DREAM IMAGES:
A Call to Mental Arms

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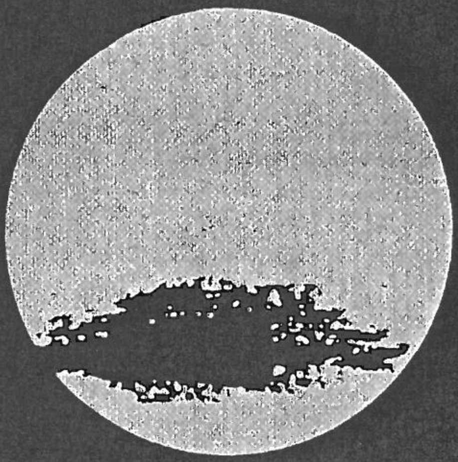

CHAPTER 3

Vestibular Involvement in the Neurocognition of Lucid Dreaming

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The confluence of contemporary emphases on cognitive processing in psychology and advances in the neurosciences has deposited a rich neurocognitive alluvium in which the seeds of an integrated, holistic approach to dreaming can germinate and flourish in coming years. The seeds of this integrated approach are very old and represent a phenomenological matrix embedded in the ontological and mythological quest of people to experience and understand themselves and their worlds. In our own quest of this understanding, we have studied a particular dream phenomenon known as lucid dreaming, or simply lucidity. The term lucid dreaming refers to a within sleep awareness that one is dreaming and that one can observe and perhaps control the course of dream mentation. As such, it represents a form of self-awareness, self-reflectiveness, or consciousness which neurologically normally implies an alert and awake person [1]. The consciousness of lucid dreaming occurs in neither an awake nor alert person, and the study of lucid dreaming consequently may afford a unique opportunity to investigate the interplay of cognitive processes underlying consciousness and the neurophysiological processes of sleep.

Consciousness, as applicable to lucid dreaming, is comparable to the self-awareness of Locke and Descartes, the conscious experience of Penfield and Perot [2], and the subjective observation of introspectionists. Self reference, as noted by James [3], is the key to the experience of consciousness. The consciousness of lucidity, whether examined in the sleep laboratory or through spontaneous personal or systematic accounts, depends on memory for consciously perceived

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events, the language capacity to relate these events, and the attentional capacity to selectively attend to sleep mentation. Without getting into specific models of the cognitive processes of memory, e.g., a multistore model as referable to conscious and unconscious contents and processes [4], and an indepth analysis of interactions between memory, language and attentional processes, topics beyond the scope of this writing, we simply point out that any neurological model of lucid dreaming must take these higher cognitive processes into account in the context of the tonic and phasic neurophysiological processes operative during sleep. Prior research has established that the vestibular nuclei in the brain stem are an integral part of a neurological system which subserves dreaming. Our own research and that of others has suggested that the vestibular system, a phylogenetically old, integrative system which includes the vestibular nuclei, is in some specific way associated with lucid dreaming. The vestibular system, in turn, is known to be involved in spatial orientation during wakefulness, and Portegal [5] has proposed that the basal ganglia, subcortical nuclei historically associated with movement and movement disorders like Parkinson's disease and Huntington's disease, may be involved in processing vestibular information with reference to egocentric spatial orientation. Our purpose in writing this chapter is to consider further the role that the vestibular system may play in the spontaneous but paradoxical experience of consciousness within asleep.

In order to probe further into the predicated association between lucid dreaming and vestibular functioning, especially with reference to the activation-synthesis dream model of McCarley and Hobson [6] and the neurocognitive systems dream model of Antrobus [7], we will first review the evidence which supports involvement of the vestibular system in lucid dreaming, then present unpublished data from a study of the balancing ability of persons who differ in their frequency of lucid dreaming, and finally relate this data to what is currently known about the neurological basis of vestibular imagery, dream mentation, and self-awareness. Although speculative at this time, we suspect that the phenomenal experience of consciousness during sleep is a portal to a brain system which has evolved for spatial representation and exploration. The essential behavior for this system is spatially oriented bodily movement, behavior which man experienced long before the evolution of language. Memories of body movement patterns have been represented in the human brain for many, many years and probably are the foundation of dance, mythology, archetypal motifs, and poetry. Through encephalization, and in particular the evolution of cortically mediated language functions, conscious access to subcortical movement patterns has been reduced. Under normal waking conditions and for many persons during sleep mentation, linguistic processes, both figuratively and neurologically, emboss this movement system and hence restrict conscious access to it. During sleep, however, and in wakefulness for some persons with differently organized or differently activated neurological systems, e.g., autistics and proficient meditators, the prepotency of language-mediated self-awareness is attenuated or altered so that vestibular-bound imagery and movement patterns, both of which are closer to actual experience than is language-mediated imagery and thinking, assume prominence. In this circumstance, a variation in self-awareness becomes possible and spontaneously can result in lucidity during sleep depending on individual differences, including individual differences in vestibular physiology [8].

Gackenbach, Snyder, Rokes, and Sachau have proposed that intense activation of the vestibular system during Stage 1 REM sleep may be associated with lucid dreaming [9]. This association was formulated on the assumptions that individual differences in vestibular neurophysiology could generate qualitatively different sleep mentations and that these individual differences would be detectable during wakefulness as well as during sleep. The latter assumption is in part based on evidence that cognitive production systems operative during sleep are basically the same cognitive processes of the waking state [7, 10]. Five lines of indirect evidence support the proposed association between lucid dreaming and vestibular activation. First, lucidity mentation [11, 12] and the within sleep induction of lucid dreaming [13] often include fictive body movements and perceptions known to involve the vestibular system during wakefulness, e.g., controlled spinning. Second, the vestibular nuclei in the brain stem become intensely activated during Stage 1 sleep and play an important role in modulating pontine-lateral genticulate-occipital (PGO) processes which trigger phasic REM events [14]. Note that lucid dreaming is preceded by REM bursts [15-17]. Third, frequent lucid dreamers have lower and more bilaterally symmetrical sensory thresholds in response to caloric stimulation of the vestibular system than do non-lucid dreamers [9]. Fourth, frequent lucid dreamers perform better on a set of equilibratory-related behaviors than do non-lucids [8]. And fifth, self-reported vestibular dysfunction is more prevalent among persons who do not dream lucidly than among those who do [8]. It may also be relevant that vestibular neuropathology can induce dreams of spatial disorientation which are experienced as unpleasant and frightening [18] and that kinesthetic distortion during REM elicits dreams of falling, spinning, flying, and physical disorientation [19].

The vestibular system is part of an extensive, multimodal afferent and efferent functional system which during wakefulness subserves the maintenance of balance and spatial orientation [20]. Vestibular contributions to this system consist of input from two sets of specialized receptors located within the semicircular canals and otolith organs of the inner ear. In prior research we focused on stimulation of the semicircular canal component of vestibular functioning and found a relationship between the frequency with which young adults spontaneously experience lucid dreaming and their responsiveness to caloric irrigation [9]. In order to more fully explore the relationship between vestibular functioning and lucidity, we have compared the otolithic responsiveness of persons who differ in lucid dreaming frequency. The previously unpublished results of this study will be presented in this chapter and used as a springboard from which to speculate about vestibular involvement in the neurocognition of lucid dreaming. Based on convergent and divergent evidence, we will suggest that the association between lucid dreaming and vestibular functioning involves a neurofunctional system which has evolved with reference to the bilateral anatomical organization of the semicircular canals. This anatomical organization, which was achieved early in evolution [21], provides a blueprint by which the brain can code and generate motion in a three-dimensional world embedded in a gravitational environment. The representation and exploration of this world during wakefulness depend on the integration of at least visual, oculomotor, proprioceptive, somatosensory, and motor processes accomplished within the cortex, neostriatum, brainstem, and vestibulocerebellum. The world of sleep mentation must also involve this neurofunctional system for representing and exploring space, though with functional modifications according to the depth of sleep, the integrity of vestibular functioning, and individual differences in higher level cognitive processing. We propose that the decrease in sensory input and motor output during sleep in combination with increased cortical activation during REM results in greater reliance on an internal frame of reference for spatial exploration of the dream world. To the degree that people differ in their capacity or proclivity to rely on internal rather than external environmental referents, we predict that there will be an increased frequency of lucid dreaming and a decreased frequency of experiencing spatial disorientation in dreams. In order to explain our rationale for studying balance performance in relation to lucid dreaming frequency, a brief overview of vestibular neuropsychology will be provided.

VESTIBULAR NEUROPSYCHOLOGY

In a narrow sense, vestibular neuropsychology can be said to involve a specialized system for detecting variations in head and body movements and changes in gravitational forces. The neuroanatomical substrate for this system would be vestibular receptors of the inner ear, vestibular nuclei in the lower brain stem, and pathways connecting these nuclei with higher and lower levels of the CNS. In a broader sense, however, vestibular neuropsychology involves a complex, multimodal, afferent and efferent neurofunctional system in which vestibular processes are but one component. This neurofunctional system also includes visual and somatic (cutaneous/kinesthetic) contributions which coordinately operate with vestibular processes in the brain stem, cerebellum, and cerebrum. It is probable that auditory [22] and spatial [5] localization are integral to this system, as may be subcortical motor processing [5]. Exogenous input to the vestibular component of this neurofunctional system for spatial exploration is detected by specialized cells of the internal ear. The inner ear is composed of the membranous labyrinth, a series of delicate chambers and passages enclosed within the body labyrinth of the same shape. Each inner ear contains three end-organs, the duct of the cochlea (the organ of hearing), the saccule and utricle (the otolith organ), and the semicircular canals. The latter two structures are referred to as the vestibular apparatus, with an oval cavity in the middle portion of the bony labyrinth, the vestibule, being the origin of the term vestibular and the location of the otolith organ. The right and left otolith organs, which give complementary information, are stimulated by alterations of the position of the head and body, by linear motion, and by variations in gravitational forces. Otolithic input is integral to regulating muscle tone and maintaining static equilibrium. Balancing on a platform and walking a beam are two behavioral means for evaluating otolithic functioning. The otolith organ is not directly stimulable by noninvasive means.

Vestibular receptors of the semicircular canals, which can be directly stimulated by several means including caloric irrigation of the ears, are affected by rotatory movements of the head. Input to the semicircular canals is important for the control of ocular movements, ocular reflexes which follow changes in the position of the head and body, and ocular fixation. There are three semicircular canals embedded in the temporal bone on each side of the cranium, and these canals are approximately planar and orthogonal to each other. The canals are designated as lateral, anterior, or posterior. The planes of the right and left lateral semicircular canals are roughly parallel. The planes of the right anterior and left posterior canals and of the left anterior and right posterior canals are also approximately parallel. This geometric configuration, which was achieved early in evolution and in general is phylogenetically invariant from elasmobranchs onward [21], represents an anatomic solution for simplifying the encoding and generation of movement in three-dimensional space [23]. It has been shown that neural activity emanating from the semicircular canals transfers the geometry of the canals to the central nervous system [24]. Consequently, centrally located vestibular neurons code the velocity of head movements in three-dimensional space according to the spatial organization of neural firing in a canal-based coordinate system. Furthermore, other components of the neurofunctional system which coordinately work with central vestibular neurons also appear to use this canal-related reference frame for information processing, including portions of the visual, oculomotor, motor, and somatosensory systems. In sum, the geometric configuration of the semicircular canals has evolved as a simplified yet elegant means to encode three-dimensional space and this geometry is preserved in CNS neural processing patterns in parts of the brain which subserve vestibular multisensory convergence. In this sense, the anatomy of the semicircular canals is a prototypical model for multisensory integration of neural activity in the brain. Since the three-dimensional world of earth is embedded in a gravitational environment, the otolithic component of the vestibular apparatus is of necessity intimately interfaced with the canal component.

Vestibular impulses of otolithic and canal origin travel to bipolar cells of the vestibular ganglia of Scarpa, from which central fibers pass as the vestibular part of the eighth cranial nerve. The majority of these fibers terminate on the four vestibular nuclei (lateral, medial, superior, inferior) in the pons and medulla but some go without synapse into the cerebellum. There are six primary pathways by which impulses travel from the vestibular nuclei [25], including those to the cerebellum for the coordination of orientation information, to the spinal cord for postural reflexes, to the reticular formation (RF) for integration with other sensory input, to the oculomotor nuclei via the medial longitudinal fasciculus (MLF) for compensatory eye movements, to the temporal lobe for motion perception, and to the vestibular apparatus for input control. Of the four vestibular nuclei, the medial and inferior (descending) have been specifically implicated with REM [14, 26]. These two nuclei consist of similar appearing cells, receive otolithic and semicircular canal fibers, and have connections with the reticular formation (RF), the cerebellum, higher centers, other vestibular nuclei, and neurons innervating the cervical musculature. They have been shown to modulate REM even with cerebellar disconnection and lesioning of the vestibular nerve [26].

Because phasic REM is the biological marker most predictive of reportable sleep mentation, including lucid dreaming [17], it is probable that intense activation of the medial and inferior vestibular nuclei during sleep is in some way associated with sleep mentation [7]. This association is especially likely for the mentation of lucidity which is distinguishable from non-sleep mentation in terms of kinesthetic and vestibular descriptors, auditory descriptors, and cognitive control but not visual descriptors [11, 19]. McCarley and Hobson's activation-synthesis model of dreaming predicts that selective activation of the vestibular nuclei engenders isomorphic sleep mentation [6]. The prominence of vestibular sensations in lucid mentation could therefore parallel intense activation of the medial and inferior vestibular nuclei.

An alternative explanation for the salience of vestibular phenomena in lucid dreaming is that cortical influences are superimposed on general activation of the RF; in other words, that in the lucid process vestibular sensations are selectively incorporated into mentation but are subcortically no more prevalent than endogenous input from other sensory systems. The fact that self-awareness and cognitive control characterize lucidity implicates cortical activation of neurocognitive systems in the lucid process [7]; however, this does not account for why vestibular imagery is more salient than visual imagery. One cortically-based explanation for the prominence of vestibular imagery in lucid mentation is that some individuals are relatively more likely to rely on vestibular than visual cues for interpretating endogenous sensory information. That is, that they have a cognitive style in which reliance on non-visual referents is prepotent. Witkin and his collaborators [27, 28] termed this type of cognitive style field independence, and lucid dreamers have been found to be more field independent than nonlucids [29].

The field independence-dependence construct was initially developed to account for the different manner in which people were observed to maintain spatial orientation with reference to gravity. For the maintenance of spatial orientation, it is necessary that homeostatic compensations be continually made in response to changes in body position, body posture, the orientation of sensory input, and gravitational forces. Momentary disturbances of balance and orientation normally are quickly and automatically compensated for either externally by a change in receptor orientation, e.g., the doll-eyes reflex of infancy, or internally by neurocognitive processes. The final determination of internal compensation appears to depend on CNS integration of weighted inputs from vestibular, visual, and somatic receptors [30]. Among humans, internal compensation is especially important because alterations in posture and receptor orientation are anatomically delimited. Balance and spatial orientation are normally accomplished with remarkable proficiency, but there are times when temporary rearrangements of sensory input lead to brief episodes of spatial disorientation, i.e., to perceptual or mental confusion about one's location in space. More prolonged disequilibrium is common among persons with vestibular neuropathology, especially in the form of vertigo, an hallucination that either the person or their environment is spinning. These vertiginous sensations are more pronounced in the dark or when the eyes are closed, conditions which prevail during sleep. Vertiginous sensations appear to be similar to the fictive images of movement experienced during sleep and in particular REM sleep [31].

The neurofunctional system of internal compensation by which balance and spatial orientation are maintained during wakefulness must operate in the world of sleep mentation but presumably with functional modifications according to the depth of sleep and perhaps the self-awareness of the dream process. During sleep, cortical activity is diminished and sensory input is altered (the eyes are closed and the body is recumbent and relatively inactive). The weighted inputs from visual, somatic, and vestibular receptors must therefore differ from those during wakefulness. The elevated sensory thresholds of desynchronized sleep could be expected to exaggerate this situation, even though cortical activity is greater than during other sleep stages. The primary exception to the sleep-wakefulness differential functioning of the system for maintaining balance and spatial orientation is the vestibular modulation of oculomotor activity. This oculomotor activity is ongoing during sleep and includes nystagmic-like bursts, REM, which are similar in velocity to awake state eye movements in the absence of visual input [32] and may be similar to nystagmus in response to spatial disorientation [33]. REM duration is known to vary directly as a function of the length of sleep and extent of sleep deprivation [34]. REM also can be enhanced by exogenous vestibular stimulation provided movement constraints are not imposed on sleepers [35, 36] and vestibular functioning is normal [36]. These combined observations indicate that vestibularly-mediated oculomotor activity is similar for wakefulness and dreaming. It is also notable that the intensity of vestibulo-ocular responses varies directly as a function of the level of arousal [37]. In as much as dream mentation and REM involve increased cortical activity, it is reasonable that individual differences in cortical activation during REM sleep could support individual differences in the activation of cognitive production systems that engender consciousness within the dream experience, i.e., lucid dreaming.

The apparent relationship between reportable sleep mentation, cortical arousal, and vestibulo-ocular responses has lead us to question whether lucid and nonlucid dreamers compensate differently for alterations in balance and spatial orientation. We have elsewhere reported that caloric stimulation of the vestibular receptors of the semicircular canals with the eyes closed during aroused wakefulness results in more vigorous nystagmus in lucid dreamers than in nonlucids [9]. In the present study we sought to determine if differences between lucid and non-lucid dreamers could be demonstrated with tasks involving stimulation of the otolithic receptors. Otolithic stimulation is of necessity indirect but can be approximated with several types of balance activities, including maintaining equilibrium on a platform and walking a beam. These two particular activities were selected for study because of their prominence in the vestibular literature [38-41].

Maintaining equilibrium on a platform, or stabilometer, involves static balance which Seashore has defined as the maintenance of a specified posture for which the antagonistic muscles are coordinated to minimize body sway [40]. Walking a beam, which requires translocation, involves dynamic balance. Factor analytic studies and low correlations between measures of static and dynamic balance indicate that performance on these two types of balance tasks is achieved by different means [39]. Otolithic and canal processes, as well as vision, are implicated in both static and dynamic balance [42], but otolithic processes are prominently implicated in the maintenance of static equilibrium [29]. This otolithic involvement can be accentuated by darkness or by distorted visual feedback. In the present study persons who differed in their likelihood of experiencing lucidity were therefore asked to perform static and dynamic balance tasks under three conditions: with illumination, without illumination, and with distorted visual information regarding verticality. Three primary hypotheses were tested: 1) that persons who report frequently experiencing lucid dreams will have better static and dynamic balance than persons who report infrequently or never experiencing lucid dreams; 2) that this group superiority in balance performance will vary as a function of the availability of visual feedback (darkness > visual distortion > normal vision) and as a function of balance task (stabilometer > beam); and 3) that persons who report infrequently experiencing lucid dreams will perform better than nonlucids but poorer than frequent lucid dreamers.

METHOD

Subjects

Undergraduate students at a midwestern university were administered en mass a set of measures which included two relevant to this study (Lucid Dreaming Questionnaire; Balance History Questionnaire). From a subject pool of 707 persons, 155 (73 females, 82 males) reported that they had never experienced a lucid dream, seventy-five (40 females, 35 males) reported experiencing one or more lucid dreams per month, and 133 (61 females and 72 males) reported at least one lucid experience in their lifetime but no more than six per annum. All students who reported experiencing lucidity were requested to write a description of one of these experiences.

These dream descriptions were subsequently judged as representative of lucidity according to whether or not they incorporated a recognition phrase like "Then I realized it was only a dream" [8]. Persons who reported lucidity but whose dream descriptions did not validate this experience were excluded. Other potential subjects were excluded because of physical conditions known to affect balance performance: severe ear problems or motion sickness [43], visual impairment not correctable with glasses [44], and bodily injury [45]. Experimental subjects were then randomly selected from each of three dreamer classifications so that there were twenty-four persons per gender and dreamer type ($N = 144$). Three dreamer classifications were defined: non-lucid, infrequently lucid (less than or equal to six lucid dreams per year), and frequently lucid (greater than or equal to 12 lucid dreams per year).

Measures

Lucid Dreaming Questionnaire (LDQ, [46]). This measure was primarily developed from the work of Green [12] and includes one item on which persons rate their frequency of lucid dreaming according to a 7-point scale, as well as a Likert-type item for rating extent of dream recall. The latter rating was used as a covariate in all data analyses because lucidity has been found to be highly correlated with extent of dream recall [8].

Balance History Questionnaire (BHQ). This self-report measure was generated expressly for this study by reviewing the literature for variables relevant to static and dynamic balance performance. Subject height and weight were obtained, with weight subsequently used as a covariate in the analyses of stabilometer performance [47]. Likert-type items were used for rating the severity of balance-related disorders (ear problems, physical handicaps, motion sickness, visual impairment uncorrectable by glasses) and the extent of subject participation in athletic and dance activities.

Apparatus

A Lafayette (Model #16020) stabilometer with a platform (91.5 cm by 122 cm) set for switch closure at 5 degrees to right and left of center was used to measure static balance. Center time in balance, right and left times out of balance, and right and left contacts (errors) were automatically recorded by the apparatus. A balance beam, 355 cm (12 ft) in length, 9.53 cm (3.75 in) in width and mounted 30.5 cm (12 in) above the floor, was used to measure dynamic balance. Stop and start positions were demarcated 40.75 cm from each end so that a path of 274.5 cm (9 ft) was traversed. The balance beam path was graduated in 15 cm (6 in) intervals so that location of errors and relocation of subjects could be determined. Visual distortion for both balance tasks was achieved with a 76.2 cm square (30 in by 30 in) luminously painted frame tilted 30 degrees to right or left of center and mounted with its horizontal axis 205.88 cm (6.75 ft) from the floor.

Procedure

Subjects were tested individually after the balance beam and stabilometer tasks were described and demonstrated. For both tasks subjects wore socks provided by the experimenter to assure uniform footwear [48]. Order of tasks was counterbalanced for gender, dreamer type (frequent lucid, infrequent lucid, nonlucid) and visual condition (light, dark, right field distortion, left field distortion). Subjects were blindfolded for the dark condition. The balance beam and stabilometer were arranged in the same room so that one wall was 8.14 cm (20.7 in) from the subject's right when walking the beam and the stabilometer was 9.91 cm (3.25 ft) to their left.

For balance beam performance, subjects were instructed to mount the beam and to position themselves at the starting point. They then walked the beam heel-to-toe (tandem) forward for nine feet and then backward the same distance. For the distorted visual field conditions, one minute retinal acclimation periods were provided. Errors on the balance beam were defined as either stepping off the beam or touching the adjacent wall. Forward time to completion, backward time to completion, and total errors per condition were recorded.

Stabilometer performance was measured under the same four visual conditions (i.e., light, dark, and right and left visual distortions) as balance beam performance and in counterbalanced order. The stabilometer platform was positioned 21.87 cm (7 ft 2 in) from the visual distortion frame. Time and error recorders were inobtrusive. Subjects were instructed to place their foot of choice inside a taped area on the platform. While resting their weight on that foot they were instructed to symmetrically place their other foot on the opposite platform side. A practice session of one minute followed. Two one-minute trials per condition were then performed with rest intervals between each trial of approximately 45 seconds. All subjects were debriefed after they had participated.

RESULTS

Subjects' performance on the two balance tasks was evaluated by doing separate analyses of covariance for each task. For both sets of analyses, dream recall and error frequency were used as covariates. It was necessary to control for dream recall because this behavior has been shown to be highly correlated with lucid dreaming frequency [8]. It was necessary to control for error frequency because the dependent variables for both balance tasks were measures of time which could have varied according to the number of errors made. Gender and dreamer type (frequently lucid, infrequently lucid, and non-lucid) were between subject variables and visual condition (light, dark, distorted right, distorted left) was a within subject variable for all analyses.

Balance Beam Performance

Time-to-walk the balance beam, measured in tenths of a second, was evaluated by doing a four-way ANCOVA for Gender by Dreamer groups walking the beam forward and backward (Direction) under the four Visual Conditions. There were main effects for Gender, $F(1,136) = 10.4$, $p < .002$, and for Visual Condition, $F(3,413) = 66.8$, $p < .0001$. Males more quickly traversed the beam than did females and both walked the beam more rapidly with illumination than with right or left distortion or in darkness. There were also two interactions. Gender interacted with Direction, $F(1,137) = p < .05$, and Direction interacted with Visual Condition, $F(3,413) = 11.3$, $p < .0001$. Since these main effects and interactions do not implicate lucid dreaming frequency as a variable relevant to balance beam performance, they will be discussed no further.

Stabilometer Performance. Time out-of-balance on the stabilometer, measured in milliseconds, was evaluated by doing a five-way ANCOVA. For this ANCOVA, body weight was used as a covariate [41], as were dream recall and error frequency. Within subject variables were Side (right vs left) and Trial (1st vs 2nd) in addition to Visual Condition. There were no significant main effects, but there were multiple interactions involving Dreamer Type, as well as two interactions (Trial and Condition, $p < .02$, and Gender, Side, Trial, and Visual Condition, $p < .001$) unrelated to lucidity. The significant interactions involving the frequency of lucid dreaming are summarized in Table 1.

The interaction between Dreamer Type, Trial, and Condition was decomposed using the Duncan procedure. This decomposition revealed that frequent lucid dreamers spent less time out of balance on the stabilometer than did either infrequent lucid dreamers or non-lucids, though only for the first trial and only under the normal light condition ($p < .05$). Otherwise, the stabilometer performance of these dreamer groups did not differ for the interaction of these three factors. The mean time out of balance during the first trial for dreamer types under the normal light condition is depicted in Figure 1. There were no dreamer differences in darkness or the two conditions of visual distortion. Since otolithic involvement is accentuated in darkness and with distorted visual feedback, the superior stabilometer performance of frequent lucid dreamers appears to be unrelated to otolithically mediated vestibular processes. Rather, semicircular canal mediated processes involving visual and oculomotor mechanisms appear to be implicated. Since the performance difference between dreamer types was evident only for the first trial, persons who do not dream lucidly or infrequently do so were able to balance as well as frequently lucid persons if afforded more opportunity. In some way, practice disproportionately enhanced the stabilometer performance of

Table 1. Significant Analysis of Covariance Effects for Stabilometer Time Out of Balance According to Lucid Dreaming Frequency

Source	*df*	*F*	*p*
Dreamer x Trial	2,137	4.75	.01
Dreamer x Side	2,137	4.13	.01
Dreamer x Gender x Side	2,137	4.46	.01
Dreamer x Trial x Condition	6,413	2.45	.02
Dreamer x Side x Condition	6,413	2.59	.02

non-lucids and infrequent lucids. In other words, they were able to compensate for their initial relative disequilibrium.

There were three interactions involving Dreamer Type and Side (rightward or leftward). Each of these interactions was analyzed further with the Duncan procedure. Decomposition of the interaction between Dreamer Type, Gender, and Side revealed that frequent lucid dreamers spent equal time out of balance to the left and right but that infrequents (L > R) and non-lucids (R > L) showed opposite lateralized imbalance which was specific to males and more pronounced for the non-lucid than the infrequently lucid group (Figure 2). Decomposition of the Dreamer, Side, and Condition interaction, which is in part depicted in Figure 3, indicated that the lateralized imbalance of infrequent and non-lucid dreamers applied only to stabilometer performance under normal light. Time out-of-balance to the left or to the right did not differ for any of the dreamer types with darkness or with either right or left visual distortion. As for the total time out of balance, frequent lucid dreamers differed from other dreamer types in the lateral distribution of balance under normal illumination. This laterality effect also leads one to suspect that dreamer differences in static balance are not related to otolithic functioning since darkness and visual distortion should accentuate otolithically-based differences.

DISCUSSION

This study of the static and dynamic balancing behaviors of persons grouped according to their frequency of reported lucid mentation was undertaken to determine the relevance of balance proficiency to lucidity and to determine if the results obtained by Gackenbach et al. for the caloric stimulation of the semicircular canal division of the vestibular system would be paralleled on tasks which are thought to tap otolithic vestibular processes [9]. The two tasks employed were walking a balance beam and maintaining postural stability on a moveable platform. Since both of these balance activities indirectly entail otolithic stimulation, we sought to increase otolithic involvement by having subjects perform not only

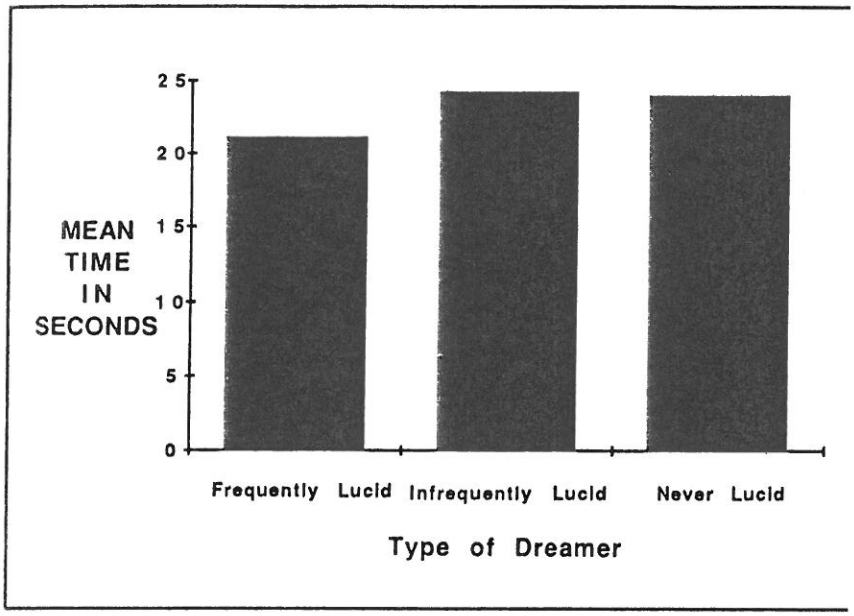

Figure 1. Stabilometer mean time out of balance of persons grouped according to lucid dreaming frequency (frequent, infrequent, never) for the first trial only under normal light.

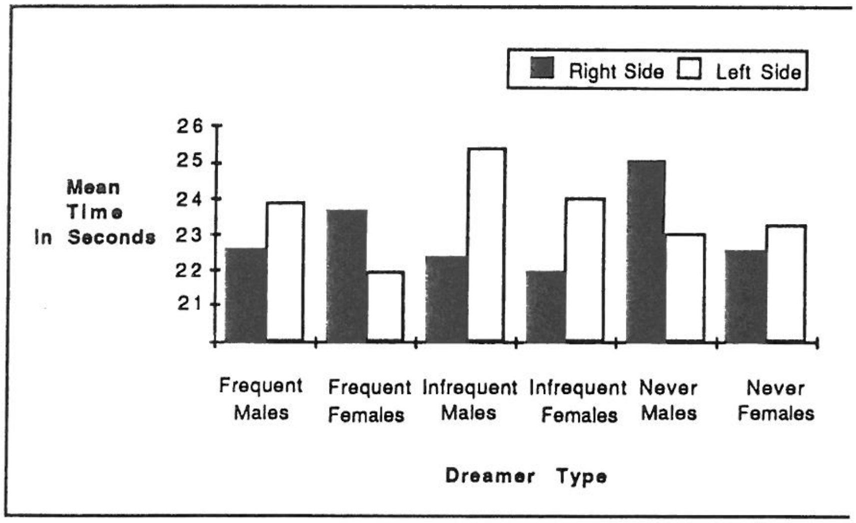

Figure 2. Stabilometer mean time out of balance as a function of lucid dreaming frequency, gender and side.

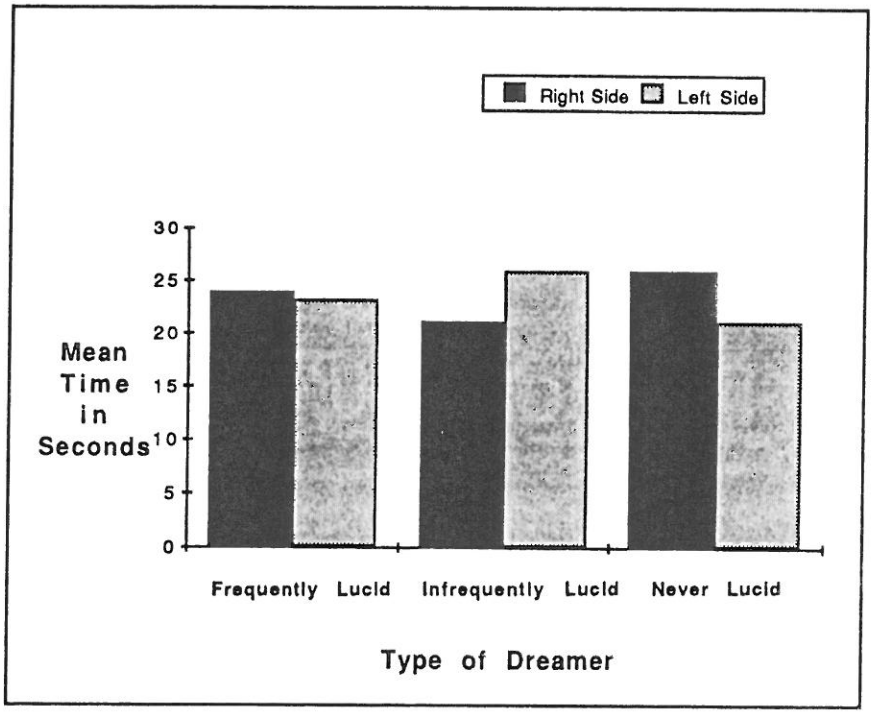

Figure 3. Stabilometer mean time out of balance as a function of lucid dreaming frequency and side under the light condition.

in the light but in two conditions in which otolithic functioning is normally enhanced, darkness and distorted visual fields. It had been hypothesized that persons who frequently experience lucid mentation, reports of which are characterized by vestibulo-kinesthetic salience, would perform better on balance tasks than would persons who infrequently or never experience lucidity. To the extent that otolithic mechanisms were implicated in this superior performance, it was also hypothesized that the differential performance of dreamer groups would be most evident in darkness and least evident in normal light.

As hypothesized, frequent lucid dreamers did perform better than cohorts who never or infrequently experience lucidity. This performance difference, however, was found only for the stabilometer task, only for the initial trial of stabilometer performance, and only under the light condition. No dreamer differences were detected for walking a balance beam, a finding which has been replicated by Hunt (personal communication, May, 1988). Differences in the stabilometer performance of dreamer types were found for total time out of balance and for the lateral distribution of time out of balance. The absence of dreamer differences in balance beam performance could be due to several factors, including inadequate sensitivity, though this is unconvincing since a gender difference was found. It is more likely, however, that lucid dreaming frequency is simply not associated with balance beam performance. Walking a beam and balancing on a platform are known to be achieved by different means [39] and it may be that this task performance difference is analogous to the free movement of wakefulness in comparison to the relative immobility of REM sleep. While linear movement and dynamic balance during wakefulness are clearly facilitated by exogenous sensory feedback, just as balance beam performance in this study was facilitated across dreamer types by visual conditions (light > distortion > darkness), imagistic "static" balance within sleep must be achieved primarily through endogenous input. With regard to the dreamer differences observed only during the visual condition of stabilometer performance, this condition, unlike distorted visual feedback or darkness, affords an occasion for relying more on external frames of reference than on internal ones if one is so disposed. Such a predilection would be more likely to be evident initially than over time, i.e., on a first trial. Persons who do not spontaneously experience lucid dreams rely more on external visual fields than on internal spatial referrents (8) and could be expected to have relatively greater visual weighting for maintaining balance than persons who rely on internal referrents. The absence of dreamer differences at walking a beam suggests that the particular weighted inputs from visual, somatic, and vestibular receptors can be changed and compensated for equally well on this task regardless of lucid dreaming status.

Stabilometer performance, which is a more sensitive and quantified measure of equilibrium maintenance than is balance beam behavior, was shown to discriminate between persons grouped according to lucid dreaming frequency, both with regard to total time in balance and with regard to the lateral distribution of time out of balance. The fact that dreamer differences in stabilometer performance were found only under the light condition signifies to us that these differences are probably not attributable to otolithic processes. We would propose, instead, that under normal light conditions stabilometer performance is more dependent on vestibular functions subserved by the semicircular canals than under conditions of diminished or distorted vision. In effect, the light and dark conditions enabled a partial dissociation between otolithic vestibular functioning and canal vestibular functioning. Direct stimulation of the semicircular canals is already known to discriminate lucid from non-lucid dreamers [9]. Whether this behavioral dissociation is related to differential activation of otolithic and canal postnuclear neural pathways during sleep mentation would appear to merit investigation. Use of a four-pole swing [25] which induces otolith stimulation without any angular acceleration also might afford a means by which to further test the differential otolithic sensitivity of persons grouped according to lucid frequency.

In addition to dreamer differences in balance performance as a function of the nature of visual and/or oculomotor feedback, the finding that dreamer types differed in terms of their spatial distribution of compensatory body positioning is notable and convergent with the asymmetrical vestibular responsiveness to caloric stimulation of non-lucids described by Gackenbach et al. [9]. In the present study non-lucid dreamers, especially males, spent more time out of balance on the stabilometer in the rightward than leftward direction, i.e., they disproportionately leaned to the right while trying to maintain equilibrium. Infrequents (again predominantly males) showed the reverse asymmetry, while the lateral compensatory posturing of frequent lucid dreamers was symmetrical. These results are consonant with those obtained with caloric stimulation and reinforce our view that dreamer differences in stabilometer performance are due more to variable functioning of the semicircular canal vestibular subsystem than to variations in otolithic functioning. The non-lucid dreamers in the study by Gackenbach and associates manifested a pronounced rightward asymmetry of nystagmus in response to bithermal caloric irrigation of the tympanic membranes, or a rightward directional preponderance. Directional preponderance is considered a measure of the coordinated activity of the right and left semicircular canals and is sometimes used clinically as an index of abnormal responsiveness. Pronounced right directional preponderance represents overcompensation to the right following stimulation of the right and left semicircular canals. Frequent and infrequent lucid dreamers were found to have mild leftward asymmetry which was fully within the normal range. Thus both in response to caloric stimulation and when balancing on a deformable platform, persons who never have experienced lucid mentation overcompensated to the right, in one case oculomotorically, in the other case in postural adjustments. While infrequent lucid dreamers showed the reverse asymmetry posturally and to a lesser degree ocularly, frequent lucid dreamers had symmetrical body displacements and weak left oculomotor asymmetry. These combined results provide convergent evidence that persons who do or do not report lucid mentation differ with respect to vestibular functioning. The direction and extent of these differences may be more pronounced for males than females.

The relative directional symmetry of frequent lucid dreamers for both stabilometer performance and responsiveness to caloric irrigation in comparison to the asymmetery of persons who infrequently or never experience lucidity is a provocative finding, especially with regard to possible neuroanatomical or neurochemical bases for these directional differences. Unilateral irritative or destructive vestibular lesions (end organ, nerve, or nuclei) cause nystagmus toward the side of the lesion until compensated for by voluntary and visual reflex circuits [25]. At least in rats, unilateral lesions in any part of the nigrostriatal system (substantia nigra, nigrostriatal bundle, or corpus striatum) similarly result in circling behavior to the side of the lesion [49]. The nigrostriatal system is a dopaminergic pathway connecting cell groups in the midbrain to cells in the basal ganglia, limbic system, and neocortex. Parkinson's disease is a pathological condition of the nigrostriatal system and involves progressive dopaminergic insufficiency. Parkinsonian patients, in addition to the typical motor symptoms of tremor and rigidity, have been shown to do poorly on tasks of spatial orientation, including the judgement of visual verticality under conditions of body tilt, judging upright posture without vision, and route-walking guided by visual maps [50]. Furthermore, there are directional differences in spatial orientation among Parkinsonian patients according to the laterality of their predominant motor symptoms [51]. Years ago it was proposed that the corpus striatum, one of the basal ganglia, represents a supravestibular system [52]. The convergent results from investigations of lucid dreaming frequency in relation to vestibular functioning, of neuropathology believed to involve vestibular pathways, and of subjective experiences associated with lucidity, provide a basis upon which to speculate about the neurofunctional system which subserves the production of lucid mentation. The remainder of this chapter will be devoted to discussing possible contributions to this system.

SPECULATIONS ON THE NEUROCOGNITION OF LUCID DREAMING

Antrobus has reviewed the neurocognitive processes which are now thought to contribute to sleep mentation. He has emphasized that subcortical structures, including the pontine vestibular nuclei, support the cognitive production systems that generate sleep mentation but that these structures do not themselves produce sleep mentation. He has also, we believe rightfully so, emphasized that sleep mentation is a multidimensional variable which needs to be examined in its different dimensions in order to more precisely identify the linkages between the neurological and cognitive events of sleep and waking mentation. Our approach to understanding these linkages has been to select a unique form of sleep mentation, lucid dreaming, and to study the neuropsychological characteristics of persons who differ in their frequency of experiencing lucidity. Unlike others who have directly sought to relate the tonic and phasic neurophysiological processes of sleep to sleep mentation, we have sought, so to speak, to work from the outside in. Although inferentially precarious, we see this path as complementary to a more direct, physiological approach. It also enables such diverse cognitive products as hallucinations, out-of-body experiences, archetypal motifs, hypnagogic imagery, witnessing during meditation, preictal auras of epilepsy, and anosognosia to be studied within an integrated format.

The mentation of lucid dreaming is defined by the presence of self-awareness, or consciousness, during sleep. Self-awareness requires sufficient cortical arousal as well as integrated cortical functioning. Disorientation-to-person in a noncomatose individual, as apparent in acute confusional states resulting from metabolic encephalopathies or other brain pathologies, informs us that the mechanisms of wakefulness are necessary but insufficient for self-awareness. Rather, cortical attentional mechanisms are required for self-awareness [53] and must therefore be more active during lucid dreaming than during other forms of sleep mentation. Antrobus has proposed that differences in the level of cortical activation account for the variability of mentation produced during sleep and wakefulness [7]. Dreaming is said to occur at a level of cortical activation intermediate between that of full wakefulness and non-REM sleep.

According to this prospectus, lucid dreaming would appear to involve increased cortical activity within REM sleep. Although "prelucid" experiences are associated with increments in EEG alpha, an index of cortical activation within REM, increased alpha has not been documented for lucidity (Hunt, personal communication, May 1988). Even if it can be established that there is greater cortical activation during lucid mentation than during other forms of sleep mentation, the source of this increment remains undetermined. Could it be that intense activation of the medial and inferior vestibular nuclei is related to this enhanced cortical activation? Or, as suggested by Antrobus, is this activation due to a general excitation of the reticular formation? Or might it be both?

Evidence against a specific role of the vestibular nuclei in the production of sleep mentation, in particular lucid dreaming, is primarily based on the increased sensory thresholds present during Stage 1 sleep. Since sensory thresholds are increased, some have reasoned that little subcortical information comes to the cortex and that sleep mentation must consequently be generated cortically as are hallucinations [7]. Others have proposed that random firing within subcortical structures does proceed to the cortex and there is integrated into the mentation of sleep [54]. These two models basically differ in terms of the modal specificity of the information received by the cortex. Hobson and McCarley have proposed that increased activation of the vestibular nuclei could result in dreams of vestibular salience. Antrobus would have us believe that such activation is relayed through nonspecific subcortical systems and therefore results in general cortical activation. We suspect that the ultimate answer to this chicken-egg dilemma lies in a more complete understanding of the neural regulation of eye movements. In as much as these movements are regulated by the vestibular system, and in particular the neural processes specific to pathways subserving the semicircular canals, we believe that a more precise role for the vestibular nuclei in the production of sleep mentation will be defined. Clearly the vestibular nuclei are but one part of a complex brain system associated with oculomotor control. The cerebellum, thalamus, caudate nucleus, and prefrontal cortex are probably integral to this system [53].

Some years ago Adey, Kado, and Rhodes proposed that REM sleep might involve an "internalization of attention" [55]. This proposal is conceptually attractive because it can incorporate the intense activation of the vestibular nuclei which precedes REM bursts, the increase in cortical arousal which occurs during dreaming, the high sensory thresholds which enable redirection of attention from exogenous stimulation, and rapid eye movements which may be related to the overt eye movements and mechanisms of covert attention described by Posner and Friedrich [56]. Lucid dreaming, in this context, can be conceived as a state of increased internalized attention in which the consciousness of wakefulness commingles with the mentation of Stage 1 REM sleep. The self-awareness of lucidity and the resultant imposition of cognitive control over sleep mentation would then be viewed as a neurocognitive process mediated by the heteromodal prefrontal cortex, an example of what Stuss and Benson have termed the highest level of cognitive functioning [57]. The frontal eye fields, which are adjacent to heteromodal cortex, have a role in directed attention and receive up to 51 percent of their caudal afferent input from unimodal visual association areas [53]. Their efferent projections provide direct access to pathways that control head, eye, and limb movements in coordination with vestibular processes, while auditory input for possible sound localization and extensive limbic inputs from the cingulate cortex are also received, the latter relevant to motivational aspects of the exploration of space. Other cortico-cortical and subcortical connections of the frontal eye fields are described by Pandya and Yeterian [58] and by Stuss and Benson [57]. There is no anatomical evidence for direct connections between the frontal eye fields and the oculomotor nuclei.

Antrobus has discussed the possible role of the frontal eye fields in sleep mentation and has proposed that they" . . . are a primary candidate for controlling the relationship between sleep mentation and REMs" [7, p. 37]. He also has reviewed the relationship between P-G-O activity, visual imagery in sleep, and eye movements in order to disambiguate the temporality of neural events associated with REM sleep mentation. Through detailed examination of what is known about neural pathways and this temporality he attempts to integrate our knowledge of vestibular physiology with recent investigations of eye movements during sleep and wakefulness. He, in turn, has made several points germane to this writing. It is pointed out that the visual images of REM sleep most probably have an extraocular origin, that the eye movements of REM sleep appear to originate in premotor neurons of the pontine RF which includes giant cells with projections to oculomotor and vestibular neurons, that the coordination of eye and head information during sleep may be mediated by different vestibular processes than during waking, and that although the frontal eye fields may control REM eye movements in response to ongoing mentation, the visual images of sleep mentation are probably not produced in these areas. Before relating these points to the data presented in this study, we wish to emphasize that the frontal cortex is not specialized for the reception, integration, and analysis of sensory information, or the production of percepts. Rather, the frontal cortex is specialized for supramodal integration, motor output, and decision making [20]; it is the source of behavioral control, including the allocation of eye movements. In this sense, eye movements are exploratory not reactive. The more a dreamer assumes an active role during sleep mentation, as in lucid dreaming, the less would we expect that eye movements are reactive to visual imagery and the more would we expect them to be related to spatial exploration of the dream world. It is at this level of neurocognition that the frontal eye fields may direct the vestibular-related eye movements of REM sleep. We would consequently expect that eye movements during sleep will vary according to the level of cortical arousal. In other words, that there may be within Stage 1 REM sleep variable sources of eye movement which have been obscured by our inadequate understanding of oculomotor control and by our predisposition to view REMs as a singular phenomenon.

Taking this information into account, what can be said about the role of vestibular functions in sleep mentation, and in particular the mentation of lucid dreaming? As stated earlier, the results of our investigations of vestibular functioning in persons who differ in the extent to which they have experienced lucidity do not enable us to directly address the neural level at which differences in vestibular functioning arise. At one extreme is the interpretation that these differences derive from differential activation of the vestibular nuclei. Frequent lucid dreamers would thereby be persons who are more sensitive to vestibular input, i.e., their vestibular apparati would more efficiently process exogenous input than would the apparati of non-lucid dreamers. There is evidence that this is part of the picture [8], but we have purposefully screened subjects in order to exclude persons with any signs of vestibular insufficiency. Consequently, more must be involved than differential sensitivity. At the other extreme is the interpretation that differences only derive from differential cortical involvement in the dream process. We believe that this too is part of the picture, especially since self-awareness (directed attention) is integral to lucid mentation. In order to explain to what extent differential vestibular sensitivity relates to lucidity, it will be necessary to determine if the vestibular nuclei of frequent lucid dreamers are more intensely activated than are those of other dreamers. It would also be necessary to determine that this greater activation is conveyed directly or indirectly to the cortex. Alternatively, it may be that frequent lucid dreamers have no more intense activation of the vestibular nuclei but that the amount of vestibular input to the cortex relative to other sensory modalities is greater for this group. Ultimately the answer lies with relating subcortical activation to cortical activation, in other words, precisely mapping the neural connections between the vestibular nuclei, the cerebellum, and the cortex, as well as the neurochemical processes which regulate information transfer along these pathways. Perhaps the partial dissociation achieved in this study between canal and otolithic processes is a small step in this direction, as may be the lateral differences found between dreamer types.

If the visual images of REM sleep mentation are of extraocular origin, then one of the functions of the vestibular system, the minimalization of retinal image motion, is unlikely to be implicated in lucid mentation. Postural adjustments in response to linear movement of the head, which are accomplished through the otolithic vestibular division, would also be unlikely if lucid mentation principally implicates the canal division of the vestibular system as suggested by our research. Could the sleep-waking difference in the coordination of the eye and head information alluded to by Antrobus reflect an otolithic-canal differential involvement in the mentation of sleep and waking? As suggested by Antrobus, we also wonder about the role of the cerebellum in sleep mentation and in the regulation of eye movements via the cortico-ponto-cerebello-thalamo-cortical closed circuit.

Perhaps the phylogenetic theory of the dual origin of the cerebral cortex [59] is applicable to the issue of eye movements and sleep mentation. This theory begins with the proposition that there are two prime moieties from which all cortical regions have evolved—the archicortical (hippocampal) and paleocortical (olfactory). The archicortical moiety is specialized for dealing with one aspect critical to survival, the question of "where," i.e., spatial processing crucial for affecting behavior in space. The paleocortical moiety is specialized for dealing with the other aspect critical to survival, the question of "what." These dual architectonic trends are represented throughout the cortex and are related to the organization of connectivity both within and between cortical regions, as well as to fronto-thalamic connections. Within brain regions the archicortical moiety follows a dorsal trend, the paleocortical a ventral trend. In the frontal lobe the dorsal trend involves input from the trunk and limbs region of the somatosensory cortex, from visual association areas relating to peripheral vision, as well as from medial paralimbic cortices. This input of visuo-spatial and motivational processes is integrated within the dorsal prefrontal regions for energizing and guiding behavior in three dimensional space [58]. It is the archicortical moiety which most probably relates to vestibular functioning and to the association between lucid dreaming, eye movements, and processes integral to the semi-circular canal division of the vestibular system. This relationship is supported by the connectivity within and between cortical and subcortical structures, including the basal ganglia, and by the emotional salience and content of lucid mentation. Whether this relationship will withstand closer empirical scrutiny remains to be seen.

Although our means of investigating the brain have advanced remarkably in recent years, there continue to be great gaps in our knowledge of the neurology and neurochemistry of the vestibular system. The loss of vestibular functions in fish, birds, and in non-human primates renders them unfit to live in their natural habitat, though in the ordinary activities of human life loss of vestibular functioning may go almost undetected. This seemingly limited role in modern human activity contrasts greatly with the notable representation of the vestibular system in the brain. In as much as the anatomy of the semicircular canals of this system provides a blueprint for mapping space and movement through space, whether extrapersonal as in wakefulness or intrapersonal as in dreams, the imprint of this system on human behavior must be considerable and dispersed throughout all levels of the CNS. With regard to human behavior, the vestibular system is still remarkably unexplored. The advent of human flight and the exploration of extraterrestrial space have stimulated scientific investigation of the vestibular system and have reinforced its importance to the development and maintenance of an individual's understanding of space. We believe that the exploration of inner space and of the cognitions produced during sleep and wakefulness will further stimulate examination of the vestibular system and its role in neurocognition. In the interim we remain intrigued by the still incompletely charted association between lucid dreaming and the semicircular canal division of the vestibular system.

REFERENCES

1. J. R. Daube, B. A. Sandok, T. J. Reagan, and B. F. Westmoreland, *Medical Neurosciences,* Little, Brown and Company, Boston, 1985
2. W. Penfield and P. Perot, The Brain's Record of Auditory and Visual Experiences—A Final Summary and Discussion, *Brain, 86,* pp. 595-696, 1963.
3. W. James, *Principles of Psychology,* Holt, New York, 1890.
4. J. F. Kihlstrom, Conscious, Subconscious, Unconscious: A Cognitive Perspective, in *The Unconscious Reconsidered,* K. S. Bowers and D. Meichenbaum (eds.), John Wiley and Sons, New York, pp. 149-211, 1984.
5. M. Portegal, Vestibular and Neostriatal Contributions to Spatial Orientation, in *Spatial Abilities: Development and Physiological Foundations,* M. Portegal (ed.), Academic Press, New York, pp. 361-387, 1982.
6. R. W. McCarley and J. A. Hobson, The Form of Dreams and the Biology of Sleep, in *Handbook of Dreams: Research, Theories, and Applications,* B. B. Wolman (ed.), Van Nostrand Reinhold, New York, 1979.
7. J. Antrobus, *Cortical Activation, Perceptual Thresholds and Sleep Mentation,* Unpublished manuscript, 1986b.
8. T. J. Snyder and J. I. Gackenbach, Individual Differences Associated with Lucid Dreaming, in *Conscious Mind, Sleeping Brain: Perspectives on Lucid Dreaming,* J. I. Gackenbach and S. LaBerge (eds.), Plenum, New York, 1988.
9. J. I. Gackenbach, T. J. Snyder, L. Rokes, and D. Sachau, Lucid Dreaming Frequency in Relationship to Vestibular Sensitivity as Measured by Caloric Stimulation, in *Cognition and Dream Research: The Journal of Mind and Behavior (special issues),* R. Haskel (ed.), 72/3, pp. 277-298, 1986.
10. R. Haskell, Cognitive Psychology and Dream Research: Historical Conceptual, and Epistemological Considerations, *Cognition and Dream Research: The Journal of Mind and Behavior (special issue), 7*:2/3, pp. 131-160, 1986.
11. J. I. Gackenbach, The Psychological Content of Lucid Dreams, in *Conscious Mind, Sleeping Brain: Perspectives on Lucid Dreaming,* J. I. Gackenbach and S. LaBerge (eds.), Plenum, New York, 1988.
12. C. Green, *Lucid Dreams,* Hamish Hamilton, London, 1968.
13. S. LaBerge, *Lucid Dreaming,* Ballentine, New York, 1985.
14. O. Pompeiano, Vestibular Influences during Sleep, in *Handbook of Sensory Physiology: Vestibular System: Part I: Basic Mechanisms,* H. H. Kornhuber (ed.), Springer-Verlag, New York, 1974.
15. K. M. T. Hearne, *Lucid Dreams: An Electrophysiological and nPsychological Study,* Unpublished doctoral dissertation, University of Liverpool, 1978.
16. S. LaBerge, L. E. Nagel, W. C. Dement, and V. P. Zarcon, Lucid Dreaming Verified by Volitional Communication during REM Sleep, *Perceptual and Motor Skills, 52,* pp. 727-732, 1981.
17. S. LaBerge, The Psychophysiology of Lucid Dreaming, in *Conscious Mind, Sleeping Brain: Perspectives on Lucid Dreaming,* J. I. Gackenbach and S. L. LaBerge (eds.), Plenum, New York, 1988.
18. P. Doneshka and A. Kehaiyou, Some Peculiarities of the Dreams of Patients with Vestibular Diseases, *Acta Medica, 32*:1, pp. 45-50, 1978.
19. T. Nielson, Kinesthetic Imagery as a Duality of Lucid Awareness: Descriptive and Experimental Case Studies, *Lucidity Letter, 5*:1, pp. 147-159, 1986.
20. A. R. Luria, *Higher Cortical Functions in Man,* Basic Books, New York, 1980.
21. W. Graf, Motion Detection in Physical Space and Its Peripheral and Central Representation, in *Representation of Three-Dimensional Space in the Vestibular,*

Oculomotor, and Visual Systems, B. Cohen and V. Henn (eds.), New York Acade of Sciences, New York, pp. 154-169, 1988.

22. D. Bowers and K. Heilman, Pseudoneglect: Effects of Hemispace on a Tactile Li Bisection Task, *Neuropsychologia, 18,* pp. 491-498, 1980.
23. B. Cohen, Representation of Three-Dimensional Space in the Vestibular, Ocu motor, and Visual Systems: Concluding Remarks, in *Representation of Thr Dimensional Space in the Vestibular, Oculomotor, and Visual Systems,* B. Cohen ar V. Henn (eds.), New York Academy of Sciences, New York, pp. 239-247, 19
24. H. Reisine, J. I. Simpson, and V. Henn, A Geometric Analysis of Semicircular Can and Induced Activity in Their Peripheral Afferents in the Rhesus Monkey, *Representation of Three-Dimensional Space in the Vestibular, Oculomotor, and Visu Systems,* B. Cohen and V. Henn (eds.), New York Academy of Sciences, New Yo pp. 10-20, 1988.
25. B. F. McCabe and J. H. Ryu, *Vestibular Physiology in Understanding the Diz Patient,* American Academy of Otolaryngology, Rochester, Minnesota, 1979.
26. O. Pompeiano and A. R. Morrison, Vestibular Origin of the Rapid Eye Movemen During Desynchronized Sleep, *Experientia, 22,* pp. 60-61, 1966.
27. H. A. Witkin and D. R. Goodenough, *Cognitive Styles: Essence and Origins,* Inte national Universities Press, New York, 1981
28. H. A. Witkin, R. B. Dyk, H. F. Faterson, D. R. Goodenough, and S. A. Kar *Psychological Differentiation: Studies in Development,* Wiley, New York, 1962.
29. J. I. Gackenbach, N. Heilman, S. Boyt, and S. LaBerge, The Relationship betwe Field Independence and Lucid Dreaming Ability, *Journal of Mental Imagery, 9*: pp. 9-20, 1985.
30. D. E. Parker, The Vestibular Apparatus, *Scientific American, 243,* pp. 118-135, 198
31. H. S. Porte and J. A. Hobson, Fictive Movement in Sleep: REM vs NREM Sle Reports, *Sleep Research, 15,* p. 82, 1986.
32. J. H. Herman, D. R. Barker, and H. P. Riffwarg, Similarity of Eye Movement Characteristics in REM Sleep and the Awake State, *Psychophysiology, 20*:5, pp. 537-54 1983.
33. J. D. DiPrete, Rapid Eye Movement during Sleep Considered as Nystagmus, *Perceptual and Motor Skills, 63,* pp. 595-598, 1986.
34. J. W. Wolfe and J. H. Brown, Effects of Sleep Deprivation on the Vestibulo-Ocul Reflex, *Aerospace Medicine,* pp. 947-949, September 1968.
35. E. M. Ornitz, A. B. Forsythe, and A. de la Pina, Effect of Vestibular and Auditor Stimulation on the REMs of REM Sleep in Autistic Children, *Archives of Genera Psychiatry, 29,* pp. 786-791, 1973.
36. E. M. Ornitz, A. B. Forsythe, and A. de la Pina, The Effect of Vestibular Stimulatio on the Rapid Eye Movements of REM Sleep in Normal Children, *Electroencephalography and Clinical Neurophysiology, 34,* pp. 379-390, 1973.
37. G. M. Jones and N. Sugie, Vestibulo-ocular Responses in Man during Sleep, *Electroencephalography and Clinical Neurophysiology, 32,* pp. 43-53, 1972.
38. R. I. Bass, An Analysis of the Components of Tests of Semicircular Cana Function and of Static and Dynamic Balance, *Research Quarterly,* pp. 33-52 1939.
39. K. D. DeOreo and M. G. Wade, Dynamic and Static Balancing Ability of Preschoo Children, *Journal of Motor Behavior, 3*:4, pp. 326-335, 1971.
40. H. G. Seashore, The Development of a Beam-walking Test and Its Use in Measurin Balance in Children, *Research Quarterly, 19,* pp. 246-259, 1948.
41. R. C. Travis, An Experimental Analysis of Dynamic and Static Equilibrium, *Journal o Experimental Psychology, 35,* pp. 216-234, 1945.

42. I. P. Howard and W. B. Templeton, *Human Spatial Orientation,* Wiley, New York, 1966.
43. W. E. Collins, Subjective Responses and Nystagmus Following Repeated Unilateral Caloric Stimulation, *Annals of Otology, Rhinology and Laryngology, 74,* pp. 1034-1054, 1965.
44. S. J. Suttie, Differential Effects of Viewing Four Patterns of Figure Movement on Performance of a Dynamic Balance Task, *Perceptual and Motor Skill, 37,* pp. 279-282, 1973.
45. H. A. Witkin, H. B. Lewis, M. Hertzman, P. B. Meissner, and S. Wapner, *Personality Through Perception,* Harper and Row, New York, 1954.
46. J. I. Gackenbach, *A Personality and Cognitive Style Analysis of Lucid Dreaming,* Unpublished doctoral dissertation, Virginia Commonwealth University, Richmond, Virginia, 1978.
47. S. Wapner and H. A. Witkin, The Role of Visual Factors in the Maintenance of Body-Balance, *American Journal of Psychology, 63,* pp. 385-408, 1950.
48. D. W. Bundy, *Performance of Kindergarten Children on Two Measures of Field-Dependence-Independence and a Selected Movement Task,* Unpublished master's thesis, Purdue University, 1974.
49. S. D. Glick, T. P. Jerussi, and B. Zimmerberg, Behavioral and Neuropharmacological Correlates of Nigrostriatal Asymmetry in Rats, in *Lateralization in the Nervous System,* S. Harnard, R. W. Doty, L. Goldstein, J. Jaynes, and G. Krauthamer (eds.), Academic Press, New York, 1977.
50. F. P. Bowen, M. M. Hoehn, and M. D. Yahr, Cerebral Dominance in Relation to Tracking and Tapping Performance in Patients with Parkinsonism, *Neurology, 22,* pp. 32-39, 1972.
51. F. P. Bowen, M. M. Hoehn, and M. D. Yahr, Parkinsonism: Alterations in Spatial Orientation as Determined by a Route-Walking Test, *Neuropsychologia, 10,* pp. 355-361, 1972.
52. L. J. Muskens, *Das Supra-Vestibulare System,* Noord-Hollandsche Uitgevers Maatschasppij, Amsterdam, 1934.
53. M. M. Mesulam, Attention, Confusional States, and Neglect, in *Principles of Behavioral Neurology,* M. M. Mesulam (ed.), F. A. Davis, Philadelphia, pp. 125-168, 1985.
54. J. A. Hobson and R. W. McCarley, The Brain as a Dream-State Generator: An Activation-Synthesis Hypothesis of the Dream Process, *American Journal of Psychiatry, 134,* pp. 1335-1368, 1977.
55. W. R. Adey, R. T. Kado, and L. Rhodes, Sleep: Cortical and Subcortical Recordings in the Chimpanzee, *Science, 141,* pp. 932-933, 1963.
56. M. I. Posner and F. J. Friedrich, Attention and the Control of Cognition, in *The Brain, Cognition, and Education,* S. L. Friedman, K. L. Klivington, and R. W. Peterson (eds.), Academic Press, New York, 1986.
57. D. T. Stuss and D. F. Benson, *The Frontal Lobes,* Raven Press, New York, 1986.
58. D. N. Pandya and E. H. Yeterian, Architecture and Connection of Cortical Association Areas, in *Cerebral Cortex, Vol. 4,* A. Peters and E. G. Jones (eds.), pp. 3-61, 1985.
59. F. Sanides, Representation in the Cerebral Cortex and Its Area Lamination Patterns, in *Structure and Function of Nervous Tissue, vol. 5,* G. F. Bourne (ed.), Academic Press, New York, pp. 329-459, 1972.