

David Kahn, Stanley Krippner & Allan Combs

Dreaming and the Self-Organizing Brain

Abstract: *We argue that the rapid eye movement (REM) dream experiences owe their structure and meaning to inherent self-organizing properties of the brain itself. Thus, we offer a common meeting ground for brain based studies of dreaming and traditional psychological dream theory. Our view is that the dreaming brain is a self-organizing system highly sensitive to internally generated influences. Several lines of evidence support a process view of the brain as a system near the edge of chaos, one that is highly sensitive to internal influences. Such sensitivity is due to several factors. First, the dreaming brain normally gates out external input and thus operates without the stabilizing influences of external feedback. Second, the pre-frontal cortex is only minimally activated during REM sleep, and hence the brain operates with weakened volition, reduced logic, and diminished self-reflection. Third, because the neuromodulatory inhibition mechanism is turned off during REM, the brain responds spontaneously to the least provocation. In addition, the dreaming brain is also subject to powerful intermittent cholinergic stimulation which may stimulate creative patterns of dream activity.*

Introduction

Over the past three decades numerous empirical and theoretical investigations have made it apparent that self-organizing dynamics are fundamental to processes at many levels of the organic as well as the physical world (e.g., Kauffman, 1993; Laszlo, 1987; Maturana *et al.*, 1974; Prigogine & Stengers, 1984). Recent work shows this to be no less true for the brain (e.g., Freeman, 1991; Kahn & Hobson, 1993; Kahn *et al.*, 1997; Pribram, 1995; Varela *et al.*, 1991), and indeed for the process structure of human experience itself (e.g., Combs, 1996; Combs & Krippner, 1998). The present paper examines such self-organizing dynamics in the brain with the aim of understanding the REM dream experience and how it differs from waking consciousness. We begin with the brain.

The Self-Organizing Brain

Many lines of evidence argue for the idea that the brain is a self-organizing system comprised of self-organizing subsystems. To begin with, how could it be otherwise?

Correspondence: Allan Combs, Department of Psychology, University of North Carolina, Asheville, NC 28804-8508, USA. Email: combs@unca.edu

Journal of Consciousness Studies, 7, No. 7, 2000, pp. 4–11

Though the brain is commonly conceptualized in terms of neural networks and circuitry, there seems little doubt that this circuitry is not rigid, but is significantly influenced by neurological development, day-to-day learning experiences, and many types of neuromodulation. Thus, the apparent neuroanatomical stability of the brain hides beneath itself many dynamic processes of change. Moreover, the widespread and continuous presence of both single unit firing and mass activity suggests that *process* itself is an essential feature of the brain, as important as anatomy. While machines and passive electrical circuits can spend indefinite periods of time in inactivity, self-organizing and self-creating (*autopoietic*) systems such as ecologies and living organisms are constantly in motion, as indeed is the living brain.

Many of the activity patterns exhibited by the brain are indicative of complex underlying self-organizing processes. The EEG rhythm, for example, tends to be roughly cyclic, but is not precisely so. It's global form is easily recognized, but the exact shape of it's waves differs from cycle to cycle, defying precise prediction. Moreover, it is unlikely that it ever exactly repeats itself. This situation of global familiarity combined with non-predictability, in a pattern that never precisely repeats itself, is exactly what defines a *chaotic* process, one whose action describes a *strange*, or 'chaotic', *attractor* (Kellert, 1993).¹ Such attractors appear to be a common if not universal feature of complex self-organizing systems such as living cells, ecologies, and evidently brains as well (e.g., Abraham & Gilgen, 1994; Basar, 1990; Freeman, 1995; Pribram, 1995; Robertson & Combs, 1995; but see also Mandell & Selz, 1997).

Additionally, the human EEG exhibits significant fractal structure (e.g., Basar, 1990; Screenivason *et al.*, 1999), further suggesting that it is the result of complex self-organizing processes (Anderson & Mandell, 1996). With regard to REM sleep, at least one investigation (Babloyantz, 1990) found REM sleep EEG to exhibit higher dimensionality than slow wave sleep, suggesting the play of a larger number of underlying influences, as one might expect if EEG activity in any way reflects the complexity of accompanying dream experiences. Anderson and Mandell (1996), who have made detailed studies of the temporal structure of REM state electrical activity in fetal rats, believe that such activity reflects self-organizing hierarchical integrative processes in the developing nervous system. Interestingly, preliminary evidence indicates that this integrative process may follow an abnormal developmental course in the case of autistic individuals (Tanguay *et al.*, 1976).

The fractal constituency of the EEG also suggests the possibility that the brain resides in a state of *self-organized criticality* (Bak, 1996). A system is said to be in a *critical* state if a small stimulation can set it into fluctuation on all length or temporal scales — in other words, if the response distribution is fractal. The classic example of a critically poised system is a sand pile ready to cascade into an avalanche when a single grain of sand is dropped onto it. Bak points out that the brain must also be critically poised. Otherwise it would not, for instance, respond globally to the appearance of a single visual image which carries but a minute amount of actual physical energy. Unlike the sand pile, however, the brain is not a randomly organized static structure,

[1] An *attractor* is a pattern of behaviour toward which all nearby patterns (or trajectories) converge. If they converge to a perfectly cyclic pattern we have a *cyclic attractor* and in a physical system we are dealing with something like a clock, that always settles into a regular rhythm. When mathematicians discovered equations for attractors that never settle down in this fashion they humorously called them 'strange', and these have continued to be known as *strange* or *chaotic* attractors.

but an enormously complex ongoing dynamical process system, a product of its own self-organizing tendencies, and thus can rightly be said to exhibit *self-organized* criticality. With regard to the importance of self-organized criticality in biological systems, Stewart Kauffman (1993) observed that ‘selection achieves and maintains complex systems poised on the boundary or edge between order and chaos. These systems are best able to coordinate complex tasks and evolve in a complex environment’ (p. xv).

All this is simply another way of understanding the notion that even small influences can exert sizable or even dramatic effects on ongoing patterns of brain activity. The best known example of this is the *butterfly effect*, which refers to the idea that no matter how small an external influence (such as sensory stimulation) might be, this influence, when compounded through many recurrent cycles of system activity, can grow to virtually unlimited proportions (Kellert, 1993; Peak, 1994).² More important than the butterfly effect, however, is the seemingly paradoxical effect known as *stochastic resonance*, that has been demonstrated in electronic circuits as well as in nerve cells (Moss and Wiesenfeld, 1995). It refers to the fact that the presence of vibration or noise keeps the system in motion and tracking an overall course of least resistance, rather than getting stuck in small groves or ‘minima’. For instance, an object on a vibrating tabletop will sometimes ‘walk’ about, especially if the table is not level, following the overall line of least resistance down the slope of the surface. Stochastic resonance can actually improve the effective signal-to-noise ratio in a communication situation. In the brain it may allow ongoing processes to ‘relax’ into inherently natural patterns of activity, an important point to which we will return shortly.

First, let us consider the possibility that the brain’s activity, like that of other extremely complex systems such as the weather, can be understood as an exquisitely intricate strange attractor, one exhibiting an intricate array of ‘wings’ or ‘compartments’ (Goertzel, 1994). During wakefulness the shape of this attractor, especially in the sensory cortices, is powerfully constrained by sensory input, which itself is often highly patterned (e.g., Gibson, 1966; 1979). Freeman and his colleagues (Freeman, 1991; 1995; Freeman & Barrie, 1994) have mapped such attractors in a variety of different sensory cortices. They found that the sensory regions of the brain are critically poised to respond robustly and in an ordered fashion to even the smallest stimulation. In the REM state, however, such attractors are not constrained by sensory input. In this state the self-organizing dynamics of the brain are set into motion not by external stimulation but by its own internal situation. Interestingly, it is possible to find such self-organizational dynamics at work in the waking state as well. Freeman, for instance, discovered that new learning experiences actually modify previously established cortical activity patterns. For example, a rabbit’s original cortical response to an odour is altered when the odour is experienced in a new context, such as a classical conditioning situation. Freeman interprets such changes to signify that the *meaning*

[2] This effect was originally discovered by meteorologist Edward Lorenz (1963) in models of fluid convection. It came to be known technically as *sensitive dependence on initial conditions* and is a distinguishing feature of chaotic behaviour. In the popular literature, as most present readers will know, the ‘butterfly effect’ refers to the notion that the stroke of the butterfly’s wing, say, in Brazil, might cascade a few days later into a hurricane in the Bahamas — or alternatively quell a potential hurricane there.

of the stimulus is as important in the production of the brain's response as the physical structure of the stimulus itself. Speaking informally, Freeman (1997) once observed that if one sees *Hamlet*, then sees *Rosencrantz and Guildenstern are Dead*, returning to *Hamlet* finds it to be a different play.

The Dreaming Brain

During REM sleep the brain is as active as it is during the waking state.³ However, information processing is inner-oriented as distinct from the outer sensory orientation of waking. In this state a number of factors combine to make the brain acutely reactive to internally generated influences. To begin with, the stabilizing effects of external sensory input are actively inhibited. Also, there is a shift away from widespread aminergic neuromodulatory inhibition which dominates the waking brain, toward cholinergic modulation that predisposes the sleeping brain to easy activation (Hobson, 1994; 1988).

In terms of activation patterns in the REM sleeping brain, recent investigations using PET scans (Braun, *et al.*, 1997; 1998; Maquet, *et al.*, 1996) show notable arousal of the extrastriate visual cortex, especially in the ventral processing stream. Notable activation is also seen in limbic and para-limbic structures, most significantly in the anterior cingulate and the amygdaloid complexes. Meanwhile, activity in the dorsolateral pre-frontal cortex is markedly reduced. Taken together, these findings point toward emotional arousal during dreaming, while at the same time suggest a reduction of memory as well as diminished capacity for logic and self-reflection. These conclusions are entirely consistent with many studies of the subjective qualities of REM dreaming (e.g., Hall & Van de Castle, 1966; Tonay, 1991).

Interestingly, Braun *et al.* (1998) also report decreased activation of the primary visual cortex during REM. This observation may seem surprising, since a deactivated primary visual cortex due, say, to a stroke results in the absence of visual awareness. It is, however, consistent with the suggestion that the conscious experience of vision is more directly associated with the extrastriate association areas, and their connections with the frontal cortex, than with the primary visual cortex itself (Crick & Koch, 1995; Koch, 1998; Revonsuo, 1998). In line with this, lesion studies show that damage to the extrastriate cortex, as well as damage to the parietal operculum and to the mediobasal frontal cortex, result in decreased dreaming (Solms, 1997; Hobson, *et al.*, 1998a). Patients who reported a global cessation of dreaming had damage in the parietal convexity or suffered disconnection of the mediobasal frontal cortex from the brainstem and diencephalic limbic regions, (Solms, 1997; Hobson *et al.*, 1998b).

PGO Stimulation, the Dream, and the Self-Organizing Brain

Sleep affords the opportunity, within certain limits, for the brain to act of itself, and dreams are the result.

Edward Clarke, *A Study of False Sight* (1878).

A prominent feature of REM sleep is the presence of large PGO (pontine-geniculate-occipital) spikes which originate in the brainstem, travel upward to the lateral geniculate bodies of the thalamus, and then on to the occipital lobes where they exert

[3] This paper does not pursue the knotty debate over the meaning or even existence of non-REM dreaming, but for an excellent critical review of this question see the recent paper by Hobson *et al.* (2000).

powerful cholinergic stimulation (Callaway *et al.*, 1987). Hobson and McCarley (1977) proposed in their original *activation-synthesis hypothesis* that this PGO activity is interpreted by the visual brain as sensory stimulation. In this view dreams resulted from efforts of the visual brain to make sense out of random PGO bombardment. Taken on face value this idea leaves relatively little room for dream experiences to be taken seriously as meaningful. Recently, however, Hobson and one of the present authors took the initial steps toward exploring the notion that the content of dream consciousness is the result of self-organizing dynamics in the brain (Kahn & Hobson, 1993). This approach, continued in the present paper, offers the potential of shedding light on how coherent dream experiences can result from the influence of seemingly unpatterned PGO stimulation. From our point of view, PGO activity might have two effects on the dreaming brain.

First, the cortical bombardment by PGO spikes might act as a perturbation to the dreaming visual cortex, creating stochastic resonance. The resulting effect would be something like that of tapping a drumhead on which sand has been sprinkled. In response to this action the sand forms complex patterns characteristic of the dynamics of the drumhead itself. These induced vibrations allow the system of the sand on the drumhead to ‘relax’ into its own unique configuration. In like fashion, this raising of the cortical ‘temperature’ by PGO stimulation would allow the ongoing patterns of cortical activity to relax into natural forms (attractors) shaped by the emotional and cognitive influences present at each moment (see also Globus, 1989). The origins of these influences are addressed below, but the point is that the dreaming brain, isolated from external sensory constraints, is subject to even subtle influences, which might lead to sizable effects on patterns of neural activity (Combs & Krippner, 1998). Such effects are felt experientially as the conscious flow of the dream. This does not mean, for instance, that dream narratives carry no forward momentum of their own. Indeed, the creation of stories seems to be virtually obligatory to the human mind and brain. Rather, the pelting of the cortex by PGO waves ‘heats up’ the entire process, yielding a stochastic resonance effect that does not let the system stagnate, but keeps it going in forward motion that is sensitive to the changing psychophysiological state of the brain — or in other words keeps the dream narrative in motion. As an interesting aside, we note that PGO timing becomes progressively more coherent over the neo-cortex during periods of REM sleep, suggestive of an underlying self-organizing stochastic process (Amzica & Steriade, 1996).

Second, the bombardment of the visual cortex with PGO waves might also have the effect of frequently derailing ongoing patterns of activity, or in other words producing ‘catastrophic bifurcations’⁴ in the attractor patterns there. One might imagine abrupt alterations in dream experiences at those times. Consistent with this idea, Mamelak and Hobson (1989) have suggested that PGO stimulation is tied to the high rate of narrative or plot shifts experienced during REM dreaming. Such shifts are significantly more frequent in REM dreaming than during dreaming reported from slow wave sleep (Cavallero *et al.*, 1992). Indeed, they seem essential to the ‘bizarreness’ of REM dreams (Porte & Hobson, 1986). Abrupt transitions in dream content are made all the more effortless during REM sleep by a diminished short-term memory and the

[4] A transformation in the form of an attractor is termed a *bifurcation*; if it occurs abruptly it is called a *catastrophic bifurcation*.

loss of a continuous objective sense of self (e.g., see Purcell *et al.*, 1986), both perhaps related to the fact that the prefrontal lobes are essentially taken off-line in the REM state.

Turning to other influences that mould the content of dreams, the observation of high activation in certain limbic structures during REM sleep is consistent with the hypothesis that emotional factors play a significant role in dreams. The brain clearly does not receive such emotional influences passively, however, but incorporates them into complex self-organized attractor patterns that play themselves out as dream narratives (Combs & Krippner, 1998). Other influences on dream content include long-term episodic and semantic memories 'relaxed' into the dream narrative, as well as recent experiences whose emotional residues remain written on the mind and the brain for as long as a few hours to a few days (Globus, 1989). Freud (1900/1955), for instance, pointed out rightly that much dream content is directly related to experiences of the prior day, a view that has found general support ever since (Hall & Van de Castle, 1966).

Recalling the importance of the butterfly effect in systems governed by chaotic dynamics suggests that even subtler influences might also be operative in the dreaming brain. These could include, for example, narratives and symbols laid down as Hebbian networks early in the development of the brain, perhaps through personal experience or even by genetic patterning (e.g., Edelman, 1992; 2000). If such networks exist they could do much to give the interpretative views of dynamic psychology a grounding in the study of the brain.

The actual details of how the brain transforms each night's panoply of emotional and cognitive influences into the rich and flowing experiences of dream life remains a deep mystery. These presentations, however, in which reality is essentially preserved, but stretched, turned about, and parcelled out into fragments, 'look' a lot more like the outcome of dynamical processes than of computational ones. Gordon Globus (1995), who has expressed similar ideas about the dreaming brain, observes of dreams that offer solutions to personal problems:

There is no unconsciousness intelligence, no 'wisdom of the species' personified in the archetype of the Wise Old Man, that is sending me a message of how to deal with this problem, as Jung thought. Instead the networks spontaneously move toward harmonious self-consistency: the 'wisdom' is akin to that of a rubber band that spontaneously relaxes after it has been stretched, but of course the neural system is much more complex. *The spontaneous movement under the harmony principle provides the dream.* The best solution to my problem is spontaneously generated by this self-organizing process (p. 10).

Dreams are still a mystery. But now they are a mystery of the brain as well as a mystery of the mind, or, more succinctly, of the brain-mind, and as such may yield to continuing scientific efforts.

References

- Abraham, F. and Gilgen, A. (1994), *Chaos Theory in Psychology* (Westport, CT: Greenwood Press).
 Amzica, F. and Steriade, M. (1996), 'Progressive cortical synchronization of ponto-geniculo-occipital potentials during rapid eye movement sleep', *Letter to Neuroscience*, **72** (2), pp. 309–14.
 Anderson, C.M. and Mandell, A.L. (1996), 'Fractal time and the foundations of consciousness: Vertical convergence of 1/f phenomena from ion channels to behavioral states', in *Fractals of Brain*,

- Fractals of Mind: In Search of a Secret Symmetry Bond; Advances in Consciousness Research*, 7, ed. M. Stamenov and G. Globus (Amsterdam and Philadelphia: John Benjamin).
- Babloyantz, A. (1990), 'Chaotic dynamics in brain activity', in *Chaos in Brain Function*, ed. E. Basar (Berlin: Springer-Verlag).
- Bak, P. (1996), *How Nature Works: The Science of Self-Organized Criticality* (New York: Springer-Verlag).
- Basar E. (ed.), (1990), *Chaos in Brain Function* (Berlin: Springer-Verlag).
- Braun, A.R., Balkin, T.J., Wesensten, N.J., Carson, R.E., Varga, M., Baldwin, P., Selbie, S., Belenky, G., Herscovitch, P. (1997), 'Regional cerebral blood flow throughout the sleep-wake cycle', *Brain*, **120**, pp. 1173–97.
- Braun, A.R., Balkin, T.J., Wesensten, N.J., Gwadry, F., Carson, R.E., Varga, M., Baldwin, P., Belenky, G., Herscovitch, P. (1998), 'Dissociated pattern of activity in visual cortices and their projections during human rapid eye-movement sleep', *Science*, **279**, pp. 91–5.
- Callaway, D.W., Lydic, R., Baghdoyan, H.A., and Hobson, J.A. (1987), 'Ponto-geniculo-occipital waves: Spontaneous visual system activity during rapid eye movement sleep', *Cellular and Molecular Neurobiology*, **7** (2), pp. 105–49.
- Cavallero, C., Cicogna, P., Natalie, V., Occhionero, M. and Zito, A. (1992), 'Slow wave sleep dreaming', *Sleep*, **15** (6), pp. 562–6.
- Clarke, E.H. (1878), *Visions: A Study of False Sight (Pseudopia)* (Boston: Houghton, Osgood).
- Combs, A. (1996), *The Radiance of Being: Complexity, Chaos, and the Evolution of Consciousness* (St Paul, MN: Paragon House).
- Combs, A. and Krippner, S. (1998), 'Dream sleep and waking reality: A dynamical view of two states of consciousness', in *Toward a Science of Consciousness: The Second Tucson Discussions and Debates*, ed. S. Hameroff, A.W. Kaszniak and A.C. Scott (Cambridge, MA: MIT Press).
- Crick, F. and Koch, C. (1995), 'Are we aware of neural activity in primary visual cortex?', *Nature*, **375**, pp. 121–3.
- Edelman, G.M. (1992), *Bright Air, Brilliant Fire: On the Matter of The Mind* (New York: Basic Books).
- Edelman, G.M. (2000), *A Universe of Consciousness: How Matter Becomes Imagination* (New York: Basic Books).
- Freeman, W.J. (February 1991), 'The physiology of perception', *Scientific American*. pp. 78–85.
- Freeman, W.J. (1995), *Societies of Brains: A Study in the Neuroscience of Love and Hate* (Hillsdale, NJ: Lawrence Erlbaum Associates).
- Freeman, W.J. (1997), 'Three centuries of category errors in studies of the neural basis of consciousness and internationality', *Neural Networks*, **10**, pp. 1175–83.
- Freeman, W.J. and Barrie, J.M. (1994), 'Chaotic oscillations and the genesis of meaning in the cerebral cortex', in *Temporal Coding and the Brain*, ed. J. Mervaille and T. Christen (Berlin: Springer-Verlag).
- Freud, S. (1900/1955), *The Interpretation of Dreams* (New York: Basic Books).
- Gibson, J.J. (1966), *The Senses Considered as Perceptual Systems* (Boston: Houghton Mifflin).
- Gibson, J.J. (1979), *The Ecological Approach to Visual Perception* (Boston: Houghton Mifflin).
- Globus, G. (1989), 'Connectionism and the dreaming mind', *Journal of Mind and Behavior*, **10**, pp. 179–96.
- Globus, G. (1995), *The Postmodern Brain* (Amsterdam: John Benjamin's).
- Goertzel, B. (1994), *Chaotic Logic: Thought and Reality from the Perspective of Complex Systems Science* (New York: Plenum).
- Hall, C.S. and Van de Castle, R.L. (1966), *The Content Analysis of Dreams* (New York: Meredith).
- Hobson, J.A. (1988), *The Dreaming Brain* (New York: Basic Books).
- Hobson, J.A. (1994), *The Chemistry of Consciousness: How the Brain Changes its Mind* (New York: Little, Brown).
- Hobson, J.A. and McCarley, R.W. (1977), 'The brain as a dream-state generator: An activation-synthesis hypothesis of the dream process', *American Journal of Psychology*, **134**, pp. 1335–68.
- Hobson, J.A., Stickgold, R. and Pace-Schott, E.F. (1998a), 'The neuropsychology of REM sleep dreaming', *Neuro Report*, **9**, R1–R14
- Hobson, J.A., Pace-Schott, E.F., Stickgold, R. and Kahn, D. (1998b), 'To dream or not to dream? Relevant data from new neuroimaging and electrophysiological studies', *Neurobiology*, **8**, pp. 239–44.
- Hobson, J.A., Pace-Schott, E.F. and Stickgold, R. (2000), 'Dreaming and the brain: Toward a cognitive neuroscience of conscious states,' *Behavioral and Brain Sciences*, **23**.

- Kahn, D. and Hobson, J.A. (1993), 'Self-organization theory of dreaming', *Dreaming*, **3**, pp. 151–78.
- Kahn, D., Pace-Schott, E. and Hobson, J. (1997), 'Consciousness in the waking brain: The roles of neuronal oscillation and neuromodulation in determining similarities and differences', *Neuroscience*, **78** (1), pp. 13–38.
- Kauffman, S.A. (1993), *The Origins of Order: Self-Organization and Selection in Evolution* (Oxford: Oxford University Press).
- Kellert, S.H. (1993), *In The Wake of Chaos: Unpredictable Order in Dynamical Systems* (Chicago: University of Chicago Press).
- Koch, C. (1998), 'Visual awareness and the frontal lobes', in *Consciousness Research Abstracts: Toward a Science of Consciousness; Tucson III*, (Thorverton, UK: Imprint).
- Laszlo, E. (1987), *Evolution: The Grand Synthesis* (Boston: Shambhala).
- Lorenz, E. (1963), 'Deterministic nonperiodic flow', *Journal of the Atmospheric Sciences*, **20**, pp. 130–41.
- Mamelak, A.N. and Hobson, J.A. (1989), 'Dream bizarreness as the cognitive correlate of altered neuronal behavior in REM sleep', *Journal of Cognitive Neuroscience*, **1**, pp. 201–22.
- Mandell A.N. And Selz, K.A. (1997), 'Is the EEG a strange attractor? Brain stem neuronal discharge patterns and electroencephalographic rhythms', in *The Impact of Chaos on Science and Society*, ed. J. Mervaille and T. Christen (Tokyo: United Nations University Press).
- Maquet, P., Peteres, J.M., Aerts, J., Delfiore, G., Degueldre, C., Luxen, A. and Franck, G. (1996), 'Functional neuroanatomy of human rapid-eye-movement sleep and dreaming', *Nature*, **383**, p. 163
- Maturana, H.R., Varela, F.J. and Uribe, R. (1974), 'Autopoiesis: The organization of living systems, its characterization and model', *Biosystems*, **5**, pp. 187–96.
- Moss, F. and Wiesenfeld, K. (1995), 'The benefits of background noise', *Scientific American*, **272**, pp. 66–69.
- Peak, D. (1994), *Chaos Under Control: The Art and Science of Complexity* (New York: W.H. Freeman).
- Porte, H. and Hobson, J.A. (1986), 'Bizarreness in REM and NREM reports', *Sleep Research*, **15**, p. 81.
- Pribram, K.H. (1995), *Proceedings of the Second Appalachian Conference on Behavioral Neurodynamics: Origins; Brain And Self-Organization* (Hillsdale, NJ: Lawrence Erlbaum).
- Prigogine, I. and Stengers, I. (1984), *Order Out of Chaos: Man's New Dialogue with Nature* (New York: Bantam Books).
- Purcell, S., Mullington, J., Moffitt, A., Hoffman, R. and Pigeau, R. (1986), 'Dream self-reflectiveness as a learned cognitive skill', *Sleep*, **9**, pp. 432–7.
- Revonsuo, A. (1998), 'How to take consciousness seriously in cognitive neuroscience', *Consciousness Research Abstracts: Toward a Science of Consciousness; Tucson III* (Thorverton, UK: Imprint Academic).
- Robertson, R. and Combs, A. (ed. 1995), *The Proceedings of the Society for Chaos Theory in Psychology and the Life Sciences* (Hillsdale, NJ: Lawrence Erlbaum).
- Screenivason, R., Pradhan, N. and Rapp, P. (ed. 1999), *Nonlinear Dynamics and Brain Functioning* (Huntington, NY: Nova Science).
- Solms, M. (1997), *The Neuropsychology of Dreams: A Clinico-Anatomical Study* (Mahwah, NJ: Lawrence Erlbaum).
- Tanguay, P.E., Ornitz, E.M., Forsythe, A.B. and Ritvo, E.R. (1976), 'Rapid eye movement (REM) activity in normal and autistic children during REM sleep', *Journal of Autism and Childhood Schizophrenia*, **6**, pp. 275–88.
- Tonay, V. (1991), 'California women and their dreams: A historical and sub-cultural comparison of dream content', *Journal of Imagination, Cognition, and Personality*, **10**, pp. 85–99.
- Varela, F.J., Thompson, E. and Rosch, E. (1991), *The Embodied Mind: Cognitive Science and Human Experience* (Cambridge, MA: MIT Press).

Paper received October 1998; revised May 2000