might generate a dream scene. In its favor in this respect, *Table 1-in-REM* easily generates obligatory dream locomotion rather than tendentious (Freud) or highly recommended (Llewellyn) dream locomotion. The table readily accounts for the typicality of typical dreams: fearful dreams, for example, or dreams of fleeing or of flying. Against Llewellyn's reading of

Sprenger et al. (2010), the table produces actual REM sleep saccade trajectories, not creative ones. As for Ch3 (diagonal band of Broca, horizontal limb), if one takes into account relative species primacy of olfaction, Table 1-in-REM would generate few olfactory dreams in humans but – this is written only partly in jest – many olfactory dreams in dogs. Most important, where cholinergic drive clamps “idea” onto “activation,” the table generates meaning: probabilistic, to be sure, and often oddly realized in REM’s mixed landscape of cortical activation and inactivation, but meaning nonetheless. For Table 1-in REM, even an “Icarus” dream is a cinch.

To entertain the idea that the experienced, intact brain constructs dreams out of directionally unbiased swaths of central cholinergic excitation is to jettison a host of dream theories, both “high” and “low.” The AAOM-in-REM is well worth salvaging, however – even if it must relinquish pride of place to a more distributed anatomy, and pride of encoding to a less singular function.

Finally and incidentally – this is the stuff of a different commentary – I am mystified, as if awakening from a dream, by the AAOM’s situation within the temporal state architecture of sleep. Exactly what happens where, and when?

Studying the relationship between dreaming and sleep-dependent memory processes: Methodological challenges

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Abstract: The hypothesis that dreaming is involved in off-line memory processing is difficult to test because major methodological issues have to be addressed, such as dream recall and the effect of remembered dreams on memory. It would be fruitful – in addition to studying the ancient art of memory (AAOM) in a scanner – to study the dreams of persons who use AAOM regularly.

Based on the analogy of the ancient art of memory (AAOM) techniques with dream content, Llewellyn hypothesizes in the target article that an off-line memory processing – termed *elaborative encoding* – is taking place during rapid eye movement (REM) sleep and that this is instigated during non-REM (NREM) sleep and facilitates the recall of episodic memories. That there is more to off-line memory processing than simple consolidation (repeating the newly acquired information exactly) is in line with the current theories (see Stickgold & Walker 2013). The major challenge posed by this hypothesis is the idea that dreaming, especially REM dreaming, reflects or participates in this function of REM sleep since one can argue that a lot of processes occur during this sleep stage, not all of which are reflected in dreaming – if recalled.

Looking at the AAOM examples, the parallel between AAOM and dream content is less than clear for me: According to Llewellyn, AAOM techniques were used to learn episodic memories that were not related directly to the person by combining those memories with personal material. Dreaming, however, often reflects personal concerns (Domhoff 2003) and emotional salient daytime experiences (Schredl 2006).

The parallel between dreams and AAOM also does not explain why dreams are quite easily forgotten (Schredl 2007). It is important to keep in mind that dreams are only memories of the dreaming process (Schredl 2008). One study (Schredl 2000), for example, did not find a correlation between dream salience, dream bizarreness, and dream recall frequency. The theory that best explains the problems the waking mind has with recalling dreams was pro-

posed by Koukkou and Lehmann (1983). The functional state-shift theory is based on the empirical evidence on state-dependent learning: the waking state differs from the REM-sleep state regarding cholinergic modulation (Hobson et al. 2000), and thus there are difficulties in remembering the dreamed experiences. In addition, the fact that the sleep profile of the night shows brief REM periods at the beginning with short, mundane dreams and longer REM periods with the more bizarre and elaborate dreams at the end of the night (Antrobus 1991; Dement & Kleitman 1957a) does not completely support the idea of instigating the REM sleep processes in subsequent NREM sleep. Furthermore, sleep-onset dreams, NREM dreams, and even daydreams often cannot be differentiated from REM dreams on a phenomenological level (Foulkes & Fleisher 1975; Nielsen 2000). The Kekulé example cited by Llewellyn (sect. 4.2.1, para. 6), for instance, is a sleep-onset dream (Strunz 1993). These issues are, however, not as important as is the question about how to test whether dreaming – defined as subjective experiencing during sleep – has a function additional to the function of sleep or REM sleep.

To illustrate the problems within this line of research, I complement the overview of Llewellyn, who cited only the nap study by Wamsley et al. (2010). The first pilot study linking dream content to overnight memory consolidation was conducted by De Koninck et al. (1996), who found that task-related dream content is related to increased performance in the procedural task (e.g., performing a task while wearing goggles that invert the visual field) the next day. Unfortunately, this result was not confirmed by a subsequent study using another procedural task: mirror tracing (Schredl & Erlacher 2010). A completely different approach was applied by Erlacher and Schredl (2010): Lucid dreamers were instructed to train for a coin-tossing task within their dreams, and those who successfully did this exhibited improved performance the next morning.

The major problem with these studies is that you have to interrupt sleep (several REM awakenings) to get a clear picture of the person’s dreams that night, and this might interfere with the off-line memory processes. If only spontaneously recalled dreams were elicited (Wamsley et al. 2010), there is a problem that the trait-variable dream recall might be associated with memory performance and not the recall of a particular dream about the task. The main methodological issue, however, is that you have to elicit dream content (verbal or written reports) in order to know whether the person had dreamed about the memory task (or the episodic memories that the researcher is interested in), and thus it cannot be ruled out that the memory-enhancing effect is not due to the dreaming during the night or can be attributed only to the remembered dream. In the Erlacher and Schredl study, for example, the successful lucid dreamers might have been more confident because of their lucid dreaming and thus performed better in the task. Having these methodological issues in mind, the suggestions by Llewellyn as to how her hypothesis might be tested have to be evaluated very carefully. Studying patients with brain lesions who report loss of dreaming (Solms 1997) has several drawbacks because one does not know what other cognitive processes were affected by the lesions. But the main question is how one can be sure that they are not dreaming and are only unable to recall any dreams.

If dreaming is defined as subjective experiencing during sleep (similar to the subjective experiencing during wakefulness), a complete cessation of dreaming might not be possible – at least in patients able to perform memory tasks or speak about their subjective processes while awake. The most promising approach suggested by Llewellyn is to study AAOM processes in the waking state by using functional magnetic resonance imaging (fMRI) techniques and look to see whether similar brain activation patterns can be found during REM sleep. This, however, can still not prove that dreaming is involved in this off-line memory processing. As a dream researcher, I would like to study the dreams of persons who use AAOM techniques in their waking lives regularly or very gifted persons. If their dreams are completely different with regard to bizarreness or content related to episodic memories, this would not support the AAOM analogy to “normal” dreaming.

To summarize, the hypothesis proposed by Llewellyn is stimulating for the field, but many important methodological issues need to be addressed before making progress in this line of research.

Dreaming is not controlled by hippocampal mechanisms

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Abstract: Links with the Humanities are to be welcomed, but they cannot be exempted from normal scientific criteria. Any hypothesis regarding the function of dreams that is premised on rapid eye movement (REM)/dream isomorphism is unsupportable on empirical grounds. Llewellyn's hypothesis has the further problem of counter-evidence in respect of its claim that dreaming relies upon hippocampal functions. The hypothesis also lacks face validity.

There is much about Sue Llewellyn's article that is appealing, not least the bridges it builds with the Humanities and its careful use of real psychological data: an individual dream report with personal associations. Cognitive neuroscience has much to gain from articles like this. It therefore pains me to say that Llewellyn's main hypothesis in unsupportable, for common-and-garden empirical reasons.

Her hypothesis is that rapid eye movement (REM) dreaming serves a similar functional purpose to the ancient art of memory (AAOM) – that is, it largely supports episodic memory consolidation – “through imaginatively associating the to-be-remembered material in a mental image” (sect. 2, para. 3). She attributes this imaginative process to “hippocampal associational function during REM dreams” (abstract, para. 2). The empirical evidence adduced in support of this hypothesis accordingly relates the function of dreaming to the physiology of the REM state and the psychology (and functional anatomy) of the hippocampus.

The premise that any function of dreaming may be derived from physiological processes unique to the REM state is untenable, since dreaming and REM sleep are certainly doubly dissociable states, notwithstanding that they are *on average* highly correlated (Solms 2000). Curiously, considering how fundamental this premise is to her entire argument, Llewellyn simply says at the outset that REM/dream isomorphism “is the position taken in this article” even though she simultaneously acknowledges, for example, that “early-night REM and late-night NREM dreams cannot be distinguished” (sect. 1, para. 1). This last fact alone disqualifies all the specific physiological and psychological evidence regarding the REM state that she subsequently cites to support her main hypothesis concerning the function of dreams. Thus, for example, there is no valid reason to assume that Llewellyn's own sample dream, which she subjectively “self-identified” (sect. 4, para. 8) as a REM dream, was indeed a REM dream.

Nevertheless, this still leaves open the theoretical possibility that REM-like dreaming (regardless of sleep stage) could serve the hypothesized function of consolidating episodic memories. More fatal for the hypothesis, therefore, is the clinical fact that bilateral hippocampal lesions – causing total loss of the episodic memory functions that Llewellyn attributes to dreaming – have no demonstrable effect on the occurrence of REM-like dreams, as I reported long ago (Solms 1997). In this regard, I hope shortly to be able to describe in detail the vivid dream reports of the celebrated patient HM (S. Corkin, personal communication, July 27, 2008). By the same token, total loss of dreaming following suitably localized cerebral lesions has no demonstrable effect on episodic memory (Solms 1997; Yu 2006). This applies also to memory for pre-sleep episodes (Marchbank 2013). Llewellyn predicts the opposite (sect. 6, para. 6).

These facts have perhaps not been sufficiently widely reported and adequately investigated. Nevertheless, my own (now extensive) experience with such cases leaves me in no doubt that the effect – if any – of loss of dreaming upon episodic memory consolidation is sufficiently slight and subtle to escape routine clinical investigation – including standardized neuropsychological assessment. It is, in short, very difficult to support Llewellyn's hypothesis that dreaming performs a function which seems to be impervious to cessation of dreaming, and a function the loss of which appears to be compatible with essentially normal dreaming. (Of course this does not mean that dreaming plays *no* part in episodic memory consolidation; it means only that the two processes do not causally depend upon each other.)

But the most puzzling aspect of Llewellyn's hypothesis is something which most commentators will surely remark upon, too: its curious lack of face validity.

AAOM was an active strategy used to produce episodic memory cues and deliberately composed idiographic associations that could later be used to assist in the voluntary and explicit “re-collection” of (usually semantic) material committed to memory. This psychological process differs from dreaming in several important respects, two of which seem fundamental. Firstly, the AAOM is an executive strategy (apparently relying on active prefrontal integration – what Llewellyn calls “organization” – of hippocampal hyper-associations), whereas dreaming is a passive – what Llewellyn calls “associative” – experience in which the prefrontal lobes play little or no part (Braun et al. 1997; Solms 1997). Secondly, the creative mental images and linkages forged in AAOM are explicitly brought back into working memory, to support the recollection process, whereas the vast majority of dreams are immediately and permanently forgotten – at least as far as explicit recollection is concerned.

Why, then, does Llewellyn equate them? The answer seems to be because they share some formal features: visualization, bizarre association, organization, narration, embodiment, and location. But apart from bizarre association, it is hard to see which of these features distinguishes dreaming from most other forms of everyday conscious experience. To paraphrase Llewellyn, “The stuff of *cognition* is the stuff of memory.”

Llewellyn addresses the face-validity problem of dream forgetting by suggesting that if its hyper-associational junctions were to become conscious, they would precipitate psychosis. It is hard to understand why this should be so for dreams but not for the AAOM. And when we *do* remember dreams in everyday life, why do we have so little difficulty staying sane?

REM sleep, hippocampus, and memory processing: Insights from functional neuroimaging studies

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Abstract: Neuroimaging studies show that episodic memory encoding is associated with increased activity in hippocampus and lateral prefrontal cortex; however, the latter structure shows decreased activity in rapid eye movement (REM) sleep. Together with few episodic memory traces in REM sleep, and REM sleep deprivation affecting hippocampus-independent emotional processes, this argues for generic information processing in REM sleep rather than linking episodic memory traces.

The emphasis placed on the role of REM sleep in episodic memory encoding calls for a closer examination of neural circuitry involved

in both episodic memory encoding and rapid eye movement (REM) sleep. A meta-analysis by Spaniol et al. (2009) of functional magnetic resonance imaging (fMRI) studies has demonstrated robust involvement of hippocampus and other temporal lobe structures (e.g., amygdala, inferior temporal gyrus) in episodic memory encoding. Furthermore, this meta-analysis showed involvement of the left lateral prefrontal cortices in episodic memory encoding, both in ventral and in dorsal areas, compared with episodic memory retrieval. It is also of interest that pioneering fMRI work (Maguire et al. 2003) in superior memorizers has shown the involvement of the retrosplenial cortex (below the posterior cingulate) besides the hippocampus during the visuospatial episodic memory strategies ("mental walk") mentioned in the target article. If episodic memory encoding were a key feature of REM sleep, one would expect increased activity in hippocampus, lateral prefrontal cortices, and posterior cingulate/retrosplenial cortex.

Contrasting REM sleep with slow-wave sleep (SWS) or wakefulness reveals increased activity in basal ganglia, anterior cingulate, and anterior temporal lobe areas (Braun et al. 1997; Maquet et al. 1996). Increased activity has been observed for hippocampus during REM sleep (although more pronounced in other regions) in the study by Braun et al. (1997), whereas Maquet et al. (1996) did not observe increased hippocampus activity. In contrast, lateral prefrontal areas and posterior cingulate cortex show a *decrease* in activity from SWS to REM sleep, which we find difficult to reconcile with the main idea proposed in the target article.

These findings in relevant neural circuitry of episodic memory encoding are in accord with neural circuitry involved in more general memory processing, which is strongly correlated to hippocampus activity in the resting state. The hippocampus is embedded within a functionally related brain network referred to as the *default mode network* (DMN), comprising anterior and posterior cingulate, precuneus/retrosplenial cortex, and inferior parietal lobules. The hippocampal formation (hippocampus and adjacent temporal lobe regions) is strongly connected to the DMN in wakefulness, particularly during episodic memory processing and future imagination (Buckner et al. 2008). It is essential to keep in mind that REM sleep recruits only *part* of this episodic memory network, specifically the anterior part (Braun et al. 1997; Maquet et al. 1996).

The relevance of findings on neural circuitry are stressed by cognitive effects in the same direction: there are fewer episodic memory traces after waking from REM sleep than from non-REM sleep. In contrast, semantic and abstract self-references are more frequent memory sources in REM sleep (Baylor & Cavallero 2001). These observations require further attention in the light of the proposed hypothesis in the target article.

We would further like to emphasize the importance of distinguishing activity of a brain region from its *connectivity*. Even if hippocampus activity is increased in REM sleep, this would not necessarily equate to increased functional connectivity between hippocampus and neocortex, which could represent increased flow from a large variety of neocortical regions to hippocampus. Findings in healthy human subjects providing whole-brain results are still lacking because of the difficulty of investigating REM sleep with the combined neuroimaging methodology required for high spatial and temporal resolution (Wehrle et al. 2007). Interestingly, neurophysiological studies in rodents have shown the greatest hippocampus synchrony during non-REM sleep hippocampal sharp-wave ripples, and lowest intrahippocampus synchrony in REM sleep (Grosmark et al. 2012). It is intriguing that these authors further observed an increase in synchrony from non-REM period to non-REM period, which was correlated with the power of theta activity during intervening REM episodes. This can be taken as evidence for synaptic down-scaling processes occurring in REM sleep.

Studies on the effects of REM sleep deprivation are also in line with the aforementioned findings. For instance, preclinical work has shown that REM sleep deprivation in rats results in impairments in hippocampus-independent *cued* fear extinction but not in hippocampus-mediated *contextual* fear extinction (Silvestri

2005). This suggests affective processing of visuospatial aspects (e.g., light was paired with foot shocks but is now safe) rather than of contextual aspects. Alternatively, it could be taken as an argument for processing of generic rather than specific features. With increasing evidence for a role of SWS in declarative and episodic memory processing (Diekelmann & Born 2010), a function of REM sleep may well lie in more generic processing of information to enable more efficient reorganization into schemas (as has recently been proposed for SWS [Lewis & Durrant 2011]). As such, comparison/integration of information with existing schemas in neocortex appears more plausible than linking episodic traces in hippocampus. The role of the hippocampus in REM sleep could be to provide incidental output to neocortex through sporadic bursts of activity (Montgomery et al. 2008). Such a view would be more in line with the aforementioned imaging, cognitive, neurophysiological, and functional findings. Further experimental work is warranted, and the literature has provided elegant solutions for testing associative processes in the light of REM sleep (Cai et al. 2009), and in our opinion these solutions are more informative and better to combine with imaging methods than are subjective or nonstandardized measurements.

Finally, the graph theory approaches mentioned in the target article have become popular for analyzing functional connectivity data, reducing the brain's complexity to a network of nodes and edges (the connections between nodes). Llewellyn refers to the increased connectivity observed in light non-REM sleep, which we would like to specify as increased *corticocortical* connectivity, since *thalamocortical* connectivity was strongly reduced in light non-REM sleep because of the thalamus being removed from the whole-brain network at sleep onset (Spoormaker et al. 2010). This demonstrates how the behavior of one critical hub can change the behavior of the whole-brain network; alternating hippocampus-neocortex connectivity from SWS to REM sleep could critically impact general network functioning and information processing. To date, all we can say is that more experimental neuroimaging work in humans is needed.

Dissociative symptoms and REM sleep

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Abstract: Llewellyn has written a fascinating article about rapid eye movement (REM) dreams and how they promote the elaborative encoding of recent memories. The main message of her article is that hyperassociative and fluid cognitive processes during REM dreaming facilitate consolidation. We consider one potential implication of this analysis: the possibility that excessive or out-of-phase REM sleep fuels dissociative symptomatology. Further research is warranted to explore the psychopathological ramifications of Llewellyn's theory.

Llewellyn makes a convincing case that rapid eye movement (REM) sleep serves the function of elaborative encoding by following ancient art of memory (AAOM) rules. At the phenomenological level, this becomes manifest in visualizations, bizarre connections, and narrative form during dreams. Llewellyn summarizes research showing that, during REM sleep, the prefrontal areas are in a state of deactivation resulting in fluid reasoning and flexible thought. However, she touches only briefly upon the ramifications of her analysis for understanding the development and perseverance of psychopathological symptoms.

We would like to emphasize the relevance of Llewellyn's analysis for one particular type of psychopathology – namely, *dissociative symptoms* (e.g., derealization, amnesia, and absorption). Dissociative symptoms are common in the healthy population, but disorders such as dissociative identity disorder (DID; formerly known as multiple personality disorder) and depersonalization disorder, represent severe, albeit rare, manifestations of psychopathology (Lynn et al. 2012). The traditional view is that dissociative symptoms reflect (transient) disruptions in memory, perception, and/or consciousness and that these disruptions are causally related to aversive life events (e.g., Dalenberg et al. 2012). More specifically, the idea is that dissociative symptoms enable individuals to distance themselves from the emotional impact of aversive events. Although there is some indirect evidence – largely correlational – for this trauma hypothesis, it suffers from one important weakness: it remains silent as to how aversive events produce dissociative symptoms.

More recently, researchers have proposed that sleep disturbances play an important role in the development of dissociative symptoms. A solid and steadily accumulating foundation of research now exists to contend that dissociative symptoms are associated with a labile sleep–wake cycle in which dreamlike mentation invades the waking state, produces memory failures, and fuels dissociative experiences (Koffel & Watson 2009; Van der Kloet et al. 2012a; 2012b; Watson 2001).

The idea that sleep disturbances and dissociative symptoms are related is not new. In the nineteenth century, double consciousness, the historical precursor of DID, was often described as *somnambulism*, which refers to a state of sleepwalking. Patients suffering from this disorder were referred to as *somnambules* (Hacking 1995), and many nineteenth-century scholars believed that these patients were switching between a “normal state” and a “somnambulist state.” In 2001, Watson investigated two large samples of undergraduate students and showed that dissociative symptoms are linked to self-reports of vivid dreams, nightmares, recurrent dreams, hypnopompic imagery, and other unusual sleep phenomena. His finding has been reproduced time and again. We (Van der Kloet et al. 2012a) summarized the findings of 23 studies and found an average correlation of $r = 0.41$ between dissociative symptoms (as measured by the Dissociative Experiences Scale [Bernstein & Putnam 1986]) and unusual sleep experiences (collected with measures such as the Iowa Sleep Experiences Survey [Watson 2001]).

The connection between sleep and dissociative symptoms seems specific in the sense that unusual sleep phenomena that are difficult to control, including nightmares and waking dreams, are related to dissociative symptoms, but lucid dreaming – dreams that are controllable – are only weakly related to dissociative symptoms. Germane to this specificity issue is the study by Koffel and Watson (2009) in which 374 participants completed a comprehensive test battery, including measures of psychopathology and sleep. The authors concluded that “unusual sleep experiences are specific to dissociation and schizotypy, whereas insomnia and lassitude are specific to depression and anxiety” (p. 551).

However, these studies on sleep and dissociation used a correlational approach, which precludes the ability to draw causal conclusions. If dissociative symptoms are, indeed, fueled by a labile sleep–wake cycle, sleep loss would be expected to intensify dissociative symptoms, thereby suggesting a specific temporal pattern. We tested this prediction in a pilot study (Giesbrecht et al. 2007) that tracked dissociative symptoms in 25 healthy volunteers during one night of sleep deprivation. We found that sleepiness, as well as spontaneous and induced dissociative symptoms, were stable during the first day, but substantially increased after one night of sleep loss. Interestingly, the increase in dissociative symptomatology was highly specific: Dissociative symptoms were affected by sleep loss sooner than were mood deterioration.

The reverse appears to be true, as well. We (Van der Kloet et al. 2012a) conducted a longitudinal study to investigate the relation between unusual sleep experiences and dissociation in a mixed

inpatient sample ($N = 195$) evaluated on arrival and at discharge six to eight weeks later. We found a robust link between unusual sleep experiences and dissociative symptoms and determined that sleep normalization was accompanied by a reduction in dissociative symptoms. The link between dissociation and sleep is likely more differentiated, as we observed that decreases in narcoleptic experiences rather than decreases in insomnia accompanied the reduction in dissociative symptoms.

Finally, in a recent study (Van der Kloet et al. 2013), we measured dissociative symptoms and EEG sleep parameters in patients ($N = 45$) suffering from insomnia. We found that it is lengthening of REM sleep that predicts dissociative symptoms. This finding is consistent with the hypothesis that a disturbed sleep–wake cycle, possibly due to aversive life events, produces excessive or out-of-phase REM activity that, in turn, underlies dissociative symptoms. These dissociative symptoms may, in turn, exacerbate or increase vulnerability to sleep disturbances, engendering a vicious cycle that may be ameliorated with interventions that target dissociation, sleep problems, or both.

Thus, one distinct scenario that warrants further investigation is that excessive REM sleep during the night and/or minor REM sleep episodes during the day fuel the type of fluid and hyperassociative cognition that is typical for dissociative disorders. This research perspective might shed new light on the propensity of dissociative individuals to develop false memories. Even more importantly, it might suggest new treatment options for dissociative patients. Whereas Llewellyn focused on the memory-promoting aspects of REM sleep, we have emphasized the pathological potential of excessive REM. It would be exciting to combine these two lines of research.

Elaborative encoding during REM dreaming as prospective emotion regulation

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Abstract: Rapid eye movement (REM) dreaming results in “emotionally intelligent encoding,” according to the target article. Building on this, we argue that elaborative encoding alters emotional processing of upcoming events and thereby functions as prospective emotion regulation. After elaborative encoding, future events are appraised differently and result in a redirected emotional response. Disturbed elaborative encoding might be relevant for emotional dysregulation in psychopathology.

The target article addresses elaborative memory encoding during rapid eye movement (REM) dreaming by integrating findings from different fields. Despite its focus on memory, the article relies extensively on concepts and findings from emotion research. Specifically, Llewellyn proposes that memory elements are being “emotionally tagged” (sect. 2, para. 9) and memory associations are being “emotionally charged” (sect. 2, para. 10; sect. 8, para. 4) during REM dreaming by using limbic structures such as the amygdala, thereby resulting in “emotionally intelligent elaborative encoding” (sect. 4.2.2, para. 5). However, *emotionally intelligent encoding* is not clearly defined in the target article. We propose that elaborative encoding during REM dreaming also supports emotional processing of *future events* (in an *emotionally intelligent* way). Thus, we argue that the encoding process during REM dreaming also functions as *prospective emotion regulation*. This

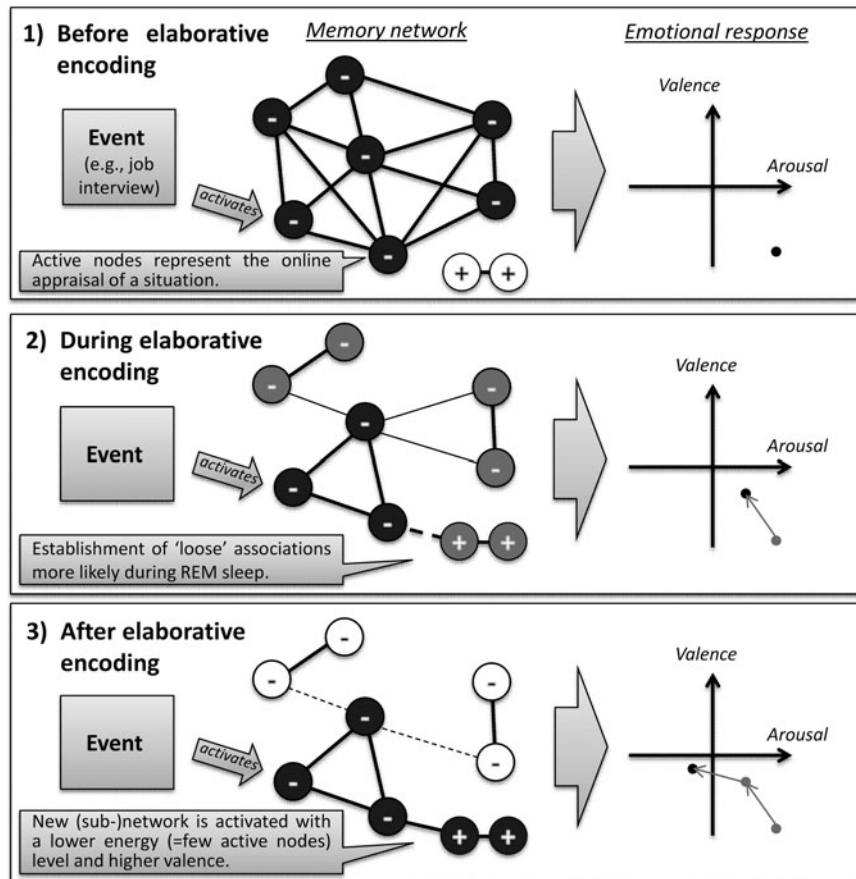


Figure 1 (Westermann et al.). Illustration of the effects of elaborative encoding during rapid eye movement (REM) dreaming with its prospective emotion regulation impact on future events and their emotional responses. Nodes represent memory elements, and links between nodes represent associations. Nodes with a plus (minus) sign elicit “pleasant” (“unpleasant”) emotions. An event (left-hand side) is being appraised by activating memory network elements (center). This activation results in an emotional response that varies in valence and arousal (right-hand side). **(1) Before elaborative encoding:** The memory network has few clusters (divisions). Each node is linked with many local nodes. The activation (black) of any node is likely to coactivate other nodes. Distant memories are not linked to the local network and are inactive (white). **(2) During elaborative encoding:** The memory network is being elaboratively encoded during REM dreaming. Distant memories with potential incongruent valences are actively associated (hyperassociation during REM). Distinct memory clusters (divisions) emerge. Some links vanish. **(3) After elaborative encoding:** The memory network is now elaboratively encoded. Several distinct clusters have emerged. The activation of a node is likely to coactivate only a subset of related nodes. Less activation is expected to result in less arousal. The emotional response is likely to be redirected during future events.

hypothesis complements the common view that REM-sleep dreaming decreases or processes *residual emotional load* from the day before (e.g., Walker 2009). Instead, REM dreaming is expected to prevent the accumulation of emotional load during the next day(s).

Emotion regulation during waking consciousness is defined as “a set of processes whereby people seek to redirect the spontaneous flow of their emotions” (Kooze 2009, p. 6). Correspondingly, we define emotion regulation during REM dreaming as set of processes whereby the spontaneous flow of emotions is redirected. The idea that active emotion regulation occurs during sleep and particularly REM sleep is not new. For example, an afternoon nap increases habituation to arousing stimuli (Pace-Schott et al. 2011) and REM sleep deprivation disturbs consolidation of fear extinction (Spoormaker et al. 2011). However, prospective emotion regulation in the sleeping brain has not been considered.

The most extensively studied emotion regulation strategy that directly impacts future appraisals of events is named *cognitive reappraisal*. Reappraisal involves changing the appraisal process within a situation in order to modify the subsequent emotional response (Gross 2001). For example, the reappraisal of a job interview as an opportunity to get to know potential, agreeable colleagues is likely to increase curiosity and decrease anxiety in the interview

situation. Reappraisal is effective in reducing negative emotions, and habitual reappraisal is positively related to mental health (Aldao et al. 2010; Goldin et al. 2008). However, reappraisal is a conscious process that is unlikely in the sleeping brain. How might prospective emotion regulation be implemented during sleep?

In our view, the target article provides a framework to conceptualize prospective emotion regulation during REM dreaming. Elaborative encoding during REM dreaming modifies memory networks and therefore affects the appraisal of upcoming events. We expect that new appraisals result in altered and potentially more adaptive (or “intelligent”) emotional responses. Our working model of the interaction of elaborative encoding and prospective emotion regulation during REM dreaming is presented in Figure 1.

After successful elaborative encoding during REM dreaming, events will be appraised differently. Occasionally, however, elaborative encoding might be interrupted or might fail. In these cases, prospective emotion regulation is disturbed. Consequently, emotional load accumulates over the next day and thus demands more intentional and effortful emotion regulation attempts.

In sum, we argue that REM dreaming is able to redirect the flow of future emotions by elaboratively encoding novel events into existing memory networks, resulting in prospective emotion regulation. Next-day emotion dysregulation might be partially

explainable by interrupted (clinical insomnia, experimental sleep deprivation) or disturbed REM dreaming (psychiatric disorders such as posttraumatic stress or depressive disorder). If research corroborates the prospective emotion regulation function of REM dreaming, its investigation in the context of psychopathology might provide valuable insights.

Minding the dream self: Perspectives from the analysis of self-experience in dreams

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Abstract: Can ancient art of memory (AAOM) principles explain the function of dreaming? The analysis of self-experience in dreams suggests that the answer is no: The phenomenal dream self lacks certain dimensions that are crucial for the efficacy of AAOM in wakefulness. However, the comparison between dreams and AAOM may be fruitful by suggesting new perspectives for the study of lucid dreaming as well as an altered perspective on the efficacy of AAOM itself.

Llewellyn proposes a novel and ambitious account of the function of dreaming. Her key claim is that “REM [rapid eye movement] dreaming may be the archetypal state for the elaborative encoding of emotional declarative memories” (sect. 4, para. 7). On this view, dreaming serves a mnemonic function by virtue of its adherence to ancient art of memory (AAOM) principles. Based on the analysis of self-experience in dreams, I argue that while there is indeed a surface similarity between dreaming and AAOM in wakefulness, this does not warrant conclusions about the functions of dreaming. I then develop constructive suggestions for the comparison between AAOM in wakefulness and dreams.

In philosophy of mind, it is widely accepted that dreams involve phenomenal experience during sleep (e.g., Revonsuo 2006): it is *like* something to dream (and not just to remember dreams [cf. Dennett 1976; Malcolm 1959]). While many studies have shown that dreams typically involve a phenomenal self (e.g., Occhionero et al. 2005), the phenomenology of selfhood in dreams is impoverished compared with wakefulness. With the exception of lucid dreams, dreams are characterized by the metacognitive deficit: dreamers do not realize that they are dreaming and are unable to distance themselves critically from the unfolding dream narrative. Dreams are experienced not as simulations but as real (Metzinger 2003a; Windt & Metzinger 2007).

By contrast, AAOM is a technique, a mnemonic tool involving the deliberate and selective imaginative composition of material with the goal of making it more memorable. As Llewellyn’s discussion of AAOM shows, this involves several steps, such as dividing the to-be-remembered material into smaller parts and reorganizing it in a personally meaningful, emotionally salient manner. On the level of phenomenal experience, the resulting narrative retains its imaginative character and is experienced as the product of deliberate construction. Indeed, it is hard to see how AAOM could be effectively used as a mnemonic tool if the resulting narratives were *not* experienced as simulations: They would be confused with reality and lose their instrumental value.

A related difference between dreams and AAOM has to do with the phenomenology of agency. Llewellyn rightly points out that dreams typically involve the phenomenology of agentively interacting with real persons and objects in a real world. This type of agency, however, is distinct from the type of agency that is crucial for AAOM – namely, the phenomenology of deliberately constructing an imaginative narrative. This latter type of agency is typically missing in dreams. Consequently, dreams cannot be

described as the product of intelligent and deliberate authorship on the part of a phenomenal self (Windt, in press). Though the narrative structure and apparent meaningfulness of dreams resembles that of AAOM, dreams lack the phenomenology of agency for the process of dream construction. Llewellyn argues that REM dreaming more closely resembles imagination than perception in terms of brain activation and eye movement patterns (sect. 4.2.2, para. 4); however, such similarities on the neurobiological level of description are compatible with saying that there are important differences on the phenomenological level of description, for instance with respect to the phenomenology of agency. Moreover, a recent study in which researchers were able to predict the contents of dream reports from sleep-onset awakenings suggests that activation in the visual areas during sleep-onset dreams is equivalent to visual perception (Horikawa et al. 2013).

Memory also distinguishes dreams from AAOM. Spontaneous dream recall is a fleeting, highly unstable phenomenon, and a vast amount of research has shown that a majority of dreams are forgotten (Hobson et al. 2000; Schredl et al. 2003). Detailed dream recall, as in Llewellyn’s “Quicksand” dream, is the exception, not the rule. By contrast, a successful application of AAOM principles requires the integration of hard-to-remember facts into a *memorable* narrative. Though Llewellyn argues that nonconscious hippocampal indexing might account for the mnemonic function of dreams, she owes an explanation of why dreams themselves are not more memorable, especially if, as she claims, elaborative encoding during REM dreams “transpires at the phenomenological level” (sect. 4.2.5, para. 5).

In sum, the dissimilarities between dreaming and waking self-experience prevent dreams from contributing to elaborative encoding in the ways suggested by Llewellyn. Even if we concede that memory is the stuff dreams are made *on* – and this is simply the empiricist view that, in the absence of external sensory inputs, dreams must be derived from memory sources – there is reason to doubt Llewellyn’s more substantial claim that elaborative encoding is what dreaming is *for*.

Despite these objections, the comparison between dreaming and AAOM might be interesting in other ways. Lucid dreams involve insight into the fact that one is now dreaming and the ability to control the unfolding dream narrative (Voss et al. 2013). They are also more easily remembered than nonlucid dreams, and short- and long-term memory, both of which are deficient in nonlucid dreams, can reach waking levels (LaBerge 2007). Because lucid dreams thereby fulfill the requirements for a successful application of AAOM principles, trained lucid dreamers could actively and deliberately apply them while dreaming. While limiting its scope to lucid dreams arising from REM sleep (Dresler et al. 2012; Voss et al. 2009), this would be a new way of testing Llewellyn’s claim that “REM dreaming may provide the most conducive state for the elaborative encoding of personal emotionally salient memories” (sect. 6, para. 4).

The comparison between REM dreaming and AAOM is not limited, however, to lucid dreams. Whereas Llewellyn argues that elaborative encoding is attenuated in wakefulness as compared to dreaming (sect. 4, para. 7), I would like to suggest the contrary: AAOM might be efficient precisely because it involves a selective but incomplete simulation of the phenomenology of dreaming. On this view, the surface similarities between AAOM and dreaming – such as hyperassociativity, emotional salience, narrative structure, the involvement of self-related imagery, and the importance of visual and spatial imagery (cf. Windt 2010) – account for the efficacy of AAOM in wakefulness even though REM dreams themselves do *not* fulfill an elaborative encoding function. In particular, AAOM is effective only because it *fails* to replicate other characteristics of (nonlucid) dreams, such as the metacognitive deficit, the lack of agentive control for the unfolding narrative, and their incomplete integration with autobiographic memory. This switch in perspective from the function of dreaming to the efficacy of AAOM in wakefulness might provide a fruitful extension of Llewellyn’s comparison between AAOM and dreaming for future research.

Author's Response

Such stuff as REM and NREM dreams are made on? An elaboration

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Abstract: I argued that rapid eye movement (REM) dreaming is elaborative emotional encoding for episodic memories, sharing many features with the ancient art of memory (AAOM). In this framework, during non-rapid eye movement (NREM), dream scenes enable junctions between episodic networks in the cortex and are retained by the hippocampus as indices for retrieval. The commentaries, which varied in tone from patent enthusiasm to edgy scepticism, fall into seven natural groups: debate over the contribution of the illustrative dream and disputes over the nature of dreaming (discussed in sect. R1); how the framework extends to creativity, psychopathology, and sleep disturbances (sect. R2); the compatibility of the REM dream encoding function with emotional de-potentialisation (sect. R3); scepticism over similarities between REM dreaming and the AAOM (sect. R4); the function of NREM dreams in the sleep cycle (sect. R5); the fit of the junction hypothesis with current knowledge of cortical networks (sect. R6); and whether the hypothesis is falsifiable (including methodological challenges and evidence against the hypothesis) (sect. R7). Although the groups in sections R1–R6 appear quite disparate, I argue they all follow from the associative nature of dreaming.

I thank the commentators and appreciate the opportunity to respond to their commentaries. In what follows, I have concentrated on the challenges to my hypothesis, along with the suggested extensions, and give less attention to those commentaries that were relatively self-contained. Most contributors and readers of *Behavioral and Brain Sciences* are cognitive scientists and neuroscientists. The humanities are a neglected source of nuanced knowledge and new approaches to dreams and memory. My background is in narrative analysis, specifically how associations impose structure and create meaning in texts. I attempted to merge this interest in textual association with the traditional experimental approach to dream research. This merger was both congratulated and rejected as unscientific.

R1. The illustrative dream and the nature of dreaming

I argue dreams picture *associations* between episodic memories. One of my own dreams illustrates this process. To date, this is atypical in the scientific literature on dreaming.

Solms comments that cognitive neuroscience can gain from this careful use of real psychological data—that is, an individual dream report with self-identified personal associations. Others argue that cognitive neuroscience cannot side-step subjective first-person accounts: “Commitment...to [the] concept of the brain/mind as a unified system [implies that] the scientific study of such a system entails the mapping of features in the domain of subjective

experience onto features in the domain of neuroscience and vice versa” (Hobson et al. 2003, p. 242; see also Hobson 1999b; Wamsley & Stickgold 2011). Nielsen and Stenstrom (2005) suggest the relationship between the subjective experience of dreaming and the neuroscience of memory will be understood only when subjects are able to identify the non-obvious memory sources for their dreams. This is what I tried to do in “Quicksand,” where I argue that memory sources are non-obvious because they are hyperassociated.

Greenberg has the intriguing idea that my choice of “Quicksand,” a house purchase-sand-death dream, may represent anxiety about the response to my hypothesis: “Will anyone buy [my] new theoretical house?” (para. 2). Well, there have been 28 viewings, suggestions it shouldn’t be on the market, and a few offers.... On a conscious level, I chose this particular dream because it was the least revealing about me. Regarding Greenberg’s suggestion, on a conscious level, I’m not sure, but, naturally, this particular dream is consciously semantically associated with my article. At any rate, my elaborative encoding hypothesis is, as **Globus** points out, about the relating, associating, binding, merging, and fusing of memory elements to engender an authentically seamless world that one takes, whilst dreaming, to be real. I argue the reality of the dream adds to its emotional impact and, therefore, mnemonic function. But Globus questions, first, how this relating and binding occur and, second, what dreaming may reveal about ontology. Regarding the first question, on the physiological level, I point to the well-known roles of the hippocampus and gamma oscillations in binding and relating diverse phenomena.

On the phenomenological level, the hyperassociation of memories in dreams produces something new. This may also be the case for creativity in wake (see sect. R2). For example, Cercas (2001/2004, p. 146) writes, “To write novels you don’t need an imagination.... Just a memory. Novels are written by combining recollections.” Human beings can create something new from associating, merging, and fusing their memories in both dreams and wake. This does not seem to be grounds for arguing, as **Globus** does, that both waking and dreaming worlds are continually created *de novo*. Although during wake we cannot circumvent our sensory capabilities (and expectations formed from memories) to access “the real world”—as Nagel (1974) points out, the bat lives in a different world because it has a different subjective experience. I note that both Globus and **Bimler** point to an interesting link between dreaming and dual identities in quantum theory. For example, in my “Quicksand” dream, there is a house *or* a bridge. Only when the dream narrative imposes a particular context is the ambiguity resolved—in favour of the house—and the narrative can unfold.

R1.1. The nature of dreaming

I argue the nature of dreaming results from its highly associative content.

Hobson describes my hypothesis as neo-Freudian because it puts personally meaningful association (sand-house-bridge) at the centre of dream construction. Association condenses episodic memories. **Erdelyi**, although drawing on Freudian concepts of fusion and condensation, describes these associations as memory errors *only*,

disregarding cited evidence on the centrality of association for memory, although the highly associative nature of memory (Vutter–Mutter–Vater) does, indeed, sometimes lead to retrieval errors. **Porte** also relates my dream hypothesis to that of Freud, seeing them both as “high,” “top-down” theories (para. 2). I argued that REM dreaming, like waking, is self-organized. There is no central “top-down” generator. **Porte** suggests, instead of “high” theory, a puzzling “egalitarian” explanation grounded in cholinergic activation. As my theory is about the *function* of REM dreaming, even while her exposition of the cholinergic system and its role in dreaming is useful and accurate, I don’t comprehend how cholinergic activation explains the content, as opposed to the form, of dreams.

Another puzzle is **Solms’s** assertion that I take the position of REM/dream isomorphism. To clarify, I argue that REM and NREM dreams are characterized by unique physiology and dream structure and, *for many purposes* (i.e., not all purposes; see sect. R5) should be considered separately. **Solms** (2000/2003b) also differentiates REM and NREM dreams, commenting, “Few people would disagree that the average NREM dream is more ‘thoughtlike’ than the average REM dream” (p. 247). On the other hand, as I acknowledge, it is hard to distinguish late-night NREM from early-night REM dreams. My hypothesis points to an explanation of this seeming paradox. I elaborate in section R5.

Greenberg (see also **Erdelyi**) argues that the target article is incomplete because, although both the neurobiology and psychology of dreaming are reviewed, there is no thorough review of the clinical research on dreams and dreaming—without this, one leg of **Greenberg’s** three-legged stool is missing. But, as **Cicogna & Occhionero** point out, empirical research on dreams and dreaming is scant and inconsistent—the third leg is distinctly wobbly. This is one of the reasons I illustrated with “Quicksand” rather than cover the clinical research on dreaming.

Erdelyi lists several analogies that can be made with dreams and dreaming: aphasia, subliminal perception, hysterical symptoms, schizophrenia, jokes, daydreams, poetry, and Bartlettian and Freudian reconstruction. I agree. I cannot comment on all of these, but I suggest that, rather than disparate to each other and memory, they are all driven by association (or, in the case of aphasia and schizophrenia, disruption of associative processes). Association is fundamental to all forms of memory (e.g., see **Fuster** 1999).

R2. Extension to creativity and psychopathology in wake, and sleep disorders

Several commentators extended my argument to creativity, psychopathology in wake, and sleep disorders. Elaborative encoding relies on creativity to identify non-obvious associations. As our most associative state, REM dreaming may be a creativity analogue. In the context of a labile sleep–wake cycle, psychopathology in wake and sleep disorders may also be linked to associative REM dreaming, as explained in sections R2.1, R2.2 and R2.3.

R2.1. Dreaming and creativity

I agree with **DeYoung & Grazioplene** that, first, emotional associativity is not silenced in wake but merely subordinated, and, second, this suppression is less in more

creative individuals (such as writers) who may be elaboratively encoding their memories in wake (cf. **Cercas** 2001/2004). This is a testable proposition because, as **DeYoung & Grazioplene** point out, creativity in wake is probably enabled by the waking neuromodulatory balance shifting toward dreaming. But **DeYoung & Grazioplene** do not explain why this shift occurs, although they note individual variation in all neuromodulators and, in **DeYoung et al.** (2012), the increased risk for psychosis in creative individuals.

In **Llewellyn** (2011), I say why shifts in neuromodulatory systems occur and how these changes could engender what I term “de-differentiation” between waking and dreaming consciousness. I argue: “Within every 24 h, two self-organized, highly activated states are achieved: waking and dreaming. Therefore, in the mind/brain, it is intuitively likely that ‘order’ is represented by an achieved differentiation between waking and dreaming and ‘chaos’ (or disorder) results from their de-differentiation” (p. 1062). De-differentiation is a matter of degree, however. When the mind/brain is poised at self-organized criticality between order and disorder, it is optimized for complex tasks (**Kauffman** 1993, p. xv). In a state of “super-criticality” (see **Pearlmutter & Houghton**, para. 3) between waking and dreaming, the waking mind may be able to make the creative, imaginative leaps of association that, usually, are possible only during dreaming. This would foster creativity, which sees non-obvious associations (i.e., similarity between, seemingly dissimilar, things). Self-organized criticality implies that even small system perturbations can have large, unpredictable, and, sometimes, deleterious effects (**Bak** 1996; **Lewin** 1993, p. 11; **Orsucci** 2006). This may explain the link between creativity and psychopathology. In more creative individuals (who are in a state of super-criticality), further, albeit small, increases in the neuromodulators that characterize REM dreaming (dopamine and acetylcholine) may increase de-differentiation and precipitate psychopathology. In consequence, small differences in initial neuromodulatory conditions can engender very different outcomes: creativity or psychopathology.

R2.2. Dreaming and psychopathology in wake

D’Agostino & Scarone note that similarities between dreaming and psychosis have been remarked upon since Aristotle, and argue that dreams are the stuff that psychoses are made on. In **Llewellyn** (2011) I agree—the intrusion of the dreaming state into wake may precipitate psychosis. Psychotic individuals may also be encoding their memories in wake through hyperassociation. **Lake** (2008) demonstrated that careful observation and questioning of a patient exhibiting “loose associations,” “derailment,” and “flight of ideas” revealed the chain of personal associations that were driving his thinking. The difference between psychopathology and creativity may be one of degree. In psychosis, dreams are uncritically accepted as real, probably because REM dream physiology, including deactivation of the critical judgement and reality monitoring functions of the dorsolateral prefrontal cortex, characterize the waking state. **Solms** asks why we usually stay sane when remembering dreams in wake, simply because critical judgement and reality monitoring are switched on, so dreams are recognized *as* dreams.

I argue that **D'Agostino & Scarone** are considering only *one side* of a de-differentiation equation. In Llewellyn (2011), I review research on dynamic reciprocity among neuromodulatory systems, concluding that de-differentiation between waking and dreaming increases mesolimbic dopaminergic and cholinergic neuromodulation in wake, which may precipitate psychosis, whilst, simultaneously, *decreasing these neuromodulators in dreaming*. The latter may impede encoding in dreams. D'Agostino & Scarone point to Laviolette (2007), who argues that dopaminergic transmission encodes the emotional salience of events and is more ubiquitous in memory processes than has been recognized previously. The mnemonic role of acetylcholine is well established. Specifically, drugs that block acetylcholine receptors impair encoding and cholinergic effects have been argued to be important for the hippocampal encoding of episodic memories (e.g., see Hasselmo 2006). If REM dreaming elaboratively encodes episodic memories, decreases in cholinergic input and mesolimbic dopamine, consequent upon the de-differentiation of waking and dreaming, would impair memory hyperassociation.

Episodic memory enables both the retrieval of emotionally salient events from the past *and* the capacity to envisage the future (Schacter et al. 2007; see also **Girard**). Indeed, the core attribute of episodic memory may be the ability to vividly imagine and experience the agential self in time (Szpunar et al. 2007; Tulving 1993). **Markowitsch & Staniloiu** rightly point out that my definition of episodic memory should have highlighted this re-experiencing. Episodic envisaging would underpin the sense of self-continuity over time, a commitment to an emotionally salient to-be-achieved programme of action and the initiation of purposeful action in relation to this. Memory impairments in schizophrenia are episodic rather than semantic (Huron et al. 1995; Tendolkar et al. 2002). The negative symptoms of schizophrenia have been conceptualized as apathy, social isolation, diminished affect, and lack of motivation (e.g., see Andreasen 1990). I noted Solms and Turnbull's (2002) observation that patients who do not dream become "aspontaneous, inert and apathetic" (p. 312). Thus, there is similarity between the symptoms of non-dreaming patients and the negative aspects of schizophrenia. This suggests that the de-differentiation of waking and dreaming consciousness, resulting in loss of functionality for waking *and* dreaming, may engender not only positive (psychotic) symptoms in wake but negative symptoms also and, hence, ultimately, schizophrenia.

R2.3. Psychopathology and sleep disorders

Two commentaries discussed psychopathology and sleep disorders. **Van der Kloet, Merckelbach, & Lynn (van der Kloet et al.)** are interested in whether excessive REM is related to dissociative symptomatology. **Girard** focuses on the specific nature of hallucinations in sleep paralysis. I concur with van der Kloet et al. that dissociative symptoms are probably engendered by a labile sleep-wake cycle where dream-like mentation invades the waking state. Like **D'Agostino & Scarone**, I argue that, in psychosis, this dream invasion into wake occurs in a more severe and enduring form. I think van der Kloet et al. are right to say that dissociative symptoms are linked to unusual sleep experiences. I reason this reflects both sides of the de-differentiation equation—which exists because of the

reciprocity of the neuromodulatory systems involved in the sleep-wake cycle. Although both sides of the equation would not necessarily be equivalent in magnitude, when wake is invaded by more dream-like mentation, dreaming would tend to be permeated by more wake-like, externally oriented thought. The dreams of people with schizophrenia tend to be not as numerous, shorter, less implausible, less emotional, less elaborate, and less self-oriented (Biddle 1963; Hadjez et al. 2003; Kramer & Roth 1973), with reduced emotionality both as regards dream content and in terms of the dreamer's expression of emotions (Zanasi et al. 2011). Scarone et al. (2008) reported that the dreams of people with schizophrenia are as bizarre as the dreams of normal individuals. It should be noted, however, that people with schizophrenia may report coherent dreams as bizarre because of thought disorder (Schredl 2011).

The invasion of more wake-like thought into REM dreaming would engender episodic memory failures because of disruption to elaborative emotional encoding. People with dissociative symptoms would also be more likely to have false memories because dream-like mentation is being elaboratively encoded during wake. For example, with dissociative symptoms, I may become convinced I had seen a house covered with sand. As regards excessive REM, this may be the brain's autopoietic response to being in a de-differentiated state. Maturana and Varela (1980) emphasized the autopoiesis of living systems; such systems self-organize *and* self-produce. If an autopoietic system is disrupted, it "can compensate for perturbations through the realization of its autopoiesis" (Varela et al. 1974). If perturbed, in this case, de-differentiated, the brain, as an autopoietic system, may organize to try to reconstitute itself (Llewellyn 2009). This organizing potential is inherent in the production of a coherence self-organized whole from constituent parts. In consequence, if REM dream encoding is disrupted through de-differentiation, then the REM period may lengthen, or intensify, to compensate. This would explain **Kirov's** point about why excessive REM is not linked to more successful emotional encoding.

Girard's analysis of sleep paralysis can be seen as one facet of a labile sleep-wake cycle that engenders dissociations—in this case the intrusion of REM-related motor inhibition and hallucinations into waking consciousness. In my terms, this is also a transient instance of de-differentiation between waking and dreaming—that is, a hybrid labile state. As Girard points out, in this hybrid state, hallucinations, understandably, take a different form from those in REM dreams. In sleep paralysis, there may be some conscious awareness of what are usually non-conscious hyperassociations between movement-related memories. Conscious awareness of these (during the hybrid state of sleep paralysis) engenders out-of-body experiences or felt presence.

R3. Is the REM dream encoding function compatible with emotional de-potentialization?

My arguments emphasize the role of emotion in dreaming; episodic memory encoding is essentially emotional. For example, in "Quicksand," the central association is irrational fear. The experiences we remember are always

emotionally salient – otherwise why would we remember them? But it is evident that the emotional charge (whether positive or negative) of memories diminishes over time. Prime facie, it seems strange to contend that REM dreams, which are suffused with primary emotions, de-potentiate memories. I argue in the next section that the emotional charge of episodic memories may be absorbed through creating highly emotionally associative REM dream scenes/junctions.

R3.1. Redirecting the flow of emotions and reducing emotional charge over time

Emotional regulation redirects the flow of emotions from experiences (Westermann, Paulus, Müller-Pinzler, & Krach [Westermann et al.]). In the context of my arguments, this redirection is to the dream scene. This would reduce the emotional charge of the episodic memories (Desseilles & Duclos) associated in the dream scene. Emotional regulation may occur in REM because this state is characterized by the suppression of the aminergic system (Hobson et al. 2003). Noradrenergic input has been linked to anxiety and stress disorders (Sullivan et al. 1999). Therefore, revisiting emotional experiences in the absence of noradrenaline may de-potentiate them (Walker & van der Helm 2009). Similarly, van Marle et al. (2013) showed that administering cortisol during sleep prioritized memory processes for emotional items but reduced emotional responses to the items during retrieval in wake. Westermann et al. point out that REM sleep has been shown to increase habituation. My “Quicksand” dream could enable habituation through the identification of my previous experiences of irrational fear, particularly in the absence of noradrenaline.

Desseilles & Duclos argue that highly traumatic events are often replayed in their entirety in dreams. This may be because nothing in the individual’s emotional history has prepared them for this particular trauma. In my terms, the memory fails to be associated with other previous memories and integrated into cortical networks because no previous associations are as negatively charged. The high emotional charge of the new traumatic event is not reduced through encoding. In consequence, as Westermann et al. predict, emotional load accumulates.

R3.2. REM dreaming, children’s episodic networks, and infantile amnesia

Desseilles & Duclos, Kirov, and Markowitsch & Staniloiu mention REM dreaming in children. A similar logic to the foregoing paragraph may apply to infantile amnesia. My model depends on the capacity to identify non-obvious emotional associations between personal memories and portray these in mental imagery during dreaming. Young children lack this ability. First, they are still working out which associations are obvious, necessary, and destined to become part of their semantic knowledge (e.g., train – station – motion – seat – ticket) and which are non-obvious, contingent, and episodic (e.g., travelling on the mid-morning train – with my mother – we sat opposite this friendly lady – who asked me where I was going – I enjoyed telling her I was going to London). Obviously semantic associations will be encountered frequently. Hence, semantic networks are likely to form earlier than

episodic. Second, young children do not have a rich history of emotional episodic experiences to which new ones can be associated. Third, children’s mental imagery ability and visuo-spatial skills develop gradually. In consequence, it seems highly unlikely that very young children remember experiences through an episodic memory network with associative, integrative junctions. Children’s memories may form around simple associations, but their networks are likely to be much less integrative than those of adults.

Markowitsch & Staniloiu cite evidence in support of this: The episodic memory system develops later in life; infants do not have episodic memory; children’s mental imagery abilities and visuo-spatial skills increase significantly after the age of seven; during the first years of life the hippocampus (essential for making associations between episodic memories) is still immature so episodic memories cannot be formed but semantic ones can – through parahippocampal areas. There is also evidence that, in children, more adult-type dreams, featuring the agential self in dynamic, emotionally charged narratives, develop over the period from 5 to 15 years of age (Domhoff 2005; Foulkes 1982; Foulkes et al. 1990). In the light of this evidence, during childhood, more sophisticated adult-type episodic networks are likely to develop gradually but, because of their different organization and structure (e.g., dynamic instantiation of junctions), may not incorporate early childhood networks. This may explain infantile amnesia.

Furthermore, if integrative adult networks do not incorporate those of early childhood, the emotional load of any traumatic early childhood experiences will not be reduced because they have not been associated with previous memories at junctions. Early traumatic childhood memories may “seek access” to the adult network in REM dreams (cf. Freud), but the associations may be too emotionally charged for hyperassociation – in REM dreams – to occur. This possibility may be what happens in the second scene of the “Quicksand” dream, in which a child/baby is thrown and disappears into the sand. These non-de-potentiated memories from early childhood are too disturbing. I awake in terror.

Kirov and Markowitsch & Staniloiu raise the question of why infants have so much REM sleep if not required for episodic memory encoding. REM sleep is needed for motor-perceptual memories (Rauchs et al. 2005) which, clearly, are relevant from birth. Incidentally, my argument is not that REM sleep (or even REM dreaming) only serves elaborative encoding. I agree with Kirov that REM sleep serves several functions. Also, as argued in this section, emotional encoding of episodic memories during dreaming is compatible with emotional de-potentiation (Desseilles & Duclos and Westermann et al.). Indeed, the elaborative, emotional encoding of memories and emotional de-potentiation are probably mutually constitutive – that is, they depend on each other.

I argue that episodic memory is *dynamic* rather than “consolidated” (in the sense of stabilized) – new junctions, formed around new nexuses of emotional associations in REM dreams, are instantiated in cortical networks during NREM sleep. Hence, the emotional load of episodic memories reduces and the emotional *significance* of personal memories over time, too, because memories acquire new associations as recent events are incorporated in networks.

R4. Scepticism over similarities between REM dreaming and the ancient art of memory

I argue that the essence of the analogy between REM dreams and the ancient art of memory (AAOM) is that they both *associate* memories in an (often bizarre) visual image.

Contemporary uses of the AAOM occur in memory championships. In a competition to remember a deck of cards that have been turned over three at a time, the king of diamonds, for example, could be represented by Bruce Springsteen as the “king” and diamonds as “smashing a guitar.” If the king of diamonds is turned up with, say, the four of spades (black feather hat digging a massive hole) and the four of diamonds (black feather hat smashing a guitar), then the composite image for all three cards merges each card’s image and some elements can be omitted: Bruce wearing a black feather hat smashing a guitar through digging a massive hole. This bizarre composite image greatly enhances the retrieval of the memories of the three separate cards because it associates them. It should be noted the AAOM requires the three cards are retained in memory *and* the image that associates them. This is the case for my hypothesis about REM dreaming, also.

To remember the sequence of each three-card composite image, these are placed along a familiar or memorized route (the method of loci [MoL]). Critical commentaries on the analogy between REM dreams and the AAOM focused on, first, the conscious, intentional nature of the AAOM image as opposed to the (usually) non-conscious dream scene and, second, whether dream scenes follow the MoL.

R4.1. Non-conscious dream scenes/junctions, episodic memory, and spatial memory

To clarify, I agree with Crick and Mitchison (1983, p. 112), the function of dreaming is, “more likely to be associated with the unconscious dreaming process...rather than with the few dreams which are recalled” (p. 112). My hypothesis does *not* depend on dream recall into wake. However, **Axmacher & Fell**, along with **Blagrove, Ruby, & Eichenlaub** (Blagrove et al.) and **Windt** take issue with me on the grounds that dreams are not usually recalled into waking consciousness, whereas the AAOM occurs during wake and produces a conscious mnemotechnique. In consequence, they question whether dreaming can function mnemonically. Axmacher & Fell remark, “A mnemotechnique that sets individual memory contents into a framework that is inherently difficult to remember is paradoxical” (para. 1). To clarify, a mnemotechnique makes memories easier to *retain* and *retrieve* because they are elaboratively encoded – that is, associated. My memory framework posits that REM dream scenes encode and are used to retrieve episodic memories. To perform these dual *related* functions, dream scenes are not lost but retained both as junctions between episodic networks in the cortex and as hippocampal indices. On retrieval, these indices/junctions are *processed* by the mind/brain as indices are matched to the corresponding junctions. This processing cuts across a strict conscious/non-conscious dichotomy. Dew and Cabeza (2011) identify “porous boundaries” between conscious and non-conscious memory; the processing of non-conscious dream scenes to retrieve episodic memories

into waking consciousness would be enabled by these porous boundaries.

Dream scenes do not usually reach waking consciousness. But nor are dream scenes non-conscious in the sense of “cannot be accessed.” One definition of *remembered* is “recalled into waking consciousness,” but another is “retained in memory.” Dreams are not usually recalled but, I argue, they are *retained* in memory. In their aforementioned comment, **Axmacher & Fell** distinguish between episodic memory contents and the organizing memory *framework*. Using their distinction, episodic memories are retrieved into waking consciousness. The framework (i.e., non-conscious dream scenes/junctions) is not retrieved but is processed.

One reason for the non-retrieval of junctions into wake may be because episodic memory networks evolved from those for spatial memory. Memory for spatial location is automatic, and information about location can be used as retrieval cues (Hasher & Zacks 1979). During spatial navigation, information about objects placed at junctions (where a decision has to be made over where to go next) can be processed—even if that information cannot be retrieved into wake (Janzen & van Turenhout 2004). Junction locations are represented (and can be retrieved) without recall into waking consciousness (Janzen et al. 2007). Objects placed at junctions are automatically strongly associated with them; this differential representation (compared to objects not at junctions) would lead to faster recognition for junctions compared to other places along a navigational route (Janzen 2006). Faster recognition of junctions and the automatic processing of the information associated with them would greatly facilitate decisions over where to go next. The evolutionary advantages (e.g., in fleeing predators) of this for spatial navigation are clear. If episodic memory evolved from spatial memory, the substrate for spatial memory will persist in episodic memory. In consequence, there is an evolutionary reason why episodic junctions are non-conscious. Such an arrangement would facilitate fast retrieval from multiple junctions and, thus, parallel processing in networks (see sect. R7).

Windt says I owe an explanation of why dreams are not more memorable. There are physiological causes. In terms of my arguments, if the dream scene/junction does not have to be retrieved *before* retrieval of the episodic micro-event memory that converges on it, retrieval is much faster. Moreover, multiple micro-events that make up a *reconstructed* episodic memory (e.g., see Schacter & Addis 2007a) can be retrieved without having to retrieve a multiplicity of mnemonic devices/dream scenes. The evidence already cited demonstrates navigation at a junction without conscious retrieval; given that episodic memory evolved from spatial memory, this evolutionary advantage may be retained in episodic networks.

Two points of clarification with regard to memory retrieval: First, **Axmacher & Fell** state, “The idea is that dreams trigger subsequent retrieval of parts of the episodes that are retained in them through non-conscious processes” (para. 1). This is not my position. To clarify, non-conscious dream scenes are retained both at junctions in episodic memory networks and as hippocampal indices. On retrieval, an index is matched to the corresponding junction/dream scene. The relevant episodic memory micro-event will be retrieved from one of the network paths that converge on the junction – *not from the dream scene itself – which*

merges memory elements from all the episodic memory paths that converge on the dream scene/function. Second, Axmacher & Fell state, “Dream memories also typically contain much less detail than does memory for experiences acquired during waking state” (para. 1). I agree, seeing this as support for my hypothesis that dream scenes are retained as indices.

An index is a *sparse* (or reduced) representation of material held elsewhere. The dentate gyrus is functionally specialized to instantiate sparse representations which are projected onto hippocampal region CA3 during encoding (Rolls 2007; see also Karlsson & Frank 2008; Waydo et al. 2006). An index also enables access to many locations. Hence, a sparse visual index must embed multiple associations. Dream scenes are sparse as compared to visual perception of the environment in waking (Llewellyn 2011). If dream scenes are retained as hippocampal indices, this may explain their sparseness.

In “Quicksand,” I experience things I have never experienced in wake—for example, walking down a street and seeing a house completely covered in sand. The evolution of episodic memory from spatial memory may also explain why we experience the never-experienced in dreams. Gupta et al. (2010) showed that, during sleep in rodents, there is replay of experienced routes but also replay of *constructed, never experienced* routes; the authors characterize these never experienced routes as “short-cuts.” As episodic memory evolved from spatial memory, experiencing never-experienced short-cut routes during sleep in animals may be the neural substrate from which human dreams evolved.

R4.1.1. Can REM dreams be mnemonic if not intentionally designed to this end? Blagrove et al. and Windt question whether REM dreaming can serve a mnemonic function—similar to the AAOM—because an AAOM mnemotechnique is created knowingly and intentionally for this purpose, whereas a REM dream is not. Windt argues that dreams are not the result of “intelligent and deliberate authorship” (para. 4). I agree they are not deliberate in the sense of intentional, but I argue dreams are intelligent—they are *emotionally* intelligent (cf. DeYoung & Grazio-**plene**). Emotional intelligence is required to identify the personal, emotional, *non-obvious* associations which create dream scenes. Authorship? Who is the author of my dreams if not me?

Blagrove et al. say, “Dreams are precisely ‘provided’ to us” (para. 4). But many debate this: For example, contra Hobson et al. (2003), Solms (2000/2003b), states, “Specific forebrain mechanisms are involved in the generation of dream imagery and this imagery is *actively* constructed through complex cognition processes” (p. 56, emphasis added). Solms also argues that dreaming is generated by the dopaminergic, “seeking” or “wanting,” system (p. 55). Thus, Solms’s observation, contra the target article, that dreams are “passive,” is somewhat surprising. Can seeking be passive? My position is the same as Solms (2000/2003b): Dreams are actively constructed, although not intentionally designed, as mnemotechniques.

If not intention, what impels the associations in REM dreaming? There are two “seeking” answers: (a) highly charged emotional connections and (b) instinctive drives (cf. Freud). As stated in section R1, I chose the “Quicksand” dream from amongst my repertoire because it was

the least revealing about me. Many of the emotional connections and instinctive drives in REM dreaming are not particularly comfortable to the psyche in waking consciousness. Therefore, knowing and intending could detract from the emotional and instinctive associations that serve mnemonic purposes in REM dreams.

A phenomenon can serve a purpose even if not intentionally designed to that end. As already stated, there is evidence that episodic memory function evolved from spatial memory function. Evolution is blind, it has no purpose, but it throws up products that serve purposes (Dawkins 1986). One of these blindly made products with a purpose may be a REM dream. Notably, a functional magnetic resonance imaging (fMRI) study of superior memorizers (i.e., individuals who win the World Memory Championships) engaged in wake on processing and memorising information showed preferential engagement of medial parietal cortex, right posterior hippocampus, and retrosplenial cortex (Maguire et al. 2003), this study did not show engagement of lateral pre-frontal cortices, as would be expected for intentions (e.g., see Pochon et al. 2001). It may be surmised that, in the AAOM, intentions to produce a mnemotechnique precede memorising; the latter, like REM dreams, do not engage lateral pre-frontal cortices.

R4.2. REM dreams and elaborative encoding

Spoormaker, Czisch, & Holsboer (Spoormaker et al.) challenge my idea that REM dreams are elaborative encoding. They cite Spaniol et al.’s (2009) fMRI meta-analysis of episodic encoding in wake which shows increased activity in hippocampus, amygdala, inferior temporal gyrus, and lateral prefrontal cortices, whereas from slow-wave sleep (SWS) to REM sleep lateral prefrontal cortices show a decrease. But my hypothesis is about *emotional* elaborative encoding, a process that identifies non-obvious *emotional* associations between episodic events. In Spaniol et al.’s meta-analysis of encoding/retrieval during wake, in 20 of the 26 studies the stimulus was a word—none of the 26 studies tested for encoding episodic events. In terms of regional brain activation, emotional associative encoding of episodic events is likely to differ from encoding words during wake. Indeed, in an fMRI study, McDermott et al. (2009) showed that laboratory word-based studies to test episodic memory shared very few regions of overlap with studies where participants were asked to remember real-life events. Hence, it is unsurprising that fMRI studies of encoding words during wake do not show all of the same regional activations as studies of REM sleep.

Spoormaker et al. also cite the Maguire et al. (2003) study of superior memorizers who demonstrated preferential engagement of the retrosplenial cortex (RSC) during encoding. In a review, Vann et al. (2009) found that the RSC is involved in episodic memory and imagination, specifically in translating allocentric viewpoints to egocentric. In the study by Maguire et al., the superior memorizers translated digits into images; this could account for the engagement of the RSC. Spoormaker et al. equate the RSC and the posterior cingulate cortex, arguing that the posterior cingulate cortex shows a decrease from SWS to REM sleep. But this equation is not justified. The Vann et al. review showed the importance of distinguishing the function of the RSC from other parts of the posterior

cingulate region, arguing that “the RSC is most likely to be involved in hippocampus-dependent functions” (p. 793).

R4.3. Dream scenes and the method of loci

Nielsen presents a detailed case against the method of loci (MoL) operating in dreams – *in exactly the same way* as it does in contemporary mnemonic techniques (see also **Dresler & Konrad**). To clarify, my hypothesis does *not* rely on dream scenes following each other along a personally familiar route (or rote memorized path as in a memory palace); this would pre-determine the order in which episodic memories are retrieved and, thus, greatly reduce memory flexibility. Nielsen notes that the MoL is a favoured technique amongst memory champions. This is because contemporary mnemonic competitions often test the ability to remember serially ordered material and recall that material *in the same order* – as noted by Dresler & Konrad.

The original uses of ordering in the AAOM were *not* to recover lists of items but to increase memory flexibility so that oratory digressions were possible. The AAOM focussed mainly on the encoding of material needed for what were, often, extempore events, such as sermons, lectures, or disputations before live audiences (Carruthers & Ziolkowski 2002, p. 3). On such occasions, it was important, clearly, to be able to extemporize. Using the AAOM, in classical antiquity, speakers could digress, to enlarge on points, because they were always sure of “where they were” in their speeches, “not in the manner of a parrot (which reciting mindlessly, never knows ‘where it is’) but in the manner of an experienced harbour pilot recalling landmarks” (p. 5).

With respect to retrieval from places, my argument is analogous to the original use of the AAOM, resting on episodic micro-event memories being recovered from *places* (i.e., junctions/retained dream scenes in the cortex) to reconstruct memories in flexible ways. In consequence, the question is how the ordering of these places (cortical junctions/hippocampal indices) is structured to enable flexibility. As **Nielsen** remarks, this ordering of dream scenes may be emotionally associational rather than spatially associational – which would be anticipated if episodic memory evolved from spatial memory. I argued, “The associations forged in REM dreaming may originally have encoded spatial landmarks but through evolutionary time became episodic” (sect. 4.2.5, para. 4). In the “Quicksand” illustration, my remote “fear of quicksand” memory has a subordinate role in scene 2 (the cloth-shroud-death-sand association to the house) but assumes a central role in scene 3, where a child/baby is thrown across the sand and disappears. Thus, it may be possible to trace emotionally salient associations across dream scenes through assuming that a peripheral (to the particular scene) emotional association in one scene becomes dominant in the next.

Dresler & Konrad suggest that mnemonic techniques linked to ordering (spatially or emotionally associational) are less relevant for episodic memories because such memories are already in sequential order. But the key attribute of human episodic and semantic memory is *flexibility* – so that memories can be used in future situations that differ from the original past context (e.g., see Reber et al. 1996; Schacter & Addis 2007a; Schacter et al. 2007). Linked to

this flexibility is the ability to identify non-obvious patterns among seemingly different events.

In the AAOM, to enhance memory flexibility, the to-be-remembered material is split up into *divisiones* or *distinctiones* (Carruthers and Ziolkowski 2002, p. 4). Similarly, I argue that in REM dreams episodic memories are split into micro-events through pattern separation in the hippocampus. This may explain the Grosmark et al. (2012) finding of synaptic downscaling in the hippocampus during REM sleep (see **Kirov**). Pattern separation facilitates flexibility because micro-events can be assembled differently. For example, in “Quicksand,” the micro-event memory of photographing bridges was an aspect of the U.S. holiday memory, but, equally, it could be retrieved in the context of memories of challenging photography experiences or feature in a discussion about bridge construction. In the latter two cases, the U.S. holiday context is irrelevant. In any case, who wants to listen to me reminiscing about the whole of my U.S. holiday? Freeing episodic micro-events from their whole memory context – to enable flexibility – greatly enhances individual learning and social interaction. Given this flexibility, how does ordering of the hippocampal index work in retrieval? I address this next.

R5. The function of NREM dreams in the sleep cycle

I argue that, during NREM sleep, associative REM dream scenes are instantiated in cortical networks as junctions and retained by the hippocampus as indices. Physiologically, these events may reflect the temporal correlation between cortical spindles (the instantiation of junctions) and hippocampal sharp-wave/ripple bursts (the retention of indices). But how is the hippocampal index ordered? I argue next that flexibility in ordering is introduced by the associative function of NREM dreams.

R5.1. The ordering of the hippocampal index

On retrieval, hippocampal indices are matched against cortical junctions, and the ordering of the hippocampal index enables this matching. Thus, cognitive maps in the hippocampus (O’Keefe & Nadel 1978) represent junctions/landmarks in the cortex. **Cheng & Werning** agree that hippocampal place cells may represent spatial locations in the cortex. I argue that hippocampal indices would be activated by place cell firing. However, the memory output from any input (external stimulus or internal thought) may not be pre-determined solely by the ordering of REM dream scenes. The reason may relate to the function of NREM dreams.

R5.2. What is the function of NREM dreams?

Cicogna & Occihionero reason that associative areas are similarly activated in REM and NREM and that the function of both REM and NREM dreams may be the forging of associations.

I argue that emotional hyperassociation is the basis for REM dreams and also that emotional association (not *hyper*association) drives the ordering of dream scenes and, thus, the ordering of hippocampal indices in the

retrieval of emotional episodic memories. The function of NREM dreams may be related to the associative ordering of the hippocampal index.

I noted a contrast between REM and NREM sleep with regard to association. Stickgold et al. (1999) showed that, “contrary to normal pattern of priming, subjects awakened from REM sleep showed greater priming by weak primes than by strong primes.... In contrast, strong priming exceeded weak priming in NREM sleep” (p. 182). They argue that weak priming immediately after awakening from REM sleep may reflect the hyperassociative nature of REM dreams. NREM dream associations may have greater similarity to the more logical associations made in wake. These NREM associations may be analogous to “cross-references” in the hippocampal “index.”

I illustrate this with a dream that may be from NREM. (Details and hypothesized memory sources are in the Appendix.) Briefly, the dream occurred during an afternoon nap after arriving at a motel. My recent memories/concerns are these: I plan to swim later and have a drink in the motel bar where I saw a man sitting with his back to me. For a woman travelling alone, this bar looks OK. I am concerned that I have not brought a sufficient supply of contact lenses for my trip; and I am attracted to K.C., who, I think, is split from his partner, like me. My remote memories/concerns are these: an emotional problem with my youngest son and a weekend with him in Barcelona; and a conference in Barcelona where, on arrival, I was confused about location.

Scene 3 is the most detailed. I suggest this dream scene is from the previous REM period (see the Appendix). In NREM, this scene is being instantiated as a junction, and the scene is again consciously experienced, albeit in a different neuromodulatory milieu. Consequently, like a dream report in wake, a NREM dream experience of a REM dream will differ.

As instantiation occurs, the hippocampus identifies associations between scene 3 and other more remote memories/concerns at other cortical junctions: My attraction to K.C., who goes frequently to Barcelona (scene 5); and arriving at a conference venue in Barcelona and walking back to my hotel from this conference (scenes 4 and 6). Scenes 1 and 2, being with my sisters by the sea and at the pool, when, because I was not wearing contact lenses, I could never see well, and scene 2, the kiss, may be cross-references to the previously instantiated junction, which will be related to Barcelona. All of these NREM associations may be analogous to cross-references in the hippocampal index; they are associations *between* junctions rather than associations *within* junctions, as in REM dreams:

Barcelona, Bar-sea-lona, Bar-see-loner: a dream illustration of more thought-like associations in simple, shorter scenes (1, 2, and 4–6) as would be engendered by strong primes, in contrast to the more complex, less obvious associations in scene 3, as would be reflected in weak primes.

Scene 1 (Swimming with my sisters was always associated with not seeing well, so “swimming with sisters” would be a strong prime for “not seeing well”). I’m lying in the sunshine. My sisters are with me. It’s a beautiful day, the light is perfect, but everything is a bit blurry. Why can’t I see very well? I am by a curvy swimming pool, but, at the same time, it feels as though I’m by

the sea. (Cross-reference from the previously instantiated junction.)

Scene 2 (I am attracted to K.C., so “K.C.” would be a strong prime for “kiss”). K.C. is kissing me, a long, deep kiss (this may be in scene 1 or there may not be a location for this kiss). (Cross-reference from the previously instantiated junction.)

Scene 3 (Complex associations between emotional issues with my youngest son, a weekend with him in Barcelona, finding more contact lenses, and spatial directions which would be engendered by weak primes). I am walking along a street in the sunshine with an expanse of long, flat water on one side. In the distance, I see D. (my youngest son) and feel worried. He stands with, but slightly apart from, some girls. I call to him to hurry up and join me, but he doesn’t seem to want to; at any rate, he stays right where he is. I feel lonely and wonder why he doesn’t come to me. I probably have to accept that he would rather be with girls now. I pick up a huge, shiny, elongated triangle off the ground. It was pointing up to where D. is. What is this? It is most peculiar. Whilst being a triangle, it is also transparent, reflective, floppy, and curved. It is concave when looked at from beneath and convex when viewed from the top. I am unsure of what to do with this object. (Instantiation of hippocampal “Barcelona” index/junction.)

Scene 4 (Arriving at a conference in Barcelona, I thought I was in the wrong place, so “arriving at a conference in Barcelona” would be a strong prime for “wrong place”). I have reached a crossroads and I’m not sure of the way. I think that it must be downhill. Suddenly the crossroads dissolves into a large, paved, shiny white open space/place. Where am I? (“Barcelona” cross-reference.)

Scene 5 (I am attracted to K.C., and he is substituted for the man in the bar so “man in a red jacket in Barcelona” would be a strong prime for “K.C.”). I enter a bar. I see K.C. from behind, sitting at the bar. He is wearing his red jacket. He is chatting with friends (men and women) and doesn’t notice me. I would like to join him—but feel that I cannot. (“Barcelona” cross-reference.)

Scene 6 (Confident of directions, I return to my Barcelona hotel after the conference, so “returning to Barcelona hotel” would be a strong prime for “confident of directions”). I am back again on the street-alone, walking downwards but feeling quite serene. (“Barcelona” cross-reference.)

This hypothesis of the associative function of NREM dreams implies increased functional cortico-cortical connectivity in stage 2 NREM as junctions are instantiated and associated with already instantiated junctions. The instantiation of new junctions would be facilitated by prior network reorganization during SWS. Spoormaker et al. (2010) demonstrated the development of a large-scale functional brain network during human NREM sleep and confirmed the Massimini et al. (2005) finding of a breakdown in cortical connectivity in SWS.

Spoormaker et al. cite Baylor and Cavallero (2001) who state that more episodic memory traces are recovered from NREM dreams than from REM. I agree this would be the case. In “Barcelona,” my memories/concerns are relatively transparent. I enter a bar (scene 5), am lying by a pool, not able to see (scene 1), and pick up a contact lens (scene 3).

Episodic elements are more difficult to identify in REM dreams like “Quicksand” because the memories are *hyper-associated* rather than only *associated*, as is the case in “Barcelona.” Hyperassociation renders memory elements less identifiable.

Hassabis et al. (2009) argue that the hippocampal neural code (index) has functional organization. If hippocampal indices are related thematically (both emotionally between REM dream scenes and more linear-logically between NREM dream scenes), multiple indices can be called up in succession. This sequential ordering relies on identifying associations *between* patterns through recurrent connections in CA3 (for a review, see Bird & Burgess 2008). Thus, whether in direct response to internal hippocampal indexical representations or through external stimuli which are matched against these indices, several cortical junctions can be identified that enable access to the several components of a whole episodic memory (the U.S. holiday) or, through cross-references, a series of associated micro-events (e.g., several of my photography experiences or several personal associations with Barcelona). This is reconstruction (cf. Bartlett 1932; also see Neisser 1962; Schachtel 1947). Entire episodes cannot be immediately “read off.” Thus, the hippocampal index (with both entries [REM dream scenes] and cross-references [NREM dream scenes]) ensures both *ordering* and *flexibility* when a stimulus triggers memory retrieval.

For example, suppose I meet someone at a party (where social chit-chat is required) who also knows Barcelona well. I have several episodic associations with the place (memory flexibility) because the “Barcelona” hippocampal index has cross-references. I can match one of these to the interests of the party companion—to start a conversation. If the person is an academic, I can talk about the conference. If the person happened to go there with one of their children, I can chat about my weekend with my son. The stimulus “Barcelona” does not trigger some predetermined extended episodic memory (in the way the MoL can be used to generate a list). This would be a social faux pas—because I would have failed to relate my interests to those of my new acquaintance. Equally, the stimulus “Barcelona” could enable learning because I could associate the contact-lens crisis with a series of other travelling-with-contact-lens disasters to work out how to avoid them.

Cicogna & Occihionero recommend that future research address the question of the recall, during dreaming, of previously encoded dream episodes/scenes because dreams, retrieved into dreaming, may serve as a basis for generating the dreams that follow them. In the foregoing, I suggest this is exactly what happens in the NREM dreams that follow REM dreams. The instantiation of a REM dream as a junction in NREM again triggers the REM dream, albeit experienced somewhat differently. The hippocampus then identifies associations between the REM dream scene/junction in NREM and the dream scene/junctions already instantiated in the cortex. This associative function in NREM maintains ordering in the hippocampal index, but through incorporating cross-references also ensures the *flexibility* of episodic memory.

Hence, I agree with **Dominey** that my hippocampal indexing model of memory retrieval is based not on the reconstruction of a *single* state trajectory but, flexibly, on the reconstruction of one (or more) of *several* state trajectories. This is ensured by cross-references in the

hippocampal index. Dominey describes hippocampal indices as “snapshots.” Again I agree with this because in modelling the cortex as a dynamic network memory system my model concurs with his.

R5.3. What is the function of the different sleep stages across the night?

Axmacher & Fell, Blagrove et al., and Deliens, Schwartz, & Peigneux (Deliens et al.) point out that if REM dreams are instantiated as junctions in NREM, then, logically, NREM sleep should follow REM (and some does), but most NREM sleep occurs in the first half of the night.

This objection disregards my statements about the earlier instantiation of semantic material in NREM:

Word-pair learning prior to sleep correlated with recall after sleep, having induced higher spindle activity; the spindle effect was largest during the first 90 minutes of sleep (Gais et al. 2002), as would be consistent with the earlier instantiation of semantic (knowledge based) material. Tamminen et al. (2010) showed that spindle activity was associated with the integration of new semantic knowledge, acquired during wake, with existing neocortical knowledge. Therefore, semantic associations (formed during wake) could be instantiated (or “integrated”) as junctions during earlier periods of NREM sleep (target article, sect. 8, para. 3).

If semantic material is instantiated in networks in earlier periods of NREM sleep, it may be necessary to distinguish between semantic and episodic memory when considering memory processes across sleep stages. This is in line with **Cicogna & Occihionero’s** arguments about the intricacy of sleep stages and the need to distinguish them carefully. In a review, Fogel and Smith (2011) suggest that complex memory tasks may require REM sleep, whereas simpler ones and/or tasks already fully encoded during wake may only require NREM sleep. In my terms, this implies that semantic knowledge that is fully encoded in wake is instantiated during early-night NREM, whereas episodic memories that are not fully encoded during wake undergo further emotional encoding in REM. Therefore, semantic material (or knowledge) encoded in wake may be instantiated and integrated into semantic memory networks during the first half of the night whilst episodic memories may be instantiated and integrated into episodic networks in the second half of the night. This would explain why early-night NREM dreams are less emotionally charged and more thought-like, whereas later-night NREM dreams (that follow REM) become more emotional and more REM dream-like as the night progresses.

I noted that Clemens et al. (2005) found a correlation between time in NREM sleep and visuo-spatial memory, as demonstrated by the retention of faces. This may be consistent with the earlier instantiation of verbal memory junctions through slow spindles and the later instantiation of visuo-spatial memory junctions through fast spindles after the onset of REM dreaming. The topographic distribution of spindles may also be relevant because slow (verbal) spindles have a more frontal, anterior distribution, whereas fast (visuo-spatial) spindles have a centro-parietal, more posterior distribution (for a review, see Fogel & Smith 2011). This implies that the shift in dream content over-night (more thought-like to more emotional) reflects movement across memory networks from anterior to posterior. If

this is correct, when I recorded “Barcelona” – after waking from a 4-hour sleep during the day – I was approximately halfway through this cycle. I may have captured a NREM dream after the first short REM period. This would explain the more semantic nature of this dream; up until this point NREM dreams had been associating semantic material. Specific REM periods may be linked to particular tasks (Smith 1993; Smith et al. 2004). For example, Stickgold et al. (2000) found that, on a visual discrimination task, performance was correlated with the amount of REM sleep in the last quarter of the night. This would make sense if REM dreams become more visuo-spatially complex over the course of the night. The first short REM period may be encoding memories/concerns that are related to semantic material, like the word “Barcelona.” A significant aspect of human memory is the recall of associations to people, places or, even, symbolically significant objects that *occurred at different times*, and the first REM/NREM cycle may support these types of memories.

Drawing on Braun et al. (1997) and Maquet et al. (1996), **Spoormaker et al.** state that the REM sleep recruits only the *anterior* part of episodic memory networks, but Braun et al. investigated the first REM period only, during which, if the aforementioned temporal shift from anterior, more semantically associated, to posterior visuo-spatial, more emotionally intense, hyperassociated REM dream content is correct, only the anterior aspect would be recruited. However, later REM periods would recruit posterior parts of the episodic network. Maquet et al. looked at two REM periods, but their analysis averaged out cortical activations specific to these periods. Therefore, Spoormaker et al.’s assumption about the recruitment of only the anterior part of episodic networks during REM sleep is somewhat risky.

R6. Associative memory networks

Memories are represented in associative brain networks. To be incorporated in networks, memories have to be associated. A recent experience that has no associations with previous ones cannot be comprehended and, hence, cannot be encoded and incorporated. In their entirety, episodic memories are unique and somewhat problematic for incorporation. This is one reason why I argue they are split into micro-events, which are encoded separately. These micro-event memories are dispersed in the cortex and represented (as are other micro-event memories) along network paths that converge at associative junctions which have been created during REM dreams. How does this fit with current network models?

R6.1. Fit with current network models

Mattei argues that my ideas of how memories are encoded in networks are supported by the current “hodotopic model” of brain function (para. 3), which relies on local recurrent activity and parallel processing driven by non-linear (chaotic) dynamics. Cross-references in the hippocampal index are non-linear and may further support parallel processing.

When connectionist computational models, to explore parallel, distributed processing, are built, they include hidden units which mediate between the inputs and the

outputs. Older connectionist models lacked these hidden units. In consequence, they modelled only stimulus-response type behaviour. With hidden units, the model becomes non-linear and can solve more complex problems and tackle an increased range of problem types (Rumelhart & McClelland 1986). The hidden units embed deep associations between the inputs and outputs through abstracting away from their more superficial features. With hidden units, the model can also better differentiate among the inputs to enable more nuanced outputs.

I suggest these hidden units in connectionist models are analogous to the non-conscious junctions/dream scenes that are *processed* during retrieval of episodic memories. The title of **Mattei**’s commentary refers to the *secret* at the crossroads. The associations embedded in junctions/crossroads between episodic micro-events abstract away from the more superficial aspects of the micro-events. For example, the central non-obvious (secret) association hidden in the various micro-events that converge on the “Quicksand” junction is irrational fear. The “Quicksand” junction also enables differentiation between the micro-events because this irrational fear association is non-obvious – that is, the phone call to my eldest son, fear of quicksand, photographing bridges in the U.S., and my middle son’s hearing problem are, superficially, very different.

R6.2. The nature of associative network junctions/dream scenes

Cheng & Werning point to further physiological evidence for aspects of my hypothesis, but they assume an argument against me by contending REM sleep generates “invariant object representations.” This puzzled me because a central association between episodic micro-events is invariant. For example, after abstraction from more superficial features, irrational fear is an invariant feature of the micro-events in “Quicksand.” I was also surprised that **Deliens et al.** characterize REM dream associations as *de novo*. Rather, irrational fear in “Quicksand” is identified through pattern identification, which is *novel* (rather than *de novo*) because it is *non-obvious*. In wake, I would be unlikely to see a pattern between the phone call to my eldest son, fear of quicksand, photographing bridges in the U.S., and my middle son’s hearing problem. To the waking mind, these seem disparate. Perogamvros and Schwartz (2012) argue that dopaminergic activation during REM sleep favours unusual (non-obvious) associations. The irrational fear association is unusual, given the nature of the micro-events involved.

Pearlmutter & Houghton argue that memory processes during sleep are secondary – the primary purpose of sleep is tuning for criticality. But, surely, sleep, like wake, has a multitude of purposes. I agree with their tuning-for-criticality idea when they say:

The obvious goals of learning, rapid responses to stimuli and prolonged retention of short-term memories, are, from a network dynamics point of view, attributes of near-critical systems. Thus, it is likely that, during learning, neuronal circuits become increasingly critical and approach super-critical behaviour – behaviour that would involve runaway oscillations and constitute a pathological disruption of normal brain function. (Pearlmutter & Houghton commentary, para. 2)

Sleep provides an opportunity to tune cortical networks to prevent runaway oscillations. I argue junctions achieve

this because they are sites of inhibition that avoid runaway oscillations. **Pearlmutter & Houghton** say that super-critical, uncontrolled behaviour would result if the network was not fully tuned during sleep. Creativity is super-critical behaviour (see sect. R2): If tuning is impeded because of increasing de-differentiation between wake and sleep, uncontrolled behaviour (e.g., psychosis or, ultimately, schizophrenia) may result. I noted spindle impairment in early psychosis and reduced spindle activity in schizophrenia.

R7. Is the hypothesis falsifiable?

Erdelyi, Nielsen, Hobson, and Schredl say testing is important. I agree. As Nielsen points out, the hypothesis is complex. I think setting out the detail of the hypothesis along with supporting evidence to date was required prior to testing. I proposed some testing modes. Schredl states that, of the tests I proposed, whether the AAOM in wake engenders a shift to a more dream-like neurobiological state is the most promising. I agree. The commentaries have suggested more tests.

R7.1. Tests suggested by the commentators

Dominey remarks that indexation is potentially testable through re-injecting indices into the neocortex to enable the unfolding of an episodic sequence. **Cicogna & Occihionero** stress the significance of dreaming in different sleep stages. I propose: NREM stage 2 dreams in the first half of the night enable the formation of junctions in semantic networks; the first REM period hyperassociates semantic and episodic memories, the next NREM period enables the formation of junctions in anterior episodic networks and associations between new junctions and ones already instantiated; and later REM periods hyperassociate emotional episodic memories that, in NREM, enable the formation of junctions in posterior episodic networks and associations between junctions. This is testable through careful analysis of dream associations along with fMRI of regional brain activation. **Dresler & Konrad** undertook a simple qualitative test of my hypothesis through asking memory champions whether mnemonics feels like dreaming. The answer was equivocal. A single question may be inconclusive, but several may work—for example, enquiring as to the similarity between the mnemonic AAOM product and a dream. Dresler & Konrad demonstrated that, after memory champions use mnemonic techniques, their REM sleep duration and REM density do not differ from those of mnemonically naïve controls. However, methodological considerations may be relevant. Dresler & Konrad state that their test required the encoding of declarative information, but this could have been episodic memories or semantic material. If the latter, changes in REM sleep parameters would not be expected—rather the impact would be on NREM sleep. Moreover, it is uncertain what impact successful elaborative emotional encoding of recent episodic memories during wake would have on subsequent REM sleep. Would there be less to encode in REM dreams? However, testing my hypothesis with memory champions is important. Another testing avenue, which is implicit in the **Markowitsch & Staniloiu** commentary, is testing whether more creative individuals,

like writers, are encoding their episodic memories in wake and, therefore, would show an enduring neurobiological shift to a state of mind/brain more REM dream-like.

R7.2. Possible evidence against the hypothesis?

Solms argues that there is evidence against my hypothesis on two grounds: First, the loss of dreaming in patients with cerebral lesions, investigated by Solms (1997) and Yu (2006), showed no demonstrable effect on episodic memory. But, so far as I can ascertain, neither Solms nor Yu tested for episodic memory loss, so Solms's conclusion seems somewhat cavalier. On his memory testing, Solms (1997) remarks:

I select the appropriate tests according to the unfolding clinical picture. However I usually begin with a simple Hidden Objects Test and follow up any signs of abnormality with systematic tests of rote verbal and visual learning [these rote verbal and visual learning tests are specified].... Thereafter, I typically assess more complex aspects of recent memory [here several protocols are mentioned, none of which tests for recent episodic memory loss]. (Solms 1997, pp. 257–58, insertions in square brackets in the preceding text are mine)

Over and above these tests, Solms (1997) remarks, “I assessed remote memory informally by questioning patients about significant public events and popular television programmes” (p. 258). Such questioning does not test patients' memory for their remote episodic experiences; it probes their remote semantic memory. Moreover, Yu (2006) comes to a rather different conclusion from Solms—he states that “it is perhaps unsurprising to find that most patients who have ceased dreaming also experience memory deficits” (p. 192). Yu describes his tests as follows: “The neuropsychological battery used in this study is composed of three primary parts, which measure executive functions, visual memory and verbal memory respectively. These three components constitute a critical test for the potential association between dream cessation and memory dysfunction” (p. 192). Unfortunately, these critical tests did not seem to include appropriate testing for patients' episodic memories. In this context, as mentioned previously, Solms and Turnbull (2002) observe that non-dreaming patients become “asapontaneous, inert and apathetic” (p. 312). This would be anticipated if there is episodic memory loss, because this would erode the patients' ability to imagine, plan, and enact the future (see sect. R2).

Second, **Solms** comments that bilateral hippocampal lesions, causing total loss of episodic memory, have no demonstrable effect on the occurrence of REM-like dreams. But why does he think this relevant? My hypothesis is not concerned with mechanisms that control the occurrence of the dream state but with dreaming *functionality*. Mere occurrence does not ensure functionality. For example, the wake state *occurs* in people with schizophrenia, but their waking *functionality* is severely impaired. Similarly, Solms argues that dreaming is not *controlled* by hippocampal mechanisms. If, by “controlled,” Solms means *generated* in the sleep cycle, I agree; but if he implies that hippocampal mechanisms are not involved in dream physiology and phenomenology and, hence, possibly in dream function, I disagree. At any rate, if Solms's lesion work is continuing and if appropriate episodic memory tests are applied, this work is significant with regard to testing

my hypothesis (but see **Schredl**, who identifies some methodological difficulties with lesion work).

Markowitsch & Staniloiu point out that testing for relationships between episodic memory and dreams will depend on how episodic memory is conceptualized and the nature of the testing paradigms employed. This is exemplified in the previously mentioned McDermott et al. (2009) study which demonstrated that laboratory word-based studies to test episodic memory shared very few regions of overlap with studies where participants were asked to remember and re-experience real-life events.

Axmacher & Fell say there is little evidence that dreaming is significant for memory, but how could there be significant evidence in view of the scant research to date? As **Nielsen** points out, though, there is actually a recent upsurge of interest in the role of dreaming in memory processes (e.g., see Smith 2010; Wamsley & Stickgold 2011; Wamsley et al. 2010). This is unsurprising given the escalating experimental evidence on the links between sleep and memory. I would welcome the opportunity to be involved in experimental approaches to test my ideas and those of others so that, as **Hobson** puts it, I “stand up” as an experimentalist. The experimental approach is fundamental to science. On the other hand, when I entered the field of dream research, I was surprised at the dearth of theory. I believe passionately in the complementary contributions of theory and data so that data can support or challenge theory and theory can situate and give meaning to data. To paraphrase Immanuel Kant, theory without data is *empty*, but data without theory is *blind*.

R8. Concluding comments

When a research field, generally, lacks theory, such theory as there is can dominate because there is little competition. This seems to be the case with the theory of memory *consolidation*, to which many sleep and dream researchers seem to have a blind allegiance. As I have argued, *consolidation* is now an umbrella term with many different meanings, both general (“strengthening,” “stabilization,” “storage,” and “resistance to interference”) and specific (“synaptic plasticity and long-term potentiation” and “system integration”). Despite consolidation implying stabilization, the term *reconsolidation* is also in use. Such imprecision can lead to confusion. How can the possible relative contributions of REM and NREM sleep and/or dreams to declarative memory processes be identified experimentally without more nuanced concepts? Surely the wealth of experimental data now available means that it is now time to sharpen conceptual tools to give more meaning to empirical findings and situate them theoretically.

In response to the commentaries, I have elaborated my hypothesis by using several concepts: elaborative encoding, indexation, junction instantiation, indices, cross-references, and retrieval. I argue that these provide a more nuanced understanding of the complex choreography of memory processes and sleep stages than does the overextended concept of memory consolidation.

I argued that the REM dream encoding process can, at least partially, be understood through AAOM principles. Several commentators point to differences between the AAOM and REM dreaming—clearly there will be some because the two occur in different states. These differences

relate to the intentional nature of the AAOM, in contrast to the more emotional and instinctive nature of REM dreaming. But intention, emotion, and instinct can all drive associations. During wake, pre-frontal regions are involved in encoding, whereas, during REM dreams, encoding is mediated by the limbic system. This difference reflects the type of material being encoded—mainly semantic in the AAOM but primarily episodic and emotional in REM dreams. The first REM period may mark a transition between semantic instantiation and episodic encoding and may provide the best analogy to the AAOM because the AAOM uses REM-like processes on semantic material. Despite some differences in production processes between the AAOM and REM dreaming, I argue that there is a *common prime producer* at work—the hippocampus—and, consequently, the *product* of both the AAOM and REM dreams is similar. I argue that this product is a composite mnemonic whole expressed in visual, often bizarre, imagery resulting from hippocampal associative function working to relate, bind, and integrate memories during both wake and sleep.

The peculiar nature of both REM and NREM dreams flows from their mnemonic function. I continue to argue that a REM dream scene is retained by the hippocampus as an index and instantiated as a junction in cortical networks in NREM stage 2 sleep. In this elaboration, I hypothesize that this instantiation again gives to the dream, but, in the different neuromodulatory milieu of NREM, more thought-like processes identify associations between this new junction and ones already instantiated. In consequence, a NREM dream that follows REM creates episodic cross-references in the hippocampal index. The NREM dreams that precede the first REM period result from the instantiation of semantic material that is more fully encoded during wake. This dual process REM/NREM dream model ensures both order *and* flexibility in episodic memory retrieval.

APPENDIX

B. Waking experiences on which “Barcelona” is based

In the early morning of Sunday, January 12, 2003, I landed in Melbourne after a long-haul flight from the U.K. I was only going to be here for a day on my way to New Zealand to spend a month as a visiting professor. By 8:00 a.m., I booked into a motor inn. On my arrival at this motel, I noticed two things particularly: the swimming pool (empty) and the bar/restaurant (there was a man in it—sitting at the bar alone, with his back to me). I love swimming, and the weather was great, so I wanted to find time to enjoy the pool while I was there. Also, I was pleased by the look of the bar/restaurant, which appeared to be the sort of place a woman travelling alone would feel comfortable in. I was planning already to go there in the evening to enjoy a gin and tonic and maybe something to eat.

I felt in a good mood, not too tired, and I decided to have a nap first, and then visit the pool in the afternoon before dinner. The only issue: I thought I forgot to bring a sufficient supply of contact lenses with me. I am extremely short-sighted and cannot cope without lenses. I worried just a little about getting them in New Zealand. (Even in the U.K., my regular optician has to order them in.) As I went to sleep, I knew I needed to remember some things: not to sleep too long to sample the pool before dinner; and to check through my case properly for extra lenses (if they were not there, I would ring my youngest son or my partner to ask him to send some more).

The word “Barcelona/Bar-sea-lona/Bar-see-loner” did not feature in the dream (in the sense that none of the dream characters articulated it), yet it was the central motif. The sea/pool/water and light/warmth/sunshine that feature in scenes 1 and 3 reminded me, whilst I was asleep, of the pleasures of swimming. The peculiar object in scene 3 may have been two things simultaneously: a triangular road marking and a contact lens. When I stay over at my partner’s and look out of the bedroom window in the morning, I am looking up a street that ends in a T-junction – but this junction is in the foreground of my line of vision with the usual elongated triangle that marks it consequently appearing particularly prominent. This object is blended because it is also one of my contact lenses – I am hoping that they “turn up” in my case so that I don’t have to give my youngest son or my partner the hassle of “looking out” for them and sending out some more. My vision is out of focus in scene 1, an associated memory of not being able to see without lenses.

In scenes 4–6 I am alone/-lona/a loner. What about K.C.? I am attracted to this man and believe that he may be also alone.

My youngest son D. appears in scene 3. I am thinking of asking him or my partner to look for the lenses. The scene also reflects a difficulty that I think characterizes our relationship and is keeping us apart (not elaborated here for personal reasons).

In this dream, the central theme is Barcelona. But why does Barcelona pull everything together? Before this New Zealand trip, the last place I visited for work was Barcelona. When I arrived at the airport, I took a taxi to the conference site, but as I got out of the taxi suddenly something didn’t seem quite right – was I in the right place? This is the crossroads/large paved area in scene 4. I made myself check with the driver that he had delivered me to the correct location before he departed. After exiting the taxi, I also oriented myself at this point (indicated by the elongated triangle arrow in scene 3) before I entered the conference building so that I wouldn’t get lost later in the day – a distinct prospect for me as I often get mixed up over directions, particularly in places that I’m not familiar with. A year previous to my solo conference visit, I enjoyed a weekend with D. in Barcelona and had hoped that this would be a bonding experience for us both. Other scenes relate to syllables in the word “Barcelona.” Scene 1 is “sea (see).” Scene 5 is “bar” (with the man I saw on arrival at the hotel, who is transposed into K.C.). Scene 7 is “lona (loner)”

Finally, in the dream, I seem to have decided that it is wise not to (or infeasible to) pursue K.C. – who travels frequently to Barcelona – because the same person who informed that he lives apart from his partner also told me that he has a woman there.

The central theme of this dream is Barcelona. All of the scenes in this dream relate to various aspects of my past and present personal connections with this place, and the word itself connotes several things that I need to remember, the bar, the sea/swimming pool, and the fact that I am alone.

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[The letters “a” and “r” before author’s initials stand for target article and response references, respectively]

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