

Dreaming: Cortical Activation and Perceptual Thresholds

John S. Antrobus

The City College of the City University of New York

It is proposed that (1) cortical activation and (2) heightened sensory thresholds are sufficient to (a) account for the particular characteristics of the Stage 1 REM dream report; (b) that these two variables modify certain characteristics of normal waking thought to produce dreamlike mentation; and (c) that no additional special cognitive operations are required to account for dreamlike mentation in Stage 1 REM. This paper attempts to specify what cognitive and neurological characteristics are required to distinguish waking mentation in noisy and understimulated environments from sleep mentation during different levels of cortical activation, namely Stages 1 REM and 2.

The structural characteristics of dreaming—hallucinatory, bizarre, story-like sequences of predominantly visual imagery—have seemed to demand extraordinary forms of explanation. The late 19th century saw various associationist theories (MacKenzie, 1965) proposed in Great Britain, followed by the psychoanalytic proposal of dreamwork (Freud, 1900, actually published 1899) in Austria. Following the Aserinsky and Kleitman (1953) discovery that dreaming was associated with Stage 1 REM sleep, Hobson and McCarley (1977) proposed a physiological-cognitive theory of dreaming. All of these approaches assume that dreaming is an event created by a cognitive system that is fundamentally altered from its normal waking status. Since none of the models is explicit about how this system produces thought and imagery in the waking state, the models are less than clear concerning how the waking system is altered to produce sleep mentation such as dreaming. None of the three approaches has been evaluated against data obtained in the waking state, and the psychoanalytic and associationistic approaches were not based on data systematically collected from either waking or sleep states.

The purpose of this paper is to sketch a general model that will account for both dreaming and the waking stream of thought, including both day-dreaming and more deliberate forms of mentation. It is argued that the uni-

que characteristics of dreaming should not be described by a special model of dreaming or sleep mentation but rather as modifications of models of waking cognition (Antrobus, 1978; Antrobus and Ehrlichman, 1980; Foulkes, 1982).

A comparison of the generally "soft" models of dreaming and their supporting evidence with the highly articulated models of waking cognitive processes, and the meticulous experimental procedures employed in cognition research, implies that an acceptable model of sleep mentation cannot be constructed and tested exclusively from data obtained in the sleep state (Antrobus, 1977). Cognitive processes can best be inferred from rapid input-output, perceptual-motor processes that can only be determined when subjects are in the waking state.

The processes by which the stream of thought and imagery is generated—in waking or sleep—are poorly understood. We do not know how or why people generate stimulus-independent images and thought when asleep, or, for that matter, when awake with their eyes closed, or open and, say, driving a car. We do not know how thoughts and images are coordinated across sensory modalities and sequenced in time. That the characteristics of the verbal reports of such imagery vary across biological states (Aserinsky and Kleitman, 1953) and environmental contexts (Antrobus, Singer, and Greenberg, 1966) affords an opportunity to isolate the salient properties of such cognitive processes and to determine how biological states and environmental contexts influence these characteristics. The proposed model, therefore, is neurocognitive in character. It is developed from a model of waking nonperceptual mentation such as daydreaming and mindwandering. The model proposes how dreamlike mentation can be produced by modifying the waking state model.

The Adaptive Control of Thought (ACT) Model of Cognitive Processes*

Although associationistic concepts such as contiguity and similarity have played a part in the account of dream mentation for years (MacKenzie, 1965) the narrow scope of earlier cognitive theories limited the potential contribution of cognitive psychology to the understanding of sleep mentation, and, for that matter, to any cognitive event that was removed by less than a few seconds from a preceding stimulus. Consequently, clinicians (Freud, 1900) and psychophysicologists, even physiologists (Aserinsky and Kleitman, 1953), proceeded to construct their own cognitive models on the basis of their private intuition rather than any empirically supported theory.

With the rapid advance of cognitive science in the past 30 years, computer-based models have been constructed which can simulate a wide variety of cognitive processes. Although none of these models has specifically addressed itself to dreaming or daydreaming, or cognitive processes that tend to be in-

dependent of immediate external stimuli (Antrobus et al., 1966), these models do provide a comprehensive, yet detailed, theoretical framework upon which the modifications necessary to account for fantasy processes can be described. The most recently published and most comprehensive of these models is Adaptive Control of Thought [ACT*] (Anderson, 1983), which is particularly noteworthy for its ability to handle temporal strings—including language comprehension, production and acquisition, spatial images and abstract propositional information—within one cognitive model. This paper will summarize characteristics of ACT* as they relate to a model of dreaming, daydreaming or the stream of thought, and characteristics of ACT* that require modification in order to account for this class of thought and imagery.

The ACT* “production system consists of three memories: working, declarative, and production. Working memory contains the information that the system can currently access, consisting of information retrieved from long-term declarative memory as well as temporary structures deposited by encoding processes and the action of productions” (Anderson, 1983, p. 19). Procedural memory contains all the information required to generate behavior such as uttering a sentence or rotating a visual image. Procedural memory contains all of the skill production information that may not be stored in declarative memory because it has never been abstracted or stored in verbal or propositional form. Declarative memory contains all of the information traditionally classified as long-term memory. At the risk of oversimplifying ACT*, one may propose that dream imagery is generated by the visual and verbal production systems. Subsequently, the dream report, if any, is generated by the speech production system from information stored in working memory. Although the source within the ACT* system of the input to the production systems during dreaming sleep is not known, this paper will address one critical source, the external environment of the sleeper.

Activation in ACT Defines Working Memory*

Working memory refers to “declarative knowledge, permanent or temporary, that is in an active state” (Anderson, 1983, p. 20). The node is the active unit in the system. It represents a chunk of information or cognitive unit. Each “cognitive unit encodes a set of (no more than five elements) in a particular relationship” (Anderson, 1983, p. 23); and the units are connected to one another in elaborate networks through which activation can pass from one unit to another. Thus, working memory accounts for one’s ability to recollect the recent productions of the system, such as dream reports, as well as the activation of goals of which one may not be “conscious.”

"Top-down" Processes

Since ACT* is designed to start processing with an external cue and stop when the response is completed, it is not programmed to generate continuous visual and speech imagery in the absence of external cues as is required for a simulation of dreaming and daydreaming. Although ACT* is designed to handle situations in which external information is one source of activation, the rules by which the model permits activation to spread through the declarative network along paths from the original source nodes to associated concept nodes (Anderson, 1983), could permit ACT* to produce output in the absence of sensory input—a primary requirement for the production of dreaming or daydreaming. In experimental perception research, “priming” (Foss, 1982; Meyer and Schvaneveldt, 1971) and “top-down” (Neisser, 1967) processing defines the processes by which the system uses information from the preceding context to assist the identification or perception of the current sensory input. Although much of this research is concerned with the effect of priming on comprehension and production of letters and words in lists and sentences, a similar process could generate output, or activate perceptual nodes in ACT*, even in the absence of sensory input. Since the spreading activation from productions in working memory can provide the “top-down” context effect for the next production, even in the absence of external input ACT* would require little modification to run as a closed system, as required for a model of dreaming or daydreaming, that is, as a system that produces continuous output in the absence of sensory input.

In the domain of language acquisition, ACT* has been developed to the point where it remembers previous external responses to its speech output and learns to modify current speech so as to maximize future approval. ACT* also has the ability to generate visual output. Such visual productions could well include the anticipated response of individuals and objects in the environment to ACT*'s behavior, as would be required by any model of dreaming. As a closed system, which would simulate the absence of external input in the sleep state, these productions, the responses of the system to its “imagined” environment and the anticipated reply of the internally constructed environment, would make up the dreaming episode. Although ACT* does not have the space to store the extensive world knowledge necessary to simulate elaborate dream scenarios, the model clearly provides the framework within which such episodes can be constructed.

ACT* would use the same visual production system that produces visual percepts to also produce the visual images of dreaming and daydreaming. The similarity of the image construction process in visual perception to the visual imaging process in the absence of appropriate sensory input has been well demonstrated by Perky (1910), Segal (1971), and Finke (1980) where subjects,

in certain conditions, could not distinguish their own visual images of an apple from an apple with different color or orientation projected by the experimenter onto a Ganzfeld. This confusion attests to the contention that the production of visual images and visual percepts is carried out by the same production system. To prevent ACT* from simultaneously producing percepts that match external sensory information and images produced in response to internal contextually based information, the model operates on a data refractory principle that prevents the simultaneous production of two incompatible patterns.

Motivation or Goals as a Source of Activation

English association cognitivists of the late 19th century attempted to explain the sequence of thought and dream images by simple associationist principles such as similarity, contrast and contiguity (MacKenzie, 1965). Thus, a waft of perfume through one's bedroom on a hot summer night might produce a dream of tropical romance. The logical positivists' argument that goals and purposes in psychological theories constituted a teleological fallacy effectively kept such notions out of experimental psychology until the development of cybernetics in the 1950s which led to the rebirth of cognitive psychology. Disregarding the strictures of the positivists, Freud (1900) emphasized the motivational, or, "wish-fulfillment" character of dream production. With the demise of the positivists' position, goal states have become an essential characteristic of all computer simulation systems such as ACT*. Goal elements in ACT* "are treated . . . as sources of high and constant activation" (Anderson, 1983, p. 156). That is, goal elements activate knowledge elements and production structures relevant to the goal. ACT* goals can be elaborate structures that decompose into hierarchical networks of subgoals that, in turn, permit the orderly sequencing of goal directed behaviors or imaginary actions, "wishes," if you will. The goals or motivational states do not have to be imposed by a human programmer but can be constructed by the system in response to new information. For example, "for one to be attacked" can be defined in declarative memory as a dangerous situation. Within the constraints of contextual information, ACT* can generate for itself the goal to escape or to defend itself. It is not clear whether ACT* has the ability to interrupt the pursuit of one goal to respond to another, if new information defines the second as more important. Reitman (1965) has argued that this ability to change goals in midstream is a salient characteristic of human thought, a characteristic that he built into his Argus IV model of human thought. Since ACT* does not currently have sufficient memory capacity to store extensive world knowledge and personal experience, it cannot construct the goals of personal significance that are familiar to adults.

The value of the ACT* model is that its accurate simulation of the goal-directed cognitive operations in rather restricted domains of knowledge implies that the functional relations described by the model could also handle more complex goal-directed processes based on a more extensive knowledge base.

How would the goal elements influence a dream narrative? As Anderson (1983) describes ACT*, "a production can focus the goal element on a structure in working memory and the element of such a focussed structure can become a source of (further) activation" (p. 89). Although goal structures in ACT* remain active until explicitly changed, as for example, by the solution to a problem, a fantasy solution in sleep may be equivalent to an external solution in the waking state. Rechtschaffen (1978) has noted the remarkable singlemindedness of dreams. One sleeper reported that he was waiting for his car in a parking garage in awakenings that spanned several hours of the night. On the other hand, there are abrupt transitions in some dreams marked by expressions such as "and all of a sudden," that suggest that the current goal in a sequence of thought was suddenly replaced without satisfying the usual criteria for terminating a sequence of thought. Similarly, the thematic material of daydreams often seems to drift from topic to topic implying a shift from one goal state to another, almost by simple association, to items in the stream of thought. That is, an element in one topic appears to activate a new goal element. Simulation of this wandering quality would seem to require some of the capabilities of Reitman's Argus IV model. But the multiple problems, or goal sources, in Argus IV were completely independent of one another. ACT* has the ability for one production governed by a given goal to activate a second partially related goal structure in declarative memory. For example, if the first goal is to construct an invitation list for a party and the search of appropriate names retrieves a friend who recently gave birth to a baby, and if one always sends gifts to friends who are new mothers, a new goal may be activated, namely to send that friend a gift. ACT* has the ability to store the second goal in declarative memory, where, especially if total activation were limited, it could get lost before the first task is finished.

Goal networks may never be activated as strongly in sleep as in waking studies of chess games where one's goal is to check one's opponent's king. In the research presented in this paper, a change in goal will be implied by a change in topic of mentation. As we shall see, the frequency of change in topic is a major discriminator of sleep and waking states.

The high rate of non-perceptual processing. Mindwandering or daydreaming is popularly thought to occur only when one is bored or drowsy (Singer and Antrobus, 1972). By contrast, Antrobus (1968) has found that nonperceptual mentation occurs in brief fragments of a second even when subjects are responding to high density information processing tasks (three binary auditory

stimuli every half second—6 bits/second). Decreasing the monetary payoff for response to the perceptual task increases the probability of such nonperceptual mentation (Task-Irrelevant Thought and Imagery [TITI]) as does the introduction of a general threat or conflict situation that is unrelated to the perceptual task (e.g., fake newscast announcing imminent state of war; Antrobus, Singer, and Greenberg, 1966). This research implies that every fraction of a second that is not occupied by external sensory processing is associated with nonperceptual cognitive processing, even though it may not always result in a conscious image or thought (Antrobus, Fein, Goldstein, and Singer, 1984). The general picture that emerges from this research is that the cognitive system is continuously constructing events whether it has sensory input or not. If the information in the sensory environment is sufficiently salient or has sufficient learned value to the individual, the processing resources of the cognitive system will be largely devoted to processing that sensory information. Otherwise the cognitive constructions may continue relatively independent of external sensory stimulation.

Retrieval of Nonperceptual Thought and Imagery

As in the case of visual and auditory perception, it must be assumed that nonperceptual thought and imagery constructed by the cognitive system remains active, i.e., in working memory, for a brief interval. Although this storage is programmed to hold about four independent items, much longer thought and imagery sequences can be stored by organizing the information into hierarchies of information chunks. Even this information will be lost if the system is not sufficiently active to permit some rehearsal of the information and at least some fragment of one chunk must survive as a cue or address to the remainder of the episode string (Raaijmakers and Shiffrin, 1981). Goodenough (1978) has reviewed the literature supporting the position that a brief interval of cortical activation (indicated by EEG alpha in the record) increases the probability that a subject can recall a dream episode. This suggests that a minimum level of overall ACT activation is essential for some cognitive processing, particularly storage in working memory. Although recall from working memory, or span memory, may have an all-or-none property, working memory is defined by increased activation of any nodes in declarative memory for recent productions and these levels are continuously distributed. An increase in the size of working memory should be associated with an increase in the activation of all associated neural structures. As we will argue below, these functions should be associated with overall cortical activation, and this level of activation should vary with biological states, including sleep stages.

Cognitive activation and bizarre mentation. Since the issue of bizarre sleep

mentation is of secondary importance to the model presented here, and since the author has presented a cognitive model for generating bizarre thought elsewhere (Antrobus, 1977, 1978), the present paper will discuss this topic only briefly. First, it must be noted that the Stage 1 REM dream reports that are obtained in the laboratory are much less bizarre than the typical strange dreams that people report at home, particularly if they sleep late on weekend mornings (Foulkes, 1979). It is our impression that we have yet to identify the physiological states in which the most bizarre dream reports can be obtained. The neat REM/NREM—dreaming/not dreaming association posited by investigators in the 1950s has perhaps discouraged further research on this matter.

Second, in the past 30 years, many cognitive and neurocognitive models have been proposed to account for the bizarreness of dreams. All of these models postulate a random process located in an ill-defined cognitive system. (Freud [1900], of course, believed that dreams were generated by a fully determined process, but then, Freud was not particularly partial to experimental evidence!) The presumed random operator is, of course, post hoc, since we already know that Stage 1 REM mentation is somewhat more bizarre than Stage 2 thought. A random generator model for bizarre thought and imagery must predict some new relationship in the cognitive or the neurological domain, or both, for it to be persuasive. The assumption that REMs, periorbital integrated potentials [PIPs] (Rechtschaffen, Watson, Wincor, Molinari, and Barta, 1972), and middle ear muscle activity [MEMAs] (Roffwarg, Adrien, Herman, Lamstein, Pessah, Spiro, and Bowe-Anders, 1973) are elicited by pontine-lateral geniculate-occipital cortex [PGO] activity, which, in turn, might disrupt cognitive processes and cause bizarre sequences of thought and imagery, predicts that mentation should be more bizarre following an interval of such phasic activity, compared to a control interval. Subsequent research has provided weak and inconsistent support for this model (Ogilvie, Hunt, Sawicki, and Samahalskyi, 1982; Pivik, 1978).

Bizarreness and ACT activation.* One might argue that any substantial deviation in cortical activation from the range of normal waking activation may produce bizarre mentation. Such states may be induced by “psychoactive” chemical agents, elevated cortical temperature or sleep, regardless of sleep stage. Mentation in all sleep stages may be more bizarre than in the waking state in a normally stimulating environment; but only in Stage 1 REM and in the transition states of sleep onset and arousal from sleep, is the system active enough to store sufficient information from the production systems so that the mentation appears bizarre in the verbal report. Although mentation reports from Stages 1 REM and 2 differ on variables such as dreamlike quality, visual and verbal imagery, Antrobus (1983b) has shown that these variables are all dependent on a difference in the number of words that

describe the recalled fantasy (Total Recall Count [TRC]: number of words in sentences describing recall of mentation, minus corrections, redundant words, and speech errors). These data are compatible with the notion that Stages 1 REM and 2 mentation are alike in quality and may differ only in quantity of recall. The Stage 1 REM report, "A yellow truck driving around the bottom of our swimming pool," is dreamlike, but a "yellow truck" reported from Stage 2 will not be judged bizarre because the incongruous context, "driving . . . pool," in which it was embedded either cannot be retrieved, or perhaps, was never created by the production system. By this argument, the greater bizarreness of Stage 1 REM is attributed to the fact that Stage 1 REM is a cognitively less activated state than the waking state, but more activated than NREM stages of sleep. The critical component of ACT* affected by a decrement in overall system activation is the working memory.

Bizarreness and working memory capacity. As described above, the size of the working memory determines the number of contextual items that are available to influence the construction of new items in the cognitive sequence. A large working memory, say four items or nodes, may permit the construction of thought and imagery that show consistent relationships from time, one moment to the next, whereas a restricted working memory size consisting of, say two nodes, cannot effectively keep track of its own past state so that new output of a production system cannot be appropriately constrained by prior output. The resultant thought and imagery sequences may include "nonsequiturs," incongruous or bizarre sequences. A reduced capacity of either the working memory or the production system, a plausible consequence of sleep (modest in sleep onset and REM, greater in Stages 2, 3 and 4), might also cause some items to be stored or retrieved with a restricted set of features. One subject reported from Stage 1 REM: "It's my brother, but he was a girl (in the dream)." This visual production "error" is similar to retrieval from LTM where an inadequate set of cues, *woman, adult, family, loved* might activate the higher frequency node, *mother*, rather than the intended *wife*. Thus the dreaming-nondreaming difference within sleep could be accounted for simply by the greater activation of ACT* in REM, whether in working memory, the production system, or both. As we shall discuss below, the greater cognitive activation of ACT* in REM sleep is consistent with current notions about the greater cortical activation of REM versus Stage 2 sleep.

Knowledge of Concurrent Environmental Context

But if greater working memory and production system capacity were the whole story then dreaming should be most characteristic of the waking state, where the capacity of these subsystems is thought to be equal to or greater than their capacity in sleep Stage 1 REM (see Cortical and ACT* Activa-

tion, below). To resolve this inconsistency we must consider a second quality of dreaming, the absence of information about both the current external environment, and one's status in that environment. This lack of knowledge of one's environmental context is a dominant characteristic of the REM dream, and to a lesser extent the elaborate waking daydream, but it is not characteristic of waking deliberate thought and is only partially true of much of sleep Stage 2 mentation where subjects often say they are awake (Antrobus and Saul, 1980; Sewitch, Pollack, Weitzman, Antrobus, and Clark, 1982). A cognitive model of dreaming, therefore, requires that the system is not only producing no perceptual responses to current external sensory stimuli, but that there is no information about the current external environment in working memory that can provide a context for the generation of the fantasy sequence. This means that very few of the nodes that describe the sleeper's real life environment and status as a sleeper are active. This argument brings us to the major paradox that any model of dreaming must solve: a large capacity working memory is typically associated with active perceptual processing which, in turn, is incompatible with dreaming.

The threshold paradox and the body-mind issue. This section is concerned with the paradoxical absence of normal perceptual responses, particularly in Stage 1 REM, despite the apparent activation of the cognitive apparatus necessary for such responses, especially as this lack of perceptual responding is associated with dreaming and other mentation. Treatment of this issue is generally oversimplified. In the stimulus incorporation literature (Arkin and Antrobus, 1978), investigators assume that an external stimulus either "gets in" or fails to "get in." In the former case, the stimulus is either incorporated into the ongoing stream of thought, the dream, or it wakes the subject up and is identified, i.e., normally perceived. In fact, the sequence from sensory transducer to cognitive response involves many way stations, each of which has its threshold, and other unique information-processing characteristics. The picture is further confused by the body-mind issue. External information is transduced into electro-chemical information which is transmitted through neural structures. One characteristic of this electro-chemical information constitutes the subjective experience that we report as imagery and thought. Thus, all subjective experience is electro-chemical in nature but only some of the electro-chemical information that we can record is associated with that subjective experience. This unity will be implied even where it is necessary to discuss the issues separately in terms of cognitive and neural measures. First, let us consider the transmission of information from sensory transducers to the cortex. In an exhaustive review of this literature, Pompeiano (1970) has shown that there is substantial inhibition during REM sleep of motor and kinaesthetic afferent information. That is, little information concerning the position of one's limbs ever reaches the cortex.

There is no solid evidence of specific precortical neural inhibition of auditory or visual information within REM sleep except during discrete rapid eye movements. Pompeiano (1970) has demonstrated that sensory inhibition during REMs, but not during REM quiescence, is due to middle ear muscle activity within Stage 1 REM. It is "not a true neural inhibition" (p. 138). But there is reason to question the generalizability of this process from cats to humans. Although Hobson and McCarley (1977) suggest that suppression of visual information during saccadic movements may account for some visual sensory inhibition during REM sleep, it is clear that such inhibition requires sensory stimulation of the retina as in waking perception (Festen and Wasserman, 1980) and therefore could not occur during sleep. Nevertheless, the fact that the early brain stem components of auditory evoked potentials are unattenuated during sleep (Mendel and Kupperman, 1974) suggests that high perceptual REM thresholds may be due to local cortical inhibition of the late components of the evoked potentials, possibly by competing cognitive activity such as the train of thought or the dream. The failure to directly test this notion has left the paradox of high cortical activation coupled with high perceptual thresholds in REM somewhat of a mystery. Several more mundane factors must be noted.

Dreaming occurs only when patterned visual input is eliminated by closing the eyelids and lying in the understimulated sensory environment of one's bedroom. By the process of habituation, the system gradually learns to ignore repetitive stimuli and other sensory events of no significance to the individual. Antrobus, Fein, Goldstein, and Singer (1984) found that it took waking subjects 11 days of one hour sessions in an unilluminated room before they habituated to stimuli in their surroundings to the extent that their waking fantasies no longer included such referents. Evoked potentials show that this information travels up the sensory pathways all night long (Amadeo and Shagass, 1973; Picton, Hillyard, Krausz, and Galambos, 1974), but is apparently not recognized or identified by the system. As intervals of nonperceptual thought increase in duration, the fantasy itself in the working memory of the system becomes the predominant context for the construction of further thought and imagery.

Perceptual thresholds are higher when a stimulus is presented out of context (Kohlers and Perkins, 1979). This also holds when the "context" is one's private train of thought: external stimuli tend to be improbable events in the context of a dream (even a daydream). ACT* already establishes that the working memory is a source of activation for subsequent output from its production systems so that no apparent modification is required here. As the items in this working memory become progressively more remote from the current sensory environment (i.e., the probability of activating nodes related to the concurrent items approaches zero), such sensory stimuli become

less frequent simply because the percepts are improbable within the remote fantasy context. Within a signal-detection model this constitutes an extreme shift in the response criterion for responding to any external stimulus. Therefore, progressively higher signal-to-noise ratios would be required to elicit a perceptual response. This process applies to both daydreaming and night dreaming.

*Stimulus "incorporation" and ACT**. The infrequent "incorporation" of external information into the dream report suggests that stimuli may be identified rather well in some cases, but distorted because they are perceived out of context (Antrobus, 1977, 1978; Arkin and Antrobus, 1978; Dement and Wolpert, 1958). The experimental cognition literature on priming is replete with examples of how the probability of recognizing an event depends on the spatial and sequential probability of the event occurring in that context. Since the dream sequence constitutes a context in which most of the items in the sleeper's bedroom are improbable, it is not surprising that they are rarely perceived (2% of awakenings; Antrobus, 1983a) within REM sleep. These external and proprioceptive stimuli are recognized much more frequently in Stage 2 (30% of awakenings) even though the cortex is less activated. ACT* should produce these "incorporations" if the stimulus feature nodes in declarative memory were activated but not the nodes that identified the system's true context: asleep in bed. ACT* would continue to produce sleep mentation on the basis of its current goal, but there would be an increased probability of producing an item that had some of the attributes recently activated by external stimuli.

Cortical activation and stimulus-independent mentation. A major goal of this paper is to identify those classes of cortical and subcortical activation that are associated with unique characteristics of stimulus-independent thought, particularly the general domain of dreaming and daydreaming. A working assumption is that dreaming can be broken down into separate dimensions, several of which may be independently related to different classes of cortical or subcortical activation. If two cognitive dimensions of mentation reports are related to the same index of cortical activation, we may assume that they have a common source of cortical activation. Similarly, if more than one cortical and subcortical class of activation is associated with the same class of cognitive activation we may assume that the sources of neural activation belong to the same neural activating system. The intention here is to eliminate redundant neural activation explanations for the same class of cognitive events. In particular, it is proposed that characteristics of sleep mentation commonly attributed to intermittent PGO activation may be due to the background, tonic, cortex-wide activation.

Cortical activation and ACT activation*. Anderson (1983) designed ACT* to operate in a steady state of activation. The distribution of activation in

ACT* varies with different cognitive operations, but total activation is held constant. For ACT* to account for differences in stimulus-independent mentation between states, ACT* total activation would need to vary across states, becoming somewhat reduced in sleep onset and Stage 1 REM, and further reduced in Stages 2, 3 and 4. Reducing the total ACT* activation would have the effect of decreasing the ability of an active node to activate related cognitive nodes in its network. If a goal node becomes active, it might, under a reduced state of activation, be unable to activate the same set of solution nodes that it would have if ACT* was operating under full (waking) activation. The solution nodes that it does activate may have a partial relevance, but be sufficiently inappropriate to be judged "bizarre" when recalled in the waking state. As discussed above, a reduction in total ACT* activation would decrease the size of working memory, thereby reducing the number of active nodes that could influence or constrain the selection of subsequent nodes in the construction of a cognitive string. Finally, the reduction in the size of the working memory would limit the ability to retrieve a cognitive string in a mentation report because fewer associates, tag, or address nodes would be sufficiently active to help one locate the preceding string of thought and imagery.

Cortical and cognitive activation. In summary, cortical activation, in this paper, is defined by changes in the EEG frequency spectra at electrode sites that have been empirically associated with increased cognitive performance. Thus, cortical activation is associated with, but does not define, cognitive activation. Cognitive activation is defined by increments in working memory capacity and/or processing rate, which, in turn, is defined by various cognitive tasks (Antrobus, 1968; Navon and Gopher, 1979; Shiffrin and Schneider, 1977). The base or general level of activation in ACT* is fixed, and local activation varies with specific cognitive operations. In this model, where general activation varies with biological state, it is assumed that local and general cognitive activation are multiplicative in the sense that an increase in general activation differentially increases the activation of all locally activated items, and thereby increases the capacity of working memory. Finally, the term *activation* will be used where a strong relation between cortical and cognitive activation has been well established. For example, an increase in auditory stimulation rate in the waking state is known to increase both cortical and cognitive indices of activation.

Measuring cortical activation. In 1970, Zimmerman proposed that dreaming is the product of an activated cortex with high sensory thresholds so that the dream is, in effect, a perception in the absence of sensory input. Unfortunately, Zimmerman confused matters by using measures of sensory threshold and motor arousal within sleep to infer cortical activation. Obviously, there can be no single measure of cortical activation. Activation varies from mo-

ment to moment, from location to location and from layer to layer of the cerebral cortex—not to mention the contribution of the supporting subcortical structures. But underlying this local short-term activity are slow changing levels of activation that characterize large areas of the cortex, if not the entire cortical surface. One convenient method of sampling the neuroelectric characteristics of the cortex is to carry out fast Fourier analyses of the EEG which yields measures of accumulated electrical energy within prescribed frequency bands over successive time intervals.

The relation between the spectral distribution of EEG energy and cortical activation can be determined empirically and is the subject of continued investigation. That is, the final criteria for determining whether a particular configuration of cortical activity is associated with cortical activation is the perceptual or cognitive output of the organism. Thus, the well established *inverse* relationship between EEG alpha (8–12 Hz) and “activation” is based upon cognitive performance criteria. Subsequently, the general principle was established that cortical activation was associated with the inhibition of the low frequency EEG generators that produce EEG delta (0.5–2 Hz), theta (4–6 Hz) and alpha (8–12 Hz), even though the precise location and function of these generators are less than clear (Li, McLennan, and Jasper, 1952). Within the band >12 Hz, and particularly 35–45 Hz, evidence has accumulated that increasing EEG energy is associated with superior cognitive performance and that frequency band is consequently positively associated with cortical activation (Loring and Sheer, 1984).

Measurement problems. Two methodological notes of caution are in order here. Rapid eye movements generate a slow electrical field that spreads out from the eye across the frontal cortex (Lopes daSilva, 1982). This field is identified in the Delta band by a fast Fourier analysis of frontal electrodes. This contamination can be avoided by analyzing only the data intervals between REMs or only the data from parietal and occipital sites, which are not contaminated by REM potentials. The second issue concerns the analysis of the upper Beta band, 35–45 Hz, that has been associated with focussed attention in the waking state (Loring and Sheer, 1984). This frequency band also includes scalp muscle activity, a contamination that is difficult to eliminate (O'Donnell, Beckhout, and Adey, 1974).

Testing the cortical activation model. The similarity of the waking and sleep Stage 1 REM EEG desynchronization is generally regarded as evidence of similar general cortical and, therefore, cognitive activation. Support for the extension of the “inverse rule” into sleep comes from Antrobus' (1983a) finding that the total number of words used to describe preawakening experience is far greater in Stage 1 REM than 2 where EEG spectral energy is substantially higher in the < 12 Hz range. By this token the greater frequency of dreaming in REM sleep compared to Stage 2 is taken as

the strongest evidence that high cortical arousal is essential to dreaming.

Since REM sleep has other distinguishing neurological characteristics, however, a more conservative test of the EEG desynchronization-cortical activation relationship is to ask whether within Stage 1, intervals of greater cortical activation are associated with independent measures of cognitive activity as well as dreamlike reports. Lehmann, Dumermuth, Lange, and Meier (1981) and Williamson, Galin, and Mamelak (1983) have both reported an association between dreaming and lower spectral power in the frequency bands <12 Hz but with small sample sizes ($N=6$ each). By contrast, Antrobus, Ehrlichman, Weiner, and Wollman (1983) found no relation between EEG power in the 2-12 Hz band and several indices of dreamlike mentation ($N=21$, 42 reports). Given the ambiguity of the evidence on this essential tenet of the model it is difficult to construct a more precise neurocognitive model of dreaming.

Alternate cortical/neural activation models. The case for a general cortical activation model of mentation is not intended to rule out additional forms of cortical or subcortical activation. It is argued rather that the contribution of each potential source of cortical activation to mentation, such as dreaming, be distinguished from alternate and often overlapping sources. The treatment of "dreaming" as a global, one-dimensional variable has tended to obscure this sorting process. For example, an increase in report length, bizarreness or visual imagery might be associated with independent sources of cortical and subcortical activation, but the independent relationships would be obscured if the three cognitive classes were absorbed in the single variable *dreaming*. The strategy of the present paper is to isolate different cognitive characteristics of the dream report and to determine the independent biological and environmental antecedents of each. Among the cortical and subcortical structures that have been proposed are general or non-specific cortical activation, activation of the PGO pathway, the right versus the left cerebral hemisphere and the frontal lobes and the association cortex, two of which will be briefly considered here.

Tonic-Phase Model

The PGO variation of the activation model further assumes that the visual cortex is more active in phasic than in tonic REM (Hobson and McCarley, 1977). These researchers suggest that intense PGO or PIP, MEMA or REM activity within Stage 1 REM sleep may produce improbable or bizarre sequences and changes in topics. Support for this notion would argue that phasic REM and perhaps all Stage 1 REM mentation is based on a different organization of cortical activation than during waking. Attempts to relate particular characteristics of REM mentation to indices of PGO activity (Rechtschaffen,

Watson, Wincor, and Molinari, 1971; Roffwarg, Dement, Muzio, and Fisher, 1962; Roffwarg, Herman, and Lamstein, 1975) have yielded equivocal results (Ogilvie et al., 1982; Pivik, 1978).

Hemisphere Asymmetry Model

Antrobus et al. (1983) applied the "inverse" rule to the analysis of hemisphere asymmetry EEG in the 2-12 Hz band and sleep mentation reports. Words implying visual and verbal imagery (visual nouns, visual verbs, visual modifiers, etc.), were significantly associated with differential left hemisphere activation, although TRC was unaffected. This implies that although TRC and the imagery count variables are associated with between-state changes in cortical EEG, they may be independent of each other when sampled over within-state variations in cortical variation. The Stage 1 REM-2 difference appears to be one of general cortical activation, whereas the imagery difference in the absence of TRC change is clearly due to an independent production system characteristic that is associated with left hemisphere activation. For a more extensive review of the hemisphere-dreaming issue see Ehrlichman, Antrobus, and Weiner (1985) and Antrobus (1986). Further research with a larger sample size and a breakdown of the frequency spectrum of the EEG is required to confirm this argument.

Cognition in Understimulated Environments

The role of cognitive-cortical activation proposed here must not be confused with Zimmerman's (1970) model of cortical arousal and dreaming versus thinking, a Stage 1 REM versus 2 difference. Zimmerman proposed that thinking occurs at a lower level of "arousal" than does dreaming. His model uses "cortical arousal" only to account for state differences in mentation and does not consider perceptual thresholds as an independent causal factor. But Zimmerman obfuscates the matter by using measures of auditory sensory threshold to infer cortical arousal!

The same analysis that has been applied to mentation during sleep can also be applied to the waking state. When the cortex is sufficiently activated to support cognitive processing, and when the environment provides few stimuli of significance, the individual will process information previously stored in long term and working memory (Antrobus, 1977, 1978, 1983b)—as in daydreaming and sleep onset mentation. If, with eyelids closed in the understimulated environment of a quiet bedroom, such a train of thought and imagery persists in time until all information identifying the individual's immediate environment is lost from working memory, then, whether waking or sleeping, the perceptual-cognitive system is obliged to accept the

stream of thought and imagery as the "real world" context. Thought and imagery produced under these conditions will be hallucinatory by definition (Antrobus, 1977). In the absence of orientation to environmental stimuli, disruption of the stream of thought is reduced so that thought sequences become longer. As they become longer, they also acquire a story-like episodic quality. Together these characteristics define the daydream, and in the extreme case, the dream. In a noisy environment, by contrast, or one with "significant" stimuli, the train of thought is disrupted, reorients to the waking environment, and becomes less dreamlike, more "thought-like."

References

- Amadeo, M., and Shagass, C. (1973). Brief latency click-evoked potentials during waking and sleep in man. *Psychophysiology*, 10, 244-250.
- Anderson, J.R. (1983). *The architecture of cognition*. Cambridge, Massachusetts: Harvard University Press.
- Anderson, J.R., and Bower, G.H. (1973). *Human associative memory*. Washington: Winston and Sons.
- Anderson, J.R., and Hinton, G.E. (1981). Models of information processing in the brain. In G.E. Hinton and J.A. Anderson (Eds.), *Parallel models of associative memory* (pp. 9-48). Hillsdale, New Jersey: Erlbaum Associates.
- Antrobus, J.S. (1968). Information theory and stimulus-independent thought. *British Journal of Psychology*, 59, 423-430.
- Antrobus, J.S. (1977). The dream as metaphor: An information processing and learning model. *Journal of Mental Imagery*, 2, 327-338.
- Antrobus, J.S. (1978). Dreaming for cognition. In A.M. Arkin, J.S. Antrobus, and S. Ellman, (Eds.), *The mind in sleep* (pp. 569-581). Hillsdale, New Jersey: Erlbaum Associates.
- Antrobus, J.S. (1983a). REM and NREM sleep reports: Comparison of word frequencies by cognitive classes. *Psychophysiology*, 20, 562-568.
- Antrobus, J.S. (1983b). Mental processes during sleep and waking. *Sleep Research*, 12, 25-27.
- Antrobus, J.S. (1986). Neurocognitive models of sleep mentation. Manuscript submitted for publication, *Psychological Bulletin*.
- Antrobus, J.S., and Ehrlichman, H. (1980). The "dream" report: Attention, memory, functional hemispheric asymmetry and memory organization. In W. Fishbein. (Ed.), *Sleep, dreams and memory* (pp. 135-136). New York: Spectrum.
- Antrobus, J.S., Ehrlichman, H., Weiner, M., and Wollman, M. (1983). The REM report and the EEG: Cognitive processes associated with cerebral hemispheres: Their ratios and sums, cross trial contrasts and EEG window duration. *Sleep*, 82, 49-51.
- Antrobus, J.S., Fein, G., Goldstein, S., and Singer, J.L. (1984). *Mindwandering: Time-sharing task-irrelevant thought and imagery with signal detection tasks*. Unpublished manuscript, City University of New York.
- Antrobus, J.S., and Saul, H. (1980). Sleep onset: Subjective, behavioral and electroencephalographic comparisons. *Waking and Sleeping*, 4, 259-270.
- Antrobus, J.S., and Singer, J.L. (1964). Visual signal detection as a function of sequential variability of simultaneous speech. *Journal of Experimental Psychology*, 68, 603-610.
- Antrobus, J.S., Singer, J.L., and Greenberg (1966). Studies in the stream of consciousness: Experimental enhancement and suppression of spontaneous cognitive processes. *Perceptual and Motor Skills*, 23, 399-417.
- Arkin, A.M., and Antrobus, J.S. (1978). The effects of external stimuli applied prior to and during sleep on sleep experience. In A.M. Arkin, J.S. Antrobus, and S. Ellman (Eds.), *The mind in sleep* (pp. 351-392). Hillsdale, New Jersey: Erlbaum Associates.
- Aserinsky, E., and Kleitman N. (1953). Regularly occurring periods of eye motility and concomitant phenomena during sleep. *Science*, 118, 273-274.

- Buchsbaum, M., Gillin, J.C., and Pfefferbaum, A. (1975). Effect of sleep stage and stimulus intensity on auditory average evoked responses. *Psychophysiology*, 12, 707-712.
- Dement, W.C., and Wolpert, E. (1958). The relation of eye movements, body motility, and external stimuli to dream content. *Journal of Experimental Psychology*, 55, 543-553.
- Ehrlichman, H., Antrobus, J.S., and Weiner, H. (1985). EEG asymmetry and sleep mentation during REM and NREM sleep. *Brain and Cognition*, 4, 477-485.
- Farah, M.J. (1983). *The neural basis of mental images, or the brain's eye*. Unpublished doctoral dissertation, Harvard University, Boston.
- Festen, G., and Wasserman, G.S. (1980). Visual masking mechanisms and theories. *Psychological Bulletin*, 88, 329-353.
- Finke, R.A. (1980). Levels of equivalence in imagery and perception. *Psychological Review*, 87, 113-132.
- Foss, D.J. (1982). A discourse on semantic priming. *Cognitive Psychology*, 14, 590-607.
- Foulkes, D. (1979). Home and laboratory dreams: Four experimental studies and a conceptual evaluation. *Sleep*, 2, 233-251.
- Foulkes, D. (1982). A cognitive-psychological model of dream production. *Sleep*, 5, 169-187.
- Foulkes, D., and Fleischer, S. (1975). Mental activity in relaxed wakefulness. *Journal of Abnormal Psychology*, 84, 66-75.
- Foulkes, D., and Schmidt, M. (1983). Temporal sequence and unit composition in dream reports from different stages of sleep. *Sleep*, 6, 265-280.
- Foulkes, D., and Scott, E. (1973). An above zero baseline for the incidence of momentarily hallucinatory mentation. *Sleep Research*, 2, 108.
- Freud, S. (1900). *The interpretation of dreams*. Leipzig: Frunze.
- Goodenough, D.R. (1978). Dream recall: History and current status of the field. In A.M. Arkin, J.S. Antrobus, and S.J. Ellman (Eds.), *The mind in sleep* (pp. 113-140). Hillsdale, New Jersey: Erlbaum Associates.
- Hobson, J.A., and McCarley, R.W. (1977). The brain as a dream state generator: An activation-synthesis hypothesis of the dream process. *The American Journal of Psychiatry*, 134, 1335-1348.
- Hubel, D.G., and Wiesel, T.N. (1965). Receptive fields and functional architecture in two nonstriate visual areas (18 and 19) of the cat. *Journal of Neurophysiology*, 28, 229-243.
- Hubel, D.G., and Wiesel, T.N. (1968). Receptive fields and functional architecture of monkey striate cortex. *Journal of Physiology*, 195, 215-243.
- Klinger, E. (1971). *Structure and functions of fantasy*. New York: Wiley.
- Kohlers, P.A., and Perkins, P.N. (1979). A pattern analyzing basis of recognition. In L.S. Cermack and F.I.M. Craik (Eds.), *Levels of processing in human memory* (pp. 363-384). Hillsdale, New Jersey: Erlbaum Associates.
- Kupferman, I. (1984). Personal communication.
- Lehmann, D., Dumermuth, G., Lange, B., and Meier, C.A. (1981). Dream recall related to EEG spectral power during REM periods. *Sleep*, 10, 151.
- Li, C., McLennan, H., and Jasper, H. (1952). Brain waves and unit discharge in cerebral cortex. *Science*, 116, 656.
- Lopes daSilva, F. (1982). Computer-assisted EEG diagnosis: Pattern recognition in EEG analysis, feature extraction and classification. In E. Niedermeyer and F. Lopes daSilva (Eds.), *Electroencephalography* (pp. 718-732). Baltimore, Maryland: Urban and Schwarzenberg.
- Loring, D.W., and Sheer, D.E. (1984). Laterality of 40 Hz. EEG and EMG during cognitive performance. *Psychophysiology*, 21, 34-38.
- MacKenzie, N. (1965). *Dreams and dreaming*. New York: Van Guard.
- Mendel, M.I., and Kupperman, G.L. (1974). Early components of the averaged electroencephalographic response to constant level clicks during rapid eye movement sleep. *Audiology*, 13, 23-32.
- Meyer, D.E., and Schvaneveldt, R.W. (1971). Facilitation in recognizing pairs of words: Evidence of a dependence between retrieval operations. *Journal of Experimental Psychology*, 90, 227-234.
- Miller, G.A. (1956). The magical number seven, plus or minus two: Some limits on our capacity for processing information. *Psychological Review*, 63, 81-97.
- Miller, J.G. (1965). Living systems. *Behavioral Science*, 10, 193-411.

- Navon, D., and Gopher, D. (1979). On the economy of the human-processing system. *Psychological Review*, 86, 214-255.
- Neisser, U. (1967). *Cognitive psychology*. New York: Appleton.
- O'Donnell, R.D., Beckhout, J., and Adey, W.R. (1974). Contamination of scalp EEG spectrum during contraction of cranial-facial muscles. *EEG and Clinical Neurophysiology*, 37, 145-151.
- Ogilvie, R.D., Hunt, H.T., Sawicki, C., and Samahalskyi, J. (1982). Psychological correlates of spontaneous middle ear muscle activity during sleep. *Sleep*, 5, 11-27.
- Perky, C.W. (1910). An experimental study of imagination. *American Journal of Psychology*, 21, 422-452.
- Pessah, M.A., and Roffwarg, H.P. (1972). Spontaneous middle ear muscle activity in man: A rapid eye movement sleep phenomenon. *Science*, 178, 773-776.
- Peterson, L.R., and Peterson, M. (1959). Short-term retention of individual items. *Journal of Experimental Psychology*, 58, 193-198.
- Picton, T.W., Hillyard, S.A., Krausz, H.I., and Galambos, R. (1974). Human evoked auditory potentials: I. Evaluation of components. *EEG and Clinical Neurophysiology*, 36, 179-190.
- Pivik, R. (1978). Tonic states and phasic events in relation to sleep mentation. In A.M. Arkin, J.S. Antrobus, and S.J. Ellman (Eds.), *The mind in sleep* (pp. 245-271). Hillsdale, New Jersey: Erlbaum Associates.
- Pompeiano, O. (1970). Mechanisms of sensorimotor integration during sleep. In E. Stellar and J.M. Sprague (Eds.), *Progress in physiological psychology*, 3. New York: Academic Press.
- Raaijmakers, J.G.W., and Shiffrin, R.M. (1981). Search of associative memory. *Psychological Review*, 88, 93-134.
- Rechtschaffen, A. (1978). The single-mindedness and isolation of dreams. *Sleep*, 1, 97-109.
- Rechtschaffen, A., Watson, R., Wincor, M.Z., and Molinari, S. (1971). *Orbital phenomena and mental activity in NREM sleep*. Paper presented at the First International Congress of the Association for the Psychophysiological Study of Sleep, Belgium.
- Rechtschaffen, A., Watson, R., Wincor, M.Z., Molinari, S., and Barta, S.G. (1972). The relationship of phasic and tonic periorbital EMG activity to NREM mentation. *Sleep Research*, 1, 114.
- Reitman, W. (1965). *Cognition and thought*. New York: Wiley.
- Roffwarg, H., Adrien, J., Herman, J., Lamstein, S., Pessah, M., Spiro, R., and Bowe-Anders, C. (1973). The relationship of phasic and tonic periorbital EMG activity to NREM mentation. *Sleep Research*, 2, 36.
- Roffwarg, H.P., Dement, W., Muzio, J., and Fisher, C. (1962). Dream imagery: Relationship to rapid eye movements of sleep. *Archives of General Psychiatry*, 7, 235-258.
- Roffwarg, H., Herman, J., and Lamstein, S. (1975). The middle ear muscles: Predictability of their phasic activity in REM sleep from dream material. *Sleep Research*, 4, 165.
- Segal, S.J. (1971). Processing of the stimulus in imagery and perception. In S.J. Segal (Ed.), *Imagery: Current cognitive approaches* (pp. 73-100). New York: Academic Press.
- Sewitch, D.E., Pollack, C.P., Weitzman, E.D., Antrobus, J.S., and Clark, W.C. (1982). Sleep-wake perception in normal sleep. *Sleep Research*, 11, 95.
- Shiffrin, R.M., and Schneider, W. (1977). Controlled and automatic human information processing: II. Perceptual learning, automatic attending, and a general theory. *Psychological Review*, 84, 127-190.
- Singer, J.L., and Antrobus, J.S. (1972). Daydreaming, imaginal processes, and personality: A normative study. In P. Sheehan (Ed.), *The function and nature of imagery* (pp. 175-202). New York: Academic Press.
- Townsend, R.E., House, J.F., and Johnson, L.C. (1976). Auditory evoked potential in Stage 2 and REM sleep during a 30-day exposure to tone pulses. *Psychophysiology*, 13, 54-57.
- Williamson, P., Galin, H., and Mamelak, M. (1983, June). *Spectral EEG correlates of mentation during sleep*. Paper presented at the International Meeting of the Sleep Society, Bologna, Italy.
- Zimmerman, W.B. (1970). Sleep mentation and auditory awakening thresholds. *Psychophysiology*, 6, 540-549.