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Lucid Dreaming Frequency in Relation to Vestibular Sensitivity as Measured by Caloric Stimulation

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Twenty-four males and 24 females with no history of vestibular dysfunction but who differed in their reported frequency of lucid dreaming (being aware of dreaming while the dream is in progress), underwent bithermal caloric irrigation to determine their electronystagmographic (ENG) responsiveness and their reported vertigo, both of which are measures of the functional integrity of the vestibular system. Evidence of a positive association between lucid dreaming frequency and ENG responsiveness was found for two graphic measures of nystagmus, amplitude per beat and speed in the slow phase, and for three other measures which imply decreased vestibular sensitivity, dysrhythmia, directional preponderance, and canal paresis. These results signify that frequent lucid dreamers are more responsive to caloric irrigation than are persons who never dream lucidly. Consonant differences between dreamer types were also found for the latency and duration of self-reported vertigo. Based on these findings and others in which lucidity frequency has been related to experiential and behavioral differences in equilabratory functioning, it is proposed that frequent lucid dreamers represent a subset of people whose vestibular system is subject to intense activation during sleep and whose dream mentation reflects this activation. It is conjectured that studies of vestibular physiology may provide a promising path for understanding the psychophysiology of sleep, the dream process, and self-awareness.

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The role of the vestibular system during sleeping and dreaming has received considerable attention. This attention has accrued because of the integral connections between the vestibular nuclei and the reticular formation, which is known to regulate arousal, and because vestibular dysfunctions have been reported to affect dream content, especially with regard to movement and balance (Doneshka and Kehaiyov, 1978; Eisinger and Schilder, 1929). An association between vestibular physiology and dreaming has also been supported by studies of rapid eye movements (REM). Pomepiano and his colleagues have demonstrated a central role for the vestibular nuclei in the production of REM bursts (Magherini, Pomepiano and Thoden, 1971; Pomepiano, 1974; Pomepiano and Morrison, 1965), which are known to coincide with dream mentation, while Ornitz, Forsythe, and de la Pena (1973) have recorded more REM bursts in sleeping children in response to vestibular stimulation than to no stimulation or auditory stimulation.

REM bursts have also been found to reliably precede the onset of a type of dream mentation known as lucid dreaming, or lucidity. This dream experience, which involves an awareness of being in a dream state during the process of dreaming, is relatively common (Palmer, 1974; Snyder and Gackenbach, in press) and has been verified in sleep laboratories by the observance of prearranged "signal" movements (Dane, 1983; Hearne, 1978; LaBerge, Nagel, Dement, and Zarcon, 1981). Based on the analysis of dreamer reports and on the performance of persons classified according to the frequency of lucid dreaming, there is evidence supportive of a special relationship between vestibular functioning and lucidity. Gackenbach and Schillig (1983), in a factor analytic study of dream content, have found that lucid dreams can be differentiated from non-lucid dreams in terms of auditory characteristics, balance, and control. In turn, the performance of persons on tasks known to involve vesticular functioning, e.g., balancing a platform or determining the upright with reference to one's own body rather than to an external visual field, have also been found to consistently discriminate between lucid and non-lucid dreamers.

Gackenbach, Sachau, Rokes, and Snyder (1985) compared the stabilometer performance of persons grouped according to their frequency of lucid dreaming. Frequent lucid dreamers, i.e., individuals who experienced lucidity at least once a month, were found to perform significantly better than infrequently lucid and non-lucid dreamers for their time in balance on a stabilometer. In contrast, differences were not found for competence and speed at walking a balance beam, whether the beam was traversed under conditions of illumination, darkness, or distorted visual fields. Balance beam performance is considered a measure of dynamic balance. Stabilometer performance is considered a measure of static balance, balance which does not involve moving from one location to another. Because dream mentation is not accompanied by physical displacement in space, it is intriguing that differences among dreamer types were evident only for a measure of static balance.

Another source of inferred differences in vestibular functioning between persons classified according to lucidity frequency has been performance on the Rod-and-Frame Test (RFT) and Embedded Figures Test (EFT). These two measures have been used by Witkin and his many collaborators over the past 30 years to study perception of the upright (Witkin and Goodenough, 1981). This perception has been attributed to apprehension through vision coordinated with apprehension through the vestibular, tactile, and kinesthetic senses. Some individuals have been found to consistently be more reliant on external visual feedback than on feedback from their own bodies for perception of the upright. Based on this distinction, persons have been classified as field dependent (reliance on external visual field) or field independent (reliance on own body). Investigation of the performance of dreamer types on the RFT and EFT has shown that individuals who frequently dream lucidly are relatively field independent, whereas persons who seldom or never dream lucidly are relatively field dependent (Gackenbach, Heilman, Boyt, and LaBerge, 1986). Inasmuch as field independence reflects greater reliance on vestibular functioning and superior stabilometer performance reflects more efficient vestibular functioning, frequent lucid dreamers would appear to be persons who have proficient and well developed vestibular physiology. In terms of dream mentation, this might account for the saliency which controlled balance and orientation have been reported to assume in the lucid experience (Green, 1968; LaBerge, 1985), in contrast to the uncontrolled movements reported for persons with vestibular diseases (Doneshka and Kehaiyov, 1978).

Because indirect measures of vestibular functioning have suggested an important relationship between lucidity and the vestibular system, the present study was undertaken to determine if differences between lucid and non-lucid dreamers would be manifest for a direct measure of vestibular physiology. In the laboratory or clinic the vestibular system can be stimulated by means of rotation tests, electrical tests, positional tests, or caloric tests (McCabe and Ryu, 1979). Of these techniques, caloric testing was selected for the present study because it has been the standard method used in clinical practice and experimental work (Clark, 1979), because it is relatively innocuous, and because it enables the right and left vestibular apparati to be stimulated separately. Caloric stimulation involves the irrigation of the external auditory canal with water which is either warmer or cooler than the canal wall. The resultant heat exchange engenders endolymphic movement within the semicircular canal and the stimulation of hair cells, the consequence of which are tremor-like oscillations of the eyes known as nystagmus. The major objective measure of the functional integrity of the vestibular system is nystagmus.

Although we know of no investigators who have directly studied the relationship between nystagmus and lucid dreaming, there is indirect evidence which suggests that persons who frequently dream lucidly can be differentiated from others with regard to ocular movement of vestibular origin. Both caloric and rotatory induced nystagmus can be altered with hypnosis in hypnotically susceptible subjects (Aschan, Frier, and Hagbarth, 1962). Previously non-lucid but hypnotically susceptible persons have been found to be trainable to be lucid (Dane, 1983), and the most common forms of lucid dream induction are based on self-suggestion (Price and Cohen, in press). Long, Ambler, and Guedry (1975) have reported that field-independent persons are less affected by the motion stimulus of the Brief Vestibular Disorientation Test than are field-dependent persons. Recall that field-independence is characteristic of frequent lucid dreamers (Gackenbach et al., 1986). Finally, Nilsson (1967) has related susceptibility to the oculargyral illusion after vestibular stimulation to anxiety; while Gackenbach (1978) has hypothesized that frequent lucid dreamers are less anxious than other persons. These findings, in combination with those based on dream content analyses and the performance of lucid dreamers on behavioral measures of vestibular functioning, led us to hypothesize that persons who frequently experience lucidity would exhibit greater vestibular sensitivity than would other individuals.

Method

Subjects

Forty-eight undergraduate students, prescreened for lucid dreaming frequency, understanding of lucidity, handedness, and history of balance-related abilities and disabilities, participated in this study. Persons were grouped according to their reported frequency of lucidity as frequent lucid dreamers (>1 lucid dream per month), infrequent lucid dreamers (<1 lucid dream per half-year), or non-lucid dreamers. There was an equal number of males and females per dreamer type. All but two subjects were consistent right-handers; one infrequently lucid male consistently preferred his left hand and one non-lucid male reported mixed preferences. No subjects were experiencing ear, nose, or throat problems. Subjects were instructed to take no drugs, including caffeine, prior to their participation.

Pre-experimental Measures

During the prescreening process in which more than 700 undergraduates were contacted, information was obtained about lucid dreaming frequency, the understanding of lucidity, and subject characteristics which would or could influence vestibular functioning. Lucidity frequency was determined by subject self-report to a single item in which one of seven general frequencies were to be selected from. To assure that potential subjects understood what a lucid dream is, a dream transcript exemplifying lucidity was collected from each person and analyzed for key recognition phrases (Snyder and Gackenbach, in press). Relevant subject characteristics were determined with two questionnaires developed by the first author:

Lucid Dreaming Questionnaire (LDQ; Gackenbach, 1978). This includes a set of 30 questions about dreaming and lucid dreams primarily derived from the work of Green (1968). One item, on which a subject's dream recall was rated, was used as a covariate in all data analyses because dream recall has been shown to differ among dreamer types (Snyder and Gackenback, in press).

Balance History Questionnaire (BHQ). This eight item scale consists of questions about balance related disorders (ear problems, physical handicaps, uncorrectible visual impairments, and motion sickness), as well as questions about balance related athletic and dance activities.

Experimental Measures

Two types of measures of vestibular functioning were collected during experimental sessions: subject reports of vertigo and electronystagmographic (ENG) recordings. Vertigo is an experiential variable which is clinically describable in terms of three dimensions of perceived movement: (1) the axis of rotation (long or sagittal); (2) the direction of rotation (clockwise or counterclockwise); and (3) the intensity of rotation. In this study intensity was rated on a scale (Lidvall, 1961a, 1961b) which ranged from a rating of 1 (no sensation of movement relative to surroundings) to a rating of 7 (very intense, unpleasant sensation of moving relative to surrounding, with a sense of physical displacement). The latency (onset time) and duration of vertigo were also recorded as recommended by Lidvall (1961a, 1961b).

Nystagmus has two components, an initial slow phase in which the eyes draw slowly to the left or right until they reach a limit, and a fast phase in which the eyes subsequently jerk leftward or rightward. ENG measures of nystagmus were determined for four parameters: (1) *Latency*, which was measured in seconds and was defined as the period between the onset of stimulation and the beginning of a response to the stimulus; (2) *Duration*, which was measured in minutes and defined by the times of onset and cessation of nystagmus; (3) *Beat Frequency*, which was measured in beats per second and represented by the highest beat frequency over a ten-second period; and (4) *Amplitude*, which was measured in average degrees of radians per beat. In addition, a set of four derived measures was determined: (1) *Frequency*, which was the summed number of beats in the first, middle, and last ten second intervals (Arslan, 1955); (2) *Speed of the slow component*, which was measured in degrees per second of eyeball speed per three 10 second intervals 60 seconds post irrigation onset (Collins, 1965; Stable, 1958); (3) *Canal paresis*, which was computed as a percentage by comparing the maximum slow component speeds for the right and left sides; and (4) *Directional preponderance*, which was computed by comparing the total right beating nystagmus time, i.e., left cool and right warm, to the total left beating nystagmus time, i.e., left warm and right cool (McCabe and Ryu, 1979). The latter two measures enable the symmetry of labyrinthine responses to be evaluated. Because dysrhythmia of ocular responses can lead to misinterpretations of the vestibulo-ocular reflexes, dysrhythmia was rated with a modification of Lidvall's (1961a) four-point scale and was accounted for in analyses. In accord with the recommendation of Spector (1967), caloric responses were also corrected for differences in spontaneous nystagmus. Interrater reliabilities were computed for graphic ENG measures as judged by two raters, one of whom scored all protocols, the other, ten randomly selected protocols. Nystagmic latency and duration were rated with correlations of .91 and .99, respectively; beat frequency and amplitude ratings were correlated at .69 and .78, respectively.

Procedure

Upon entering the experimental setting subjects were given a general overview of the experimental procedure. They were then given a brief description of vertigo, including the concepts of direction, axis, and intensity. To prepare subjects for their self-reporting of calorically-induced vertigo, they were required to report on the vertigo which they experienced when spinning themselves with eyes opened, then closed, in each case for five seconds duration and without fixation. Subject reports included the direction (clockwise or counterclockwise), axis (long or saggital), and intensity of perceived vertigo. They were then instructed that during the course of the experiment they were to report on any vertigo which they experienced.

Following subject preparation for reporting on vertigo, baseline measures of spontaneous eye movements were obtained for each subject. Calibration of the ENG was determined with subjects looking straight ahead, gazing rightward and then leftward at marks placed ten degrees off center and at six feet distance (Spector, 1967). Each fixation was done for 15 seconds, initially with illumination and subsequently without. ENG recordings of spontaneous movement were scored in terms of beats/second and amplitude/beat. Interrater reliabilities for these two measures were .95 and .85, respectively, as judged by the two aforementioned raters.

Subjects were next instructed to lie supine on the bed with their head on the 30 degree support. In accord with the bithermal procedure outlined by

Hallpike (1966), separate water baths at 44°C and 30°C were prepared and a caloric irrigation receptacle was placed beneath the ear to be irrigated in order to collect aqueous overflow. After the subject reported that he/she was ready, he/she was told to close his/her eyes and 150 ml. of water was injected into the external auditory canal of one ear for a 30 second period. The ENG operator marked recordings immediately prior to and after irrigation. The subject was then asked to open his/her eyes in the now darkened room and to press a button beneath his/her preferred hand when vertigo began and when it ceased. Oral rating of the intensity of vertigo along the 7-point scale previously described was then solicited, after which subjects serially subtracted from 100 by 7's in order to maintain mental alertness (Collins, 1965). Each ear temperature trial (right warm, right cool, left warm, left cool) was of three minutes duration, with six minute intertrial intervals to assure that eye movements had returned to baseline (Lidvall, 1961a, 1961b). The order of trials was counterbalanced across subjects with regard to water temperature (warm vs. cool) and ear stimulated (right vs. left). Note, that although some subjects reported extreme vertigo sensations, none delimited their participation, though they had been informed that discontinuance was their right. All subjects were fully debriefed as to the purpose of the experiment prior to their departure.

Results

This section is presented in two parts, the results of baseline analyses and the results of experimental analyses. The former were done prior to the analyses of experimental measures (self-reported vertigo and nystagmus) so that group differences in the relevant variables of vertiginous experience and spontaneous nystagmus could be determined and controlled for in the analyses of experimental variables.

Baseline Analyses

Two sets of baseline analyses were computed, one set for potential group differences in self-reported vertigo and another set for potential group differences in spontaneously occurring nystagmus. For the former a total of 12 sex and dreamer chi-squares were calculated on the direction subjects chose to spin their bodies when being taught how to report vertigo (clockwise or counter clockwise), on the axis of reported vertigo (long or sagittal), and on the direction of experienced vertigo (clockwise or counter clockwise) under conditions of eyes opened and closed. No significant differences emerged. However, a 2 (Sex) × 3 (Dreamer Type) × 2 (Eye Condition) analysis of covariance of the intensity of vertigo reported in response to body spin, with

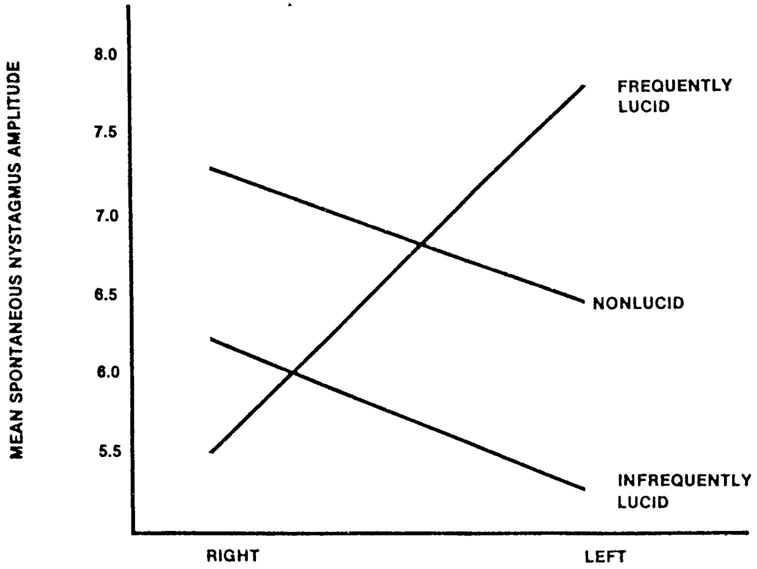

Figure 1. Mean spontaneous nystagmus amplitude by type of dreamer and direction of eye movement.

self-reported dream recall as the covariate, did result in a significant main effect for the eye condition $F(1,42)=9.09$, $p<.004$. Across sex and dreamer type, vertigo was reported as being more intense when subjects had their eyes closed than when their eyes were opened. Since none of these analyses indicated any differences among dreamer types for self-reported vertigo, subsequent analyses of reported vertigo in response to caloric stimulation were not adjusted for group differences.

In contrast, significant differences for dreamer types were found for the analyses of spontaneous nystagmus. Two 2 (Sex of Subject) × 3 (Dreamer Type) × 2 (Lighting Condition: on or off) × 4 (Eye Movement Instructions: straight, right, left, closed) × 2 (Eye Movement Direction: right or left) analyses of covariance, again with dream recall as the covariate, were computed on spontaneously emitted beats/second and amplitude/beat. Only main effects and interactions involving the three within subject variables reached significance for the analysis of beats/second. However, for the analysis on amplitude the Dreamer Type × Eye Direction interaction was found to be significant ($F(2,42)=5.01$, $p<.01$), as were several other effects not involving dreamer type.[1] It can be seen in Figure 1 that the frequent lucid dreamers

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[1] For beats/second these included main effects for lights ($F(1,42)=29.35$, $p<.00001$) and eye instructions ($F(3,126)=14.40$, $p<.00001$) and interactions between lights and eye instructions ($F(3,126)=3.88$, $p<.01$), eye instruction and eye direction ($F(3,126)=3.15$, $p<.03$). Whereas for amplitude these included an eye instruction ($F(3,126)=24.13$, $p<.00001$) main effect and an interaction between eye instructions and eye direction ($F(3,126)=74.72$, $p<.00001$).

Table 1

Summarized Analyses of Covariance on Self-reported Vertigo in Response to Bithermal Caloric Irrigation of Right and Left Ears of Dreamers Classified According to the Frequency of Lucid Dreaming and Sex of Subject

Source	Dependent Variable	*df*	MS	F
Sex	Latency	1	2961.01	5.03*
Error	Latency	41	388.67	–
Ear	Intensity	1	2.92	5.35*
Error	Intensity	42	0.54	–
Temperature	Latency	1	5535.18	12.30**
	Duration	1	133236.00	45.13**
	Intensity	1	46.35	120.59**
Error	Latency	42	450.10	–
	Duration	42	2952.19	–
	Intensity	42	0.38	–
Temp×Dreamer	Latency	2	1532.33	3.40*
Error	Latency	42	450.10	–
Temp×Sex×Dreamer	Latency	2	1543.90	3.43*
	Duration	2	10022.90	3.40*
Error	Latency	42	450.10	–
	Duration	42	2952.19	–
Ear×Temp×Sex	Intensity	1	2.52	4.12*
Error	Intensity	42	0.61	–

$*p<.05$ $**p<.001$

accounted for this interaction. That is, they showed a significant (Duncan post-hoc $q=5.95$, $p<.01$) left bias in the amplitude of their spontaneously generated nystagmus. Post-hoc tests on non-lucid and infrequently lucid dreamers showed no side preference. As a consequence, for all analyses on amplitude, dependent variables in response to caloric stimulation, rightward and leftward spontaneous nystagmus amplitudes were used as covariates.

Experimental Manipulation Analyses

Statistical analyses presented in this section were done on data derived from self-reports of vertigo and on ENG measures. Self-reported dream recall ability is the covariate in all analyses; in those in which amplitude is the dependent variable, two additional covariates are used as noted above.

Vertigo Self-Reports

Three measures of vertigo in response to caloric stimulation were analyzed: duration, latency, and mean intensity for the six reports during each three minute trial. For all three dependent variables, a 2 (Sex of Subject) × 3

Table 2

Mean Ratings for Self-Reported Vertigo in Response to Bithermal Caloric Irrigation by Dreamers Classified According to Frequency of Lucidity and Sex of Subject

Self-Reported Vertigo	Group					
	Frequently Lucid		Infrequently Lucid		Nonlucid	
	Male	Female	Male	Female	Male	Female
Warm Water:						
Vertigo Latency	25.55	15.43	32.03	6.72	5.33	14.97
Vertigo Duration	24.73	29.60	80.16	11.50	14.31	31.16
Cool Water:						
Vertigo Latency	30.52	21.71	27.76	20.12	38.08	26.27
Vertigo Duration	108.35	73.76	99.29	82.96	77.26	65.97

(Dreamer Type) × 2 (Ear Side: right and left) × 2 (Temperature of Water: warm or cool) analysis of covariance was computed. Nine effects reached significance for these analyses and are presented in Table 1. Only effects involving type of dreamer will be discussed. The significant Temperature × Dreamer interaction for latency was accounted for by the non-lucid dreamers' differential reaction to warm (mean = 10.15 seconds) versus cool (mean = 32.18 seconds) water (Duncan post-hoc $q = 5.87$, $p < .01$). The two types of lucid dreamers showed no difference in the latency to their feelings of dizziness. This finding for non-lucid dreamers seems to be accounted for, in the main, by males, as apparent in the Temperature × Sex × Dreamer interaction. It can be seen in Table 2 that only for male non-lucid dreamers was there a significant difference between latency times for reporting vertigo from warm to cool water ($q = 6.18$, $p < .01$). No temperature differences emerged for male or female frequent or infrequent lucid dreamers, or for female non-lucid dreamers.

This same three-way interaction, Temperature × Sex × Dreamer, appeared for length of self-reported vertigo sensations (see Table 2). Cool water irrigation had no differential effect for dreamer types regardless of sex. However, for warm water irrigation, infrequently lucid men reported significantly longer vertigo sensations than their female counterparts ($q = 5.06$, $p < .05$), and the other two types of male dreamers (frequently lucid $q = 4.08$, $p < .06$; non-lucid $q = 4.85$, $p < .05$). As with cool water irrigation, frequently lucid and non-lucid individuals showed no sex difference with warm water irrigation.

Graphic ENG measures. Five indicates of the caloric response will be con-

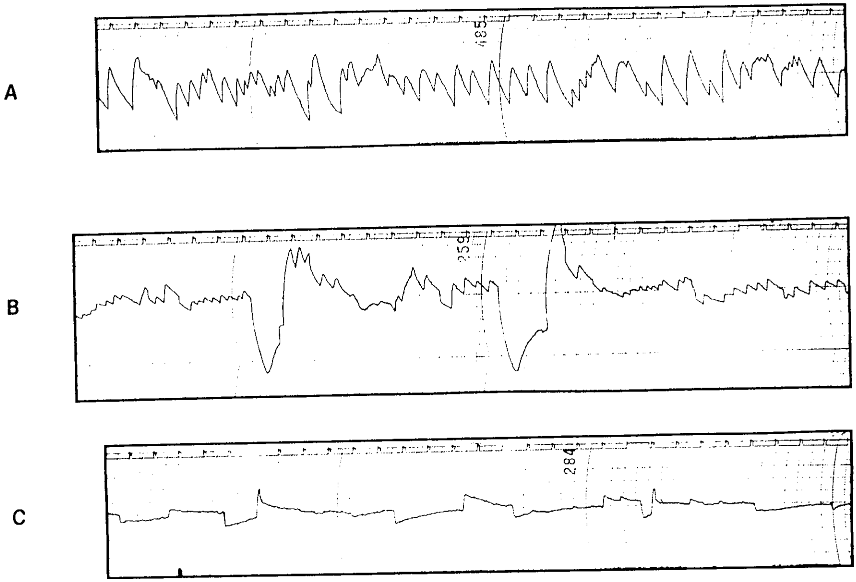

Figure 2. Illustrative eye-movement charts of (a) regular or rhythmatic nystagmus, (b) irregular nystagmus, and (c) absence of nystagmus in response to caloric irrigation with cool water.

sidered in this section: dysrhythmia, latency, duration, beat frequency, and amplitude. For the first three variables separate 2 (Sex of Subject) × 3 (Type of Dreamer) × 2 (Ear Irrigated) × 2 (Temperature of Water) analyses of covariance were computed on the first episode only. Degree of dysrhythmia was determined by experimenter ratings of the first episode as being a classic, rhythmatic nystagmus response (Stable, 1958) or one which was irregular and not typical of nystagmus. Ratings were according to a 5-point scale which ranged from 5 (certain that rhythmatic nystagmus is present) through 3 (uncertain if rhythmatic nystagmus is present) to 1(sure that rhythmatic nystagmus is absent). The aforementioned analysis of covariance on these dysrhythmia ratings resulted in one main effect for temperature ($F(1,42)=36.45$, $p<.00001$) such that this judge was more confident that rhythmatic nystagmus did *not* occur in warm (mean = 1.15) rather than cool (mean = 2.27) water irrigation.

Three Sex × Dreamer chi-squares were also calculated on the classification the judge actually made as to the type of nystagmic responses: regular, irregular, or none. The chi-square for the regular and irregular classifications of the response did not differ as a function of sex and dreamer; however, the chi-square for the no nystagmus classification was significant ($\chi^2(2)=16.22$, $p<.01$). Although a very small minority of the caloric responses were judged to evidence no nystagmus (8%), of those 16 judgements, half occurred in female nonlucid dreamers. Sample regular, irregular and no nystagmus eye movement charts can be seen in Figure 2.

Table 3

Summarized Analyses of Covariance on ENG Measures in Response to Bithermal Caloric Irrigation of Right and Left Ears of Dreamers Classified According to the Frequency of Lucid Dreaming and Sex of Subject

Source	Dependent Variable	*df*	*MS*	*F*
Sex × Dreamer	Amplitude	2	62.03	3.80*
Error	Amplitude	39	16.31	
Temperature	Beats	1	51.64	35.58**
Error	Beats	42	1.44	
Temp × Dreamer	Amplitude	2	37.49	4.15*
Error	Amplitude	42	9.03	
Ear	Beats	1	110.92	86.91**
Error	Beats	42	1.28	
Eye	Beats	1	91.18	90.50**
Error	Beats	42	1.01	
Ear × Temp	Beats	1	113.47	170.35**
Error	Beats	42	0.67	
Ear × Eye	Beats	1	109.48	132.13**
Error	Beats	42	0.83	
Temp × Eye	Beats	1	127.33	164.15**
	Amplitude	1	18.18	5.07*
Error	Beats	42	0.78	
	Amplitude	42	3.59	
Ear × Temp × Eye	Beats	1	115.98	124.49**
Error	Beats	42	0.93	

*$p<.05$ **$p<.0001$

For analyses of the latency and duration of nystagmus, only a main effect for temperature emerged in each case (latency: $F(1,42)=7.68$, $p<.01$ and length: $F(1,42)=5.89$, $p<.02$). Caloric reaction to warm water took longer to emerge (mean = 46.15 seconds) but did not last as long (mean = 58.28) as nystagmus

Table 4

Mean ENG Responses to Bithermal Caloric Irrigation by Dreamers Classified According to Frequency of Lucidity

	Group		
ENG Responses	Frequently Lucid	Infrequently Lucid	Nonlucid
Warm Water:			
Amplitude	3.65	2.90	4.33
Speed Slow Phase	3.56	2.79	3.91
Cool Water:			
Amplitude	4.97	3.57	3.54
Speed Slow Phase	6.75	4.52	5.33

reaction to cool water (latency mean=32.49; length mean=76.68).

Analyses of covariance for nystagmus beats and amplitude took the same form as the aforementioned three analyses with the addition of an eye direction (right and left) within subject variable. Also, as noted earlier, spontaneous right and left amplitudes were used as additional covariates in the amplitude analysis. Table 3 presents the analyses of covariance for these two dependent variables. Only the effects involving dreamer type will be discussed. Two interactions occurred in the amplitude analysis: Sex × Dreamer and Temperature × Dreamer (see Table 4). In the former interaction, females who frequently experience lucid dreams provide the key to interpretation. That is, these dreamers experienced significantly more amplitude in their eye movements than did their male counterparts ($q=3.4$, $p<.06$) and than did the other two types of female dreamers (infrequent $q=4.35$, $p<.05$; non-lucids $q=3.96$, $p<.05$). In the Temperature × Dreamer interaction (see Table 4), frequently lucid dreamers evidenced more amplitude with cool than with warm water ($q=4.99$, $p<.01$), whereas other dreamer types showed no difference for the amplitude of their eye movements as a function of water temperature.

Derived ENG measures. The results of analyses of the four dependent variables derived from primary nystagmus measures will be offered in this section. These include: frequency, velocity of the slow phase, canal paresis, and directional preponderance, each of which is briefly described at the beginning of the results section.

Two 2 (Sex of Subject) × 3 (Dreamer Type) × 2 (Ear Irrigated) × 2 (Temperature of Water) × 2 (Eye Direction) analyses of covariance were calculated on frequency, a derivative of beat frequency, and velocity of the slow phase, a derivative of amplitude. In both cases dream recall was a covariate; for the analysis of velocity of the slow phase rightward and leftward spontaneous amplitudes were also covariates. Total nystagmic beats is generally considered to be an unreliable measure, whereas frequency is recommended as being more reliable under standard test taking conditions (Spector, 1967). As in the beats analysis, no effects for type of dreamer reached conventional significance levels. There was, however, a main effect for temperature ($F(1,42)=26.49$, $p<.00001$), a main effect for eye direction ($F(1,42)=6.89$, $p<.01$) and an Ear × Eye × Sex interaction ($F(1,42)=4.13$, $p<.05$).

Although "the total amplitude of the nystagmus is considered by some to be very significant, most authorities agree that the speed of the slow phase directly parallels vestibular sensitivity (Spector, 1967, p. 69). There is, however, some disagreement as to during what interval the maximum speed should be determined. Stable's (1958) recommendation of between the 60th and 90th second is used in this inquiry. Several effects not involving type of dreamer were significant for analysis of this variable. These include Temperature ($F(1,42)=42.22$, $p<.00001$); Eye Direction ($F(1,42)=7.55$, $p<.01$); Ear Irrigated

× Eye Direction ($F(1,42)=6.07$, $p<.02$); and Ear Irrigated × Temperature × Eye Direction ($F(1,42)=8.00$, $p<.007$). Two effects with dreamer type approached conventional levels of significance and will be presented here due to the importance of this nystagmic indicant: Temperature × Dreamer Type ($F(2,42)=2.81$, $p<.07$) and Ear Irrigated × Temperature × Dreamer Type ($F(2,42)=2.79$, $p<.07$). A posteriori analyses on the former (see Table 2) showed that the speed of the slow phase for each type of dreamer was faster under cool water irrigation than under warm (frequents $q=11.32$, $p<.01$; infrequents $q=6.14$, $p<.01$; non-lucids $q=5.05$, $p<.01$). A posteriori differences also emerged within each temperature between dreamer types. Within the warm water condition, non-lucid ($q=3.95$, $p<.05$) and frequently lucid ($q=2.73$, $p<.06$) dreamers experienced a significantly faster slow phase than did infrequently lucid dreamers. All three dreamer types differed within cool water, with frequently lucid dreamers experiencing a faster slow phase than either non-lucid ($q=5.04$, $p<.01$) or infrequently lucid ($q=7.90$, $p<.01$) dreamers, the former of these two dreamer types experiencing a faster slow phase than the latter ($q=2.86$, $p<.05$).

This temperature by dreamer interaction is illuminated by the Ear × Temperature × Dreamer interaction which also approached conventional significance levels. It can be seen in Figure 3 that a differential reaction for dreamer types to the side of the head at which cool water irrigation took

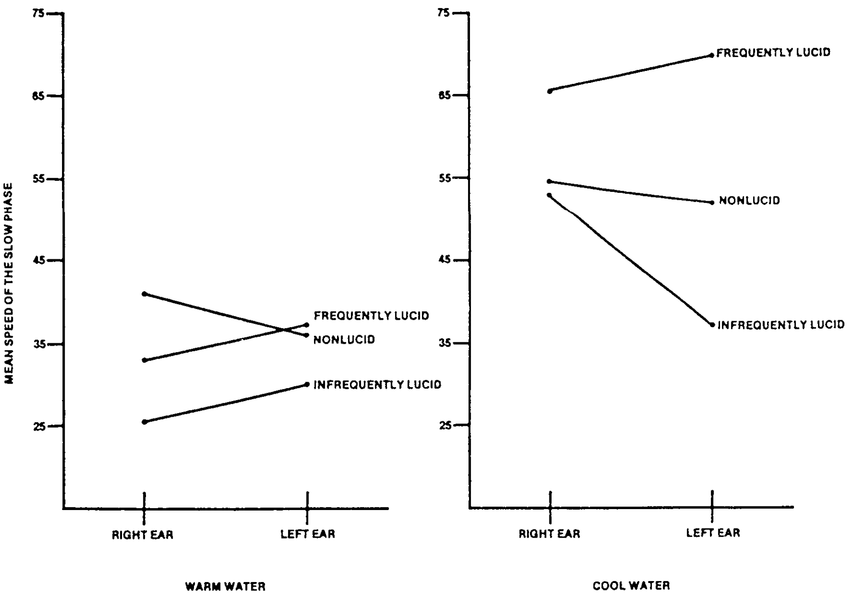

Figure 3. Mean speed of the slow phase (degrees/second) by type of dreamer, ear irrigated and temperature of water.

place accounted for this interaction. That is, a posteriori tests of warm water responses revealed that there were no dreamer differences across sides nor within the left side. However, non-lucid dreamers did experience significantly more speed in the slow phase with warm water irrigation in the right ear than did infrequent lucid dreamers ($q=6.23$, $p<.01$). Cool water irrigation resulted in several dreamer differences. No side preference was evident for frequents or non-lucids, but infrequents experienced faster speeds in the slow phase on their right side than on their left side ($q=6.06$, $p<.01$). Within each side under cool water irrigation several differences also emerged. On both sides frequently lucid dreamers were more vestibularly sensitive (faster speed of slow phase) than their dreamer counterparts (right: infrequents $q=5.24$, $p<.01$; non-lucids $q=4.76$, $p<.01$; and left: infrequents $q=6.51$, $p<.01$; non-lucids $q=6.51$, $p<.01$). Infrequently lucid dreamers did not differ in their vestibular sensitivity on the right side from non-lucid dreamers but were significantly less sensitive than non-lucids on their left sides ($q=5.91$, $p<.01$).

The final two analyses of covariance were calculated on two derivatives of duration of nystagmus. Canal paresis and directional preponderance are both used clinically as indicates of abnormal bithermal responses. According to Spector (1967), directional preponderance is expressed in terms of the length of the caloric response by the following equation: with RW=right ear irrigated with warm water, LW=left ear irrigated with war water, RC=right ear irrigated with cool water and LC=left ear irrigated with cool water.

$$\frac{(LC+RW)-(RC+LW)}{(LC+RW+RC+LW)} \times 100$$

A 2 (Sex of Subject) × 3 (Type of Dreamer) analysis of covariance with dream recall as the covariate was calculated on this transformation of nystagmic duration. A main effect for dreamer type was significant ($F(2,42)=4.21$, $p<.02$) such that non-lucids showed a pronounced rightward directional preponderance (mean=18.84 seconds) whereas both frequently lucid (mean=−4.17) and infrequently lucid (mean=−8.85) evidenced a less distinct leftward directional preponderance.

Canal paresis is said to occur when the labyrinthic responses of irrigation of the right and left ears differ and is expressed by the formula (Spector, 1967):

$$\frac{(LC+LW)-(RC+RW)}{(LC+RW+RC+LW)} \times 100$$

The same 2 × 3 analysis of covariance was computed on this duration transformation as above and again a main effect for dreamer was found ($F(2,41)=3.80$, $p<.03$). Non-lucid dreamers (mean=59.64) had significantly more evidence of canal paresis than did frequently lucid (mean=30.60; $q=3.61$, $p<.05$) or infrequently lucid (mean=36.32; $q=2.90$, $p<.05$) dreamers. Spector notes that canal paresis is not considered pathological unless it is two or more times the standard deviation. In this sample the standard deviation was 33.37 and non-lucids therefore approximate the pathological range. However, for these dreamers who did not report lucidity, differences between the right and left ears under warm and cool water irrigation did not exceed the 40 second mark pointed to by Spector (1967) as the limit of normal functioning.

Discussion

This study was undertaken to determine if individuals who report frequently experiencing a self-awareness of dreaming while in the process of dreaming would manifest more eufunctional vestibular responses to caloric stimulation than would persons who report never or seldomly experiencing lucidity. This hypothesis was formulated on evidence of a relationship between lucid dreaming and balance, evidence derived from factor analyses of lucidity mentation and from experimental studies in which frequent lucid dreamers have demonstrated superior performance on behavioral measures of vestibular functioning. According to the results of this study, the hypothesized relationship between the frequency of lucidity and a direct measure of vestibular physiology—nystagmus in response to caloric stimulation of the vestibular apparatus—is generally confirmed. This confirmation is based on our findings that non-lucid dreamers differed from infrequent and frequent lucid dreamers with regard to the probability of canal paresis, a term denotative of marked asymmetrical responsivity to caloric stimulation of the right and left vestibular organs, and with regard to another measure of asymmetrical responsivity, directional preponderance. Dreamer group differences were relatedly apparent for the speed of the slow phase of ocular movements in response to caloric stimulation and for the amplitude of these movements; however for these unilateral ENG differences the temperature of the water used for aural irrigation modulated responsiveness. A modulating effect for water temperature was also found for subject reports of their awareness of vertigo in response to caloric stimulation, both in terms of how long that experience was perceived to endure and how long it was before subjects became aware of vertigo. Dreamer differences for the latency and duration of self-reported vertigo were also found to differ according to the sex of subjects. Since self-reported vertigo is an experiential variable which would be expected to be influenced by sociocultural factors as well as biological factors, it is not surprising that our results differ somewhat for physiological and experiential measures of vestibular stimulation. It is clear, however, that the temperature of water used for irrigation is a critical within subject variable