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Patterns of Female Sexual Arousal During Sleep and Waking: Vaginal Thermo-Conductance Studies

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The main objective of this investigation was to ascertain whether there are, in the female, periods of sexual excitation or arousal during REM sleep similar to the cycle of penile erections in the male. In a group of 10 subjects, 21-35, utilizing a thermoconductance method that gives a measure of vaginal blood flow (VBF), we are able to confirm that females manifest cyclic episodes of vascular engorgement during REMPs equivalent to erections in men. They occur with equal frequency (95% of REMPs) but differ in distribution, in greater frequency during NREM sleep, in the shorter duration of individual VBF episodes, and in the less tight linkage of VBF episodes to the REMPs. The increases in VBF, in terms of rises of the recording pen on the graph paper, varied from 10 to 45 mm. In order to ascertain the significance of these increases, we compared these sleep responses with waking VBF responses evoked by nonerotic and erotic stimuli and by masturbation. Only erotic stimuli gave VBF responses, the greatest to the movie and masturbation; these were no greater than the maximum levels attained during sleep, namely 40 to 45 mm. Maximum vascular engorgement is finite in male and female and is limited by anatomy. The fact that VBF REM increases appear to be identical to VBF responses to passive waking erotic stimulation and show similar cardio-

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respiratory patterns suggests that they, too, are erotic in nature. Additionally, the preliminary results of the waking experiment demonstrate that a very high percentage of VBF REM increases are associated with dreams that contain overt or symbolic sexual content. The results indicate that REM periods with VBF increases have a far greater chance of being associated with sexual dreams than do REMPs or NREMPs with minimal VBF increases.

KEY WORDS: REM sleep; femal sexual arousal; vaginal blood flow; masturbation orgasm.

INTRODUCTION

It is well know by now that the revolutionary discoveries of sleep research of the last 25 years have shown that there are two kinds of sleep which, along with waking, constitute three organismic states. Dreaming, or REM sleep, takes up a quarter of total sleep time and is distributed throughout the night in a 90-minute ultradian cycle; NREM sleep constitutes the remaining three quarters of sleep time. Associated with REM sleep is an intense activation of both cortical and subcortical parts of the brain and of most physiological systems. Among the more striking aspects of this activation is that more than 90% of REM periods in the male are associated with full or partial erection. Both REM sleep and the accompanying erections arise spontaneously, are peremptory, obligatory, cyclic, and universal, and are present from birth to old age.

After the demonstration of the phenomenon of REM erection (Fisher *et al.*, 1965; Fisher, 1966; Karacan, 1965; Karacan *et al.*, 1976), the question naturally arose whether some analogous sexual activation took place in the female, associated with vascular, contractile, or secretory changes. In the mid-1960s Fisher and his colleagues attempted to study tumescent fluctuations in the clitorial body with thermistors and strain gauges but did not observe consistent changes. Karacan *et al.* (1970) reported increases in clitoral circumference, analogous to the findings in males, in two women with hypertrophied clitorii associated with the adrenogenital syndrome. While suggestive, these findings are open to the reservation that the women were not normal. Jovanovic (1972) reported regular increases averaging about 0.5°C in clitoral temperature correlated with each REMP in 10 young women, but this work has never been replicated.

More convincing results have been obtained by investigating intravaginal vascular changes associated with sexual arousal. The first such attempt was made by Cohen, Shapiro, and their co-workers (Cohen and Shapiro, 1970, 1971; Shapiro *et al.*, 1968), who reported significant increases in relative vaginal blood flow (VBF) in both REM and NREM periods. Their recording technique was based on Masters and Johnson's (1966) and Sherfey's (1966) observations that sexual arousal in the female leading to orgasm depends on development of marked increases in vasocongestion of paravaginal venous plexuses, the clitoris and the crura, the vestibular bulbs, labia minora, and other covert erectile tissues. Abel *et al.* (1979), using a photoplethysmograph, recorded changes in vaginal pulse pressure and blood volume and reported findings analogous to REM erections in the male.

With the use of the VBF device, we (Fisher *et al.*, 1980) have been continuing the investigation begun by Cohen and Shapiro on a larger group of subjects. Our objectives are the following:

1. To make quantitative and qualitative comparisons between VBF changes in the female and erectile fluctuations in the male, e.g., frequency, magnitude, and duration of changes in REM and NREM periods
2. To compare VBF changes during REM and NREM sleep with presleep stimulation evoked by nonerotic affective memories, sexual memories or fantasies, exposure to an erotic auditory tape or film, and masturbatory or REM dream orgasm
3. To record and compare heart and respiratory rates associated with VBF increases in all the sleep and waking conditions mentioned above
4. Finally, to discuss the possible functional significance of VBF-REM changes in the female and REM erections in the male.

METHOD

Selection of Subjects

Subjects solicited through local newspapers, graduate schools, and Mount Sinai Hospital, were interviewed, given a questionnaire and a short mental test[6] to exclude psychotic, paranoid, or litigious individuals.

[6]This test was the SCL-90-R by Leonard R. Derogatis, Ph.D., Director, Clinical Psychometrics Research Unit, Johns Hopkins University.

All but one subject had normal scores, the exception falling between normal and psychiatric outpatient ranges.

This preliminary report is based on findings for 10 subjects, average age 30 (range 22-34), selected only if capable of experiencing orgasm either by clitoral stimulation or through vaginal intercourse. Only subjects whose sole method of contraception was the use of the diaphragm and who were experienced in using it were selected (see procedure section). Seven of nine subjects reported that they were capable of orgasm during intercourse, through penile thrusting alone, 45 to 99% of the time (four reported more than 90%), and two not at all. Seven of nine subjects always had orgasm with clitoral masturbation and two sometimes.

With one exception, all were college graduates, five of whom were pursuing an M.A. or Ph.D., and all were middle or upper middle class. They were a sexually responsive and sophisticated group with an average of nearly 7 years experience with heterosexual intercourse. Stated motivations for participation were scientific interest, fee for time, and eagerness to contribute knowledge about female sexuality. All but two had been or were in psychotherapy, and only one sought treatment for sexual problems.

Procedure

A female technician applied electrodes for all-night recording of EEG, EOG, and heart and respiratory rates. The subject herself inserted the sterilized VBF device. The experiments were carried out in privacy, the technician being in an adjoining room available through an intercom. On the assumption that VBF effects would be enhanced during the ovulatory phase (cycle days 10-16), we elected to carry out the study during this period. Subjects were observed for three consecutive nights around the assumed ovulatory day.

On either the second or third night, a number of pre-sleep experiments were carried out in which half of the subjects evoked memories of non-sexual affective experiences involving (a) happiness, (b) physical pain, (c) guilt, and (d) fright, the other half memories of (a) anger, (b) jealousy, (c) pleasurable eating, and (d) sadness. Both groups then evoked memories of exciting sexual experiences, engaged in free erotic fantasy, listened to a taped description of an erotic scene, and finally viewed a silent, black-and-white erotic film lasting about 12 minutes. Subjects rank-ordered their responses and rated them according to intensity. The purpose of these pre-sleep experiments was to ascertain whether VBF responses during waking were evoked *only* by sexual stimulation.

It should be noted that any particular VBF increase does not in itself inform us of the relative intensity of sexual arousal since the increase is a

function of the gain setting of the polygraph. Because of this, four subjects volunteered upon request to masturbate in privacy while being recorded. We felt that in order to interpret the quantitative significance of any VBF changes during any of the experiemental conditions described it was necessary to obtain a measure of VBF increases during intense maximal sexual arousal such as might be elicited during masturbation to orgasm. We would then have a standard against which to compare increases during REM and NREM sleep in terms of intensity of sexual arousal.

Instrumentation

An eight-channel Beckman polygraph was used to record EEG, EOG, heart and respiratory rates, and changes in VBF. Cohen and Shapiro's (1970) sensor is a thermoconductance flowmeter consisting of a matched pair of microthermistors (VECO 37A3) mounted in an acrylic holder clipped to the ring of a vaginal diaphragm (Fig. 1) of the size that had been prescribed for each subject for contraceptive purposes; this holds the transducer fixture firmly against the lateral vaginal mucosa. The subjects were asked to check for correct placement of the diaphragm ring. The use of jelly was optional. Earlier experience by Cohen (1976) indicated that the use of KY jelly was without significant influence on the VBF recordings. The pair of thermistors is connected so that changes in ambient temperature or shifts in

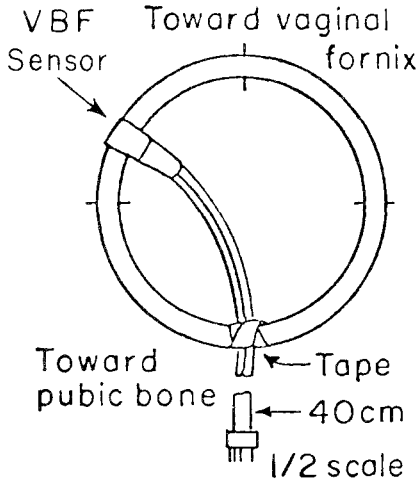

Fig. 1. Diagram of VBF sensor clipped to diaphragm ring.

relative position are self-cancelling. One thermistor is heated 5°C above ambient body temperature by an intrinsic heater element energized by a square wave pulse train, and the other is at core body temperature. When a change in blood flow occurs, the thermal conduction properties of the tissue change, and the rate at which heat is carried away from the externally heated thermistor also changes. This shift is sensed by a DC amplifier that modulates the pulse width of the square waves, driving the now unbalanced bridge back toward its null position. This servo-type device is monitored for the changes in the heating necessary to keep it in the null position. A drop in the temperature of the heated thermistor alone indicates an increase in vaginal blood flow, and an equivalent rise in temperature indicates a corresponding decrease.

Data Collection and Scoring of Records

The all-night polygraphic record scored for EEG sleep stages and VBF changes for each subject was charted on a single sheet of graph paper with the VBF values appearing directly below the EEG recording line. From this record it was possible to evaluate the relative frequencies of REM and NREM increases, their comparative amplitudes and durations, and, finally, their distribution within individual REM or NREM periods.

The sensitivity of the polygraph was adjusted to obtain a 1-cm pen deflection per 200 mv change in sensor output voltage (200 mv/cm). The position of the recording pen was placed about 1 cm above the lower limit of the channel to allow upward deflections of up to 45 mm. The channel permits 50- to 55-mm deflections on the recording paper.

There were two factors which made for instability of the baseline. The first was that upward deflections of the pen were often caused by large body movements, and such increases could be as great as normal deflections occurring during REM and NREM sleep. Such body movement increases were not included in calculating frequencies. The second factor involved possible indeterminate slight displacements of the diaphragm ring and its attached sensor.

Because of the variations of the baseline, we treated each REM and NREM period as a separate unit. Zero baseline was considered to be the lowest point reached by the VBF tracing in any given REM or NREM period. Any increases of 10 mm or more associated with such low points were counted as valid. If there were two or more peaks during an increase they were treated as a single rise. However, if the second or third peaks returned to baseline and remained there for a minute or more they were considered to be independent episodes.

The total number of minutes of sleep accompanied by VBF rises over 10 mm was computed for each NREM and REM period throughout the

night. From these figures the mean of means duration per subject per night of all the NREM and REM VBF increases could be calculated. We also were able to calculate the mean figure for the duration of the individual REM and NREM increases.

RESULTS

Comparison of VBF Increases with REM Erections

Figure 2 is a graphic representation of the cycle of five full penile erections in a young man that begin and end in close temporal relationship to the onsets and terminations of the REMPs (upper graph). There were

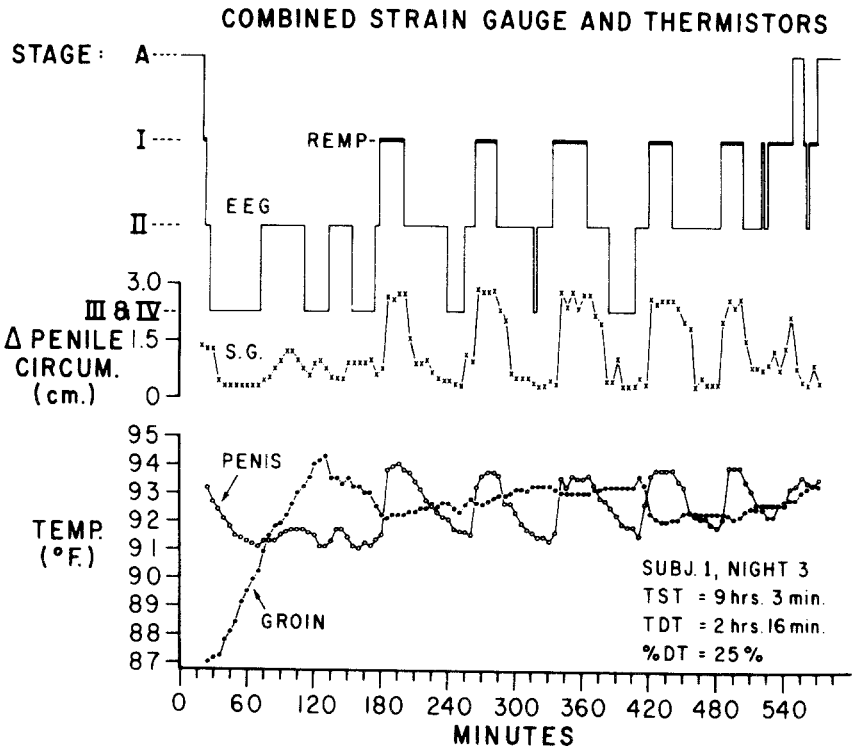

Fig. 2. The upper graph illustrates a 9-hour sleep cycle in a 30-year-old male, showing five REM periods associated with five full erections as recorded by the mercury strain gauge. The lower graph is a simultaneous recording of penile skin temperature showing the same five erections. This figure is to be compared with Fig. 4, which illustrates four VBF increases whose duration varied from 8 to 12 minutes. The REM erections all lasted for 25 minutes or more.

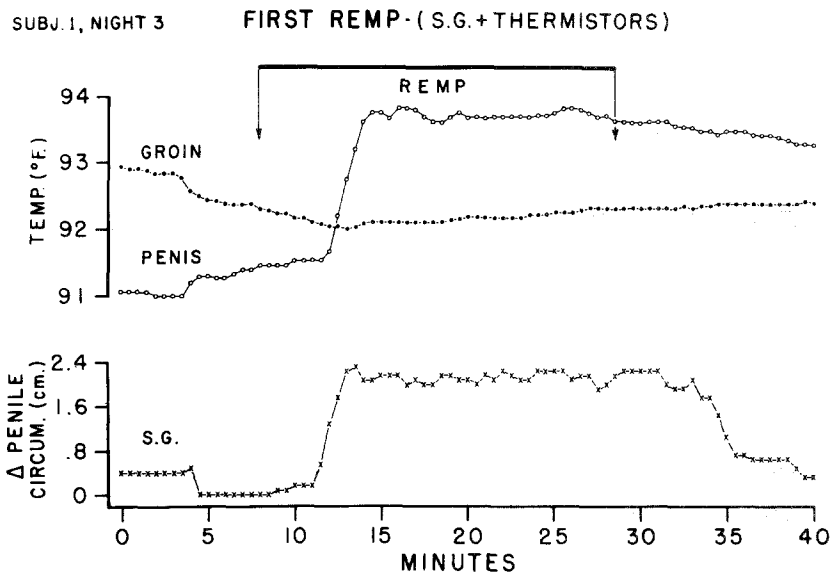

Fig. 3. The lower graph is an enlarged drawing of the first REM in Fig. 2 and the upper graph is an enlargement of the accompanying skin temperature recording. The prolonged, nonfluctuating nature of the REM erection is to be compared with the much briefer VBF increases.

more than 2 hours of sustained erection in 9 hours of sleep. Figure 3 (lower graph) shows an enlarged representation of the first erection in Fig. 2 and its temporal relationship to the REMP. The erections and REMPs may be 90% or more coextensive, maintained at a high maximum level with little fluctuation for a half hour or more, but the erections may begin before REM onset and persist beyond its termination. Figure 4 is a graphic representation of an entire night's sleep in a 29-year-old female showing four REMPs, each associated with a VBF increase between 20 and 30 mm, lasting from 5 to 12 minutes. The contrast with the male in terms of duration and distribution is striking.

Relative Distribution of VBF Increases in REM and NREM Periods

Of the 30 nights the 10 subjects were recorded, only 19 yielded scorable data; the remaining had to be discarded because of technical difficulties, e.g., gross body movements with dislocation of the baseline, dislocation of the diaphragm ring, excessively wide fluctuations of the baseline for unknown reasons, and others.

For 10 subjects there was a total of 74 REMPs on 19 nights, an average of 3.9 per night. There were 84 VBF increases in the 74 REMPs. Seventy of the REMPs, or 95%, showed VBF increases of 10 mm or more.

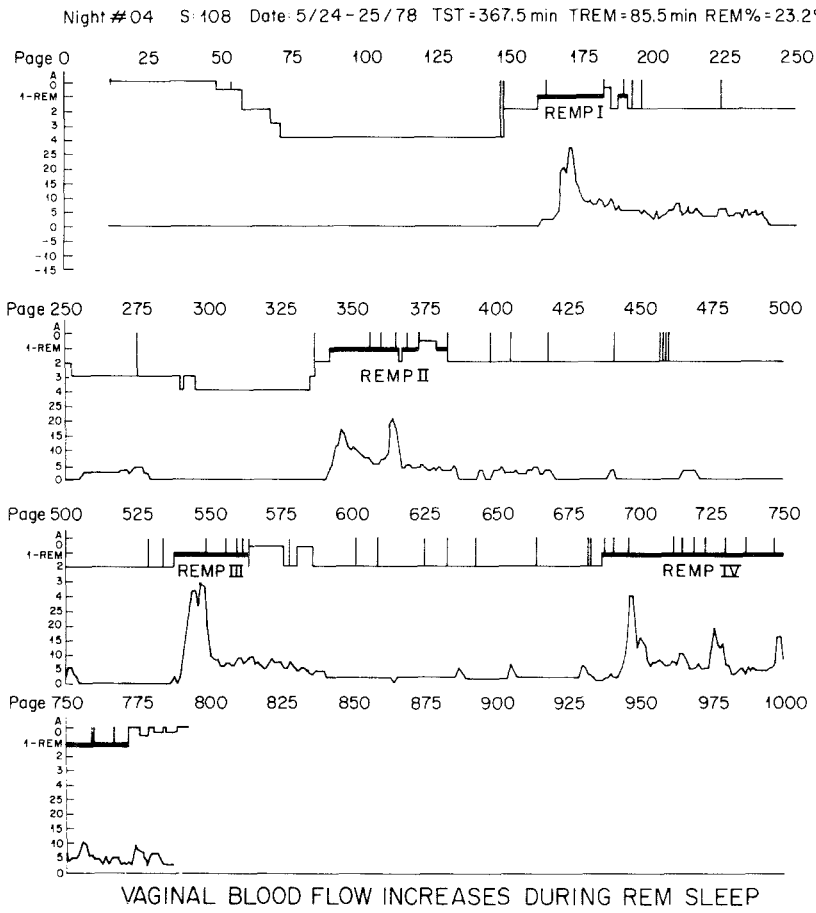

Fig. 4. Graph of a full night's sleep in a 29-year-old female showing 4 REMPs associated with VBF increases of 20 to 30 mm. Note the brevity of the VBF increases as compared to REM erection and their occurrence during the first third to half of the REMPs.

There was a total of 83 NREM periods, an average of 4.3 per night, with 55 of the NREMPs (66%) showing increases of 10 mm or more. There were 79 such increases. Many of the NREMPs had more than one rise (see Table I).

Frequency, Duration, and Amplitude of REM and NREM VBF Increases

Since the data used were derived from a varying number of nights for each subject (from 1 to 3, for a total of 19 nights), we first calculated mean figures for each subject and then the mean of means for the total of 10 subjects.

Table I. Relative Distribution of VBF Increases above 10 mm in REM and NREM Periods

	REM (84 min)	NREM (307 min)
Total number of periods	74	83
Number of periods with rises > 10 mm	70 (95%)	55 (66%)
Average number of periods per night	3.9	4.3
Total number of rises > 10 mm	84	79

Frequency

There was a mean of 4.4 VBF increases per night during 84 minutes of REM sleep, a mean of 0.052 increases per minute, and 4.2 VBF rises during 307 minutes of NREM sleep, a mean of 0.013. This difference is statistically highly significant, $p < 0.005$ ($t = 4.63$, one-tailed test).

The absolute figures for frequency of VBF episodes per night did not differ greatly during REM and NREM sleep, 4.4 as against 4.2. In terms of frequency per minute, however, there were four times as many REM increases as NREM. Also, 95% of REMPs showed VBF increases of 10 mm or more, compared to only 66% of NREMs.

Duration

Another way of looking at the data involves comparing the total mean time in minutes per night of the REM and NREM VBF increases in relation to the total minutes per night of REM and NREM sleep. Thus, the 4.4 VBF REM increases per night lasted a total of 31 minutes, or 37% of the total REM time of 84 minutes, while the 4.2 VBF NREM rises totalled 51 minutes, or only 16% of the total NREM time of 307 minutes; this difference is highly significant, $p < 0.005$ ($t = 3.56$).

Amplitude

The mean of means amplitude for the 79 NREM increases was 21.6 mm, and for the 84 REM increases, 21.0, a nonsignificant difference, (p not significant; $t = 0.35$). The distribution of these increases by 10-mm ranges for the REM rises indicated that 51% fell between 10 and 19 mm, 37% between 20 and 29 mm, 7% between 30 and 39 mm, and 4% between 40 and 45 mm. The corresponding figures for the NREM increases were 44%, 35%, 11%, and 5%. It can be seen that they did not differ significantly. Of the REM increases, 44% fell between 20 and 39 mm, almost identical with 46% of the NREM. Increases above 30 mm were not frequent, only 11% of the REM and 16% of the NREM falling in the range between 30 and 45

Table II. Distribution in 10-mm Ranges of VBF REM and NREM Amplitudes

Range	Number of REMs	Percentage of REMs	Number of NREMs	Percentage of NREMs
10-19	43	51%	35	44%
20-29	31	37%	28	35%
30-39	6	7%	9	11%
40-45	3	4%	4	5%
Total	83		76	

mm. The maximum levels attained were between 40 and 45 mm (see Table II).

Duration of Increase

The mean duration of individual VBF increases was 7.9 minutes for REM and 13.7 for NREM. Duration was measured at a level 10 mm above baseline.

Other Interrelationships between REM and NREM Increases

Of peak VBF increases, 70% occurred within the first half of individual REMPs, often preceded by a NREM increase in close temporal relationship to REMP onset; the remaining 30% took place in the second half. This distribution is shown in Fig. 4.

Of the 79 NREM increases, over 40% extended into the 5-minute NREM interval preceding the next REMP. More than a third of the total 79 VBF increases began 10 minutes or less before the succeeding REMPs, an average of 7.6 minutes before. Of these increases, 65% extended into the REMPs, merging with them or becoming continuous with the first peak of the REM VBF increase. We have designated them NREM-REM complexes. An excellent example of such a complex is shown in Fig. 5, in which a marked NREM VBF increase quickly merges with the first of a series of 6 VBF peaks occupying about two-thirds of the entire REMP. Such prolonged VBF increases were not common. It should be noted that the low heart rate (48-52/minute) is associated with a quite marked VBF increase in this NREM-REM complex. Additional excellent NREM-REM complexes are illustrated in Fig. 6.

VBF Increases during Presleep Experiments Compared with Those in REM and NREM Sleep, Masturbation, and REM Dream Orgasm

1. Figure 6 is a graphic illustration showing the magnitude of VBF increases during all the conditions of the experiment (S110). There were

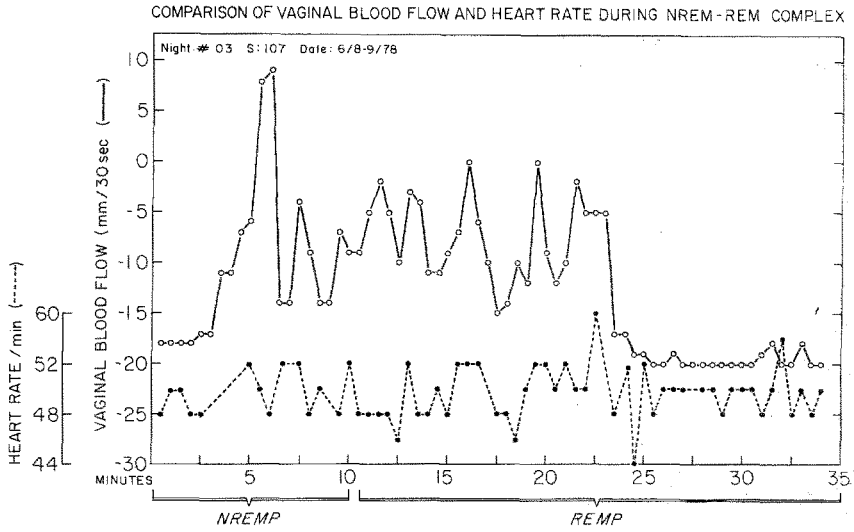

Fig. 5. NREM-REM complex, merging of the large NREM VBF rise with the series of REM peaks, and the low, normal heart rate associated with the complex.

slight nonsignificant responses to the "affects," minimal responses to sexual memory and fantasy, an abnormal response to the erotic tape due to body movement, a moderate, sustained rise during the erotic film of 25 mm, followed by a marked increase up to 40 mm during masturbation to orgasm, sustained at peak level for 15 minutes post orgasm, gradually declining as the subject fell asleep, and continuing through NREM sleep for an hour, finally merging with the NREM-REM complex at the onset of the first REMP. The remaining three REMPs showed a variety of NREM-REM combinations.

2. *Presleep Experiments.* All subjects had nonsignificant fluctuations in response to nonerotic "affects." Among the erotic stimuli the movie gave by far the highest rank-order ratings and the highest ratings for subjective intensity of sexual arousal. The tape produced more moderate responses and sexual memory and fantasy the least. VBF responses to the film were as great as 25-40 mm. These experiments, however, suggest that VBF increases during waking occur only in response to erotic stimulation, implying that the same may be true during REM sleep.

3. *Masturbation to Orgasm.* Of four subjects, three masturbated once, the fourth on three occasions. We found, to our surprise, that masturbation to orgasm did not produce VBF increases any greater either than the maximum levels attained spontaneously in the other experimental conditions or than the maximum responses to erotic film and tape.

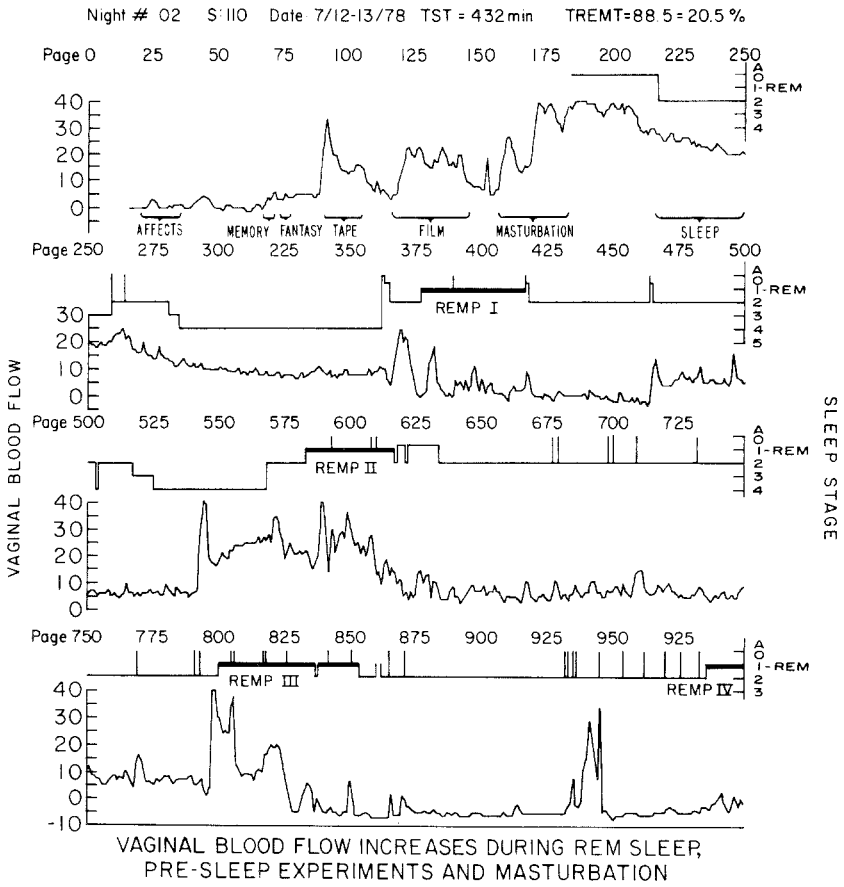

Fig. 6. Graph of a polygraphic recording showing comparative magnitudes of VBF increases during presleep experiments, masturbation, REM and NREM sleep. Note the three NREM-REM combinations.

Figure 7 is a graphic representation of VBF and cardiac increases associated with the most intense orgasm recorded, both objectively and subjectively. It developed after 13 minutes of masturbation, showed a prolonged VBF rise to a maximum of 40 mm, extending for at least 15 minutes beyond orgasm. At the point of orgasm, heart rate had risen from 68 to 170/minute and respiration was markedly increased in both rate and amplitude, especially just prior to and following orgasm. It is to be noted that there was little increase in heart rate during tape and film, even though there were moderate VBF increases. During the film, heart rate actually decreased slightly. Heart rate began to accelerate instantaneously with onset of masturbation. It is of interest, however, that VBF remained elevated at

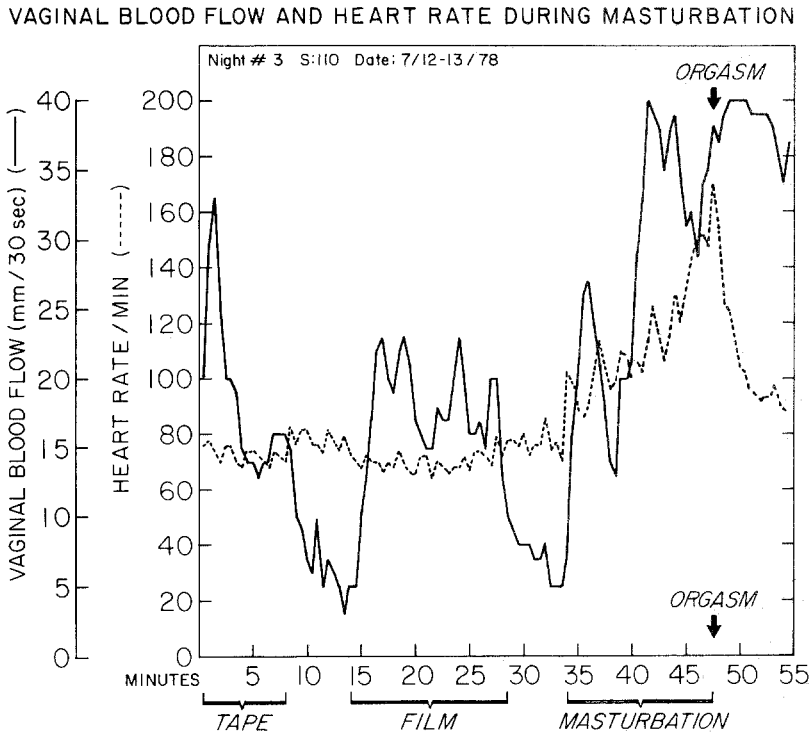

Fig. 7. Graph of recording of masturbation in the same subject as shown in Fig. 6. This is the most intense orgasm recorded, the VBF increase reaching a maximum of 40 mm and the heart rate increasing from 68 to 170/minute. Note the decline in heart rate during the viewing of the film, illustrating the absence of increased heart rate in the presence of a 25-mm VBF increase and a high subjective rating of sexual arousal. Postorgasm VBF remains maximal, while heart rate falls precipitously.

maxmimum level for 15 minutes postorgasm, while heart rate fell precipitously.

Subject 108 masturbated on three occasions with similar results. Figure 8 shows that after 7 minutes of masturbation VBF rose to 40 mm, heart rate from 64 to 140/minute, and respiratory rate from 15 to 30/minute, with markedly increased amplitude at orgasm.

4. *Orgasm during REM Dream.* We have recorded a single dream with orgasm during which there was a very marked VBF response, with heart rate increasing from 50 to 100/minute, and respiratory rate from 12 to 22/minute with increased amplitude (see Fig. 9). The entire episode lasted about 2 minutes with a subjective sensation of intense orgasm. The next morning the subject reported a strange and upsetting dream:

> I was being made love to by an older woman whom I did not recognize. I was passive while this woman kissed me a lot. I do not remember if I responded but I had a very

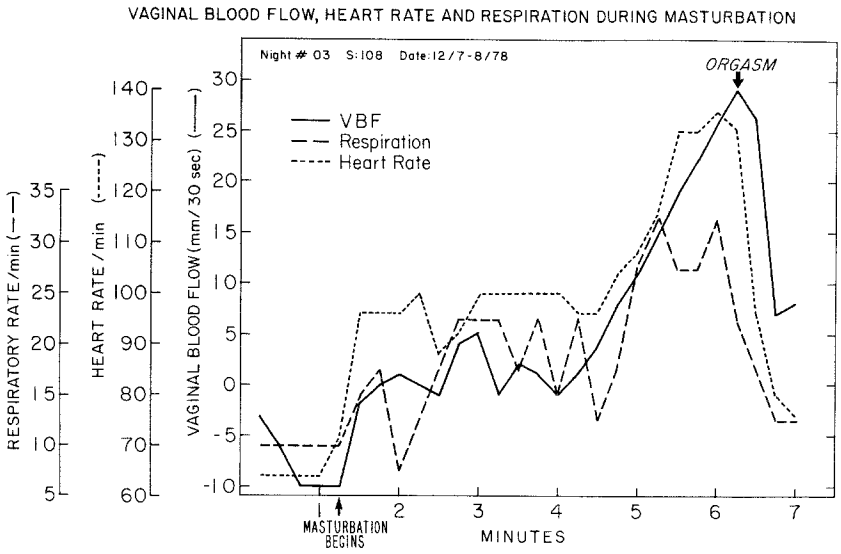

Fig. 8. VBF, heart, and respiratory rates during masturbation. This was one of the most marked masturbatory responses observed, VBF rising to 40 mm, heart rate from 64 to 140/minute, respiratory rate from 15 to 30/minute, with marked increase in amplitude at orgasm.

> good time; it was exciting. I believe the woman masturbated me externally but did not insert her finger. The weird and disturbing part of the dream was when I reached down after orgasm and discovered that it was a man and not a women. She had two penises, one was small in the usual place and the other large like a breast in the groin.

The penis she described as small she indicated with her fingers was 6 to 8 inches long, "curled like a snake and looked disgusting." She did not remember if the woman had breasts. The subject stated that she had never had homosexual experiences or homosexual dreams or felt attracted to women. She was shocked and upset by this dream. The provocation for it probably came from the fact that she was attended by two women during the experiment, that she read some erotic material before going to sleep containing homosexual scenes, and, additionally, that she was stimulated by the sexual nature of the experiment, insertion of the VBF device, the protruding wires (snakes?), and other day residues surrounding the experiment (e.g., one of the assistants was an older woman).

5. *Comparison of Cardiorespiratory Changes in Different Baseline Conditions.* We have long been surprised and puzzled by observing that in men during REM erections there are nonsignificant increases in heart and respiratory rates. The same is true of VBF increases in the female. Figure 10 shows that, in 30-second epochs with maximum VBF-REM and NREM increases, heart and respiratory rates show fluctuations no greater than in the absence

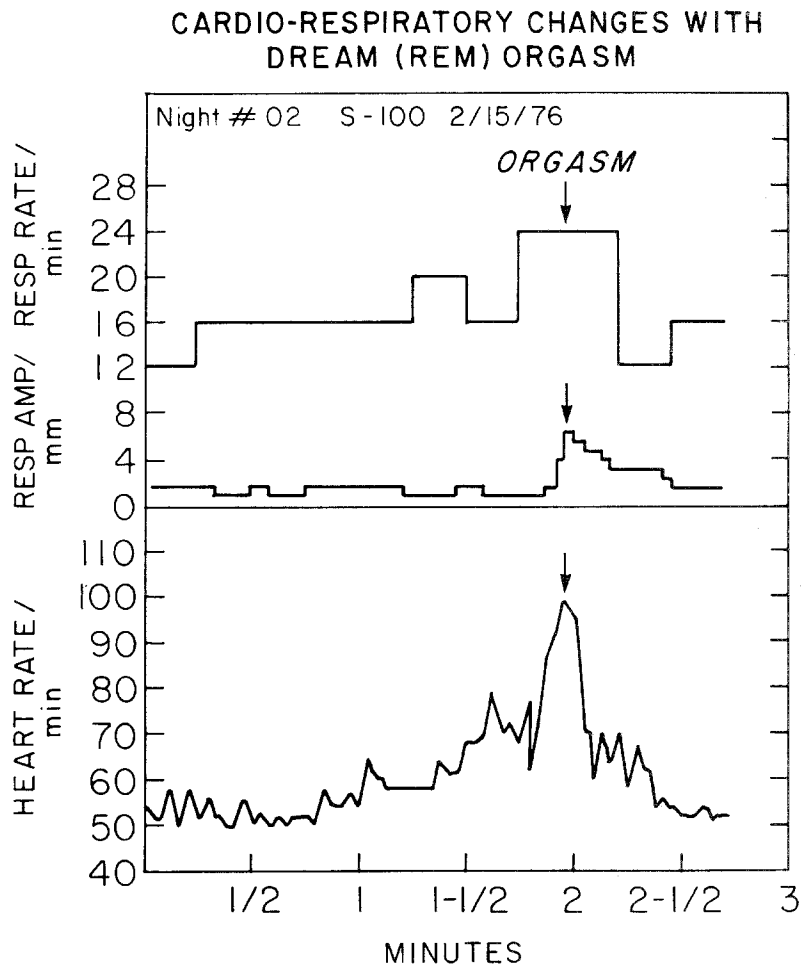

Fig. 9. A rare graphic representation of the cardiorespiratory changes associated with a REM dream orgasm.

of VBF rises. These rates are incomparably less than the doubling and tripling associated with masturbatory or REM orgasm.

Detailed analysis of cardiorespiratory responses to tape and film reveals consistent slight decreases in heart rate as compared to baseline. Respiratory rates were usually within normal range but quite often also showed a slight slowing. For example, we averaged both the baseline VBF values for four subjects, who showed good responses in the presleep experiments, and the heart rates attained in each of the presleep experiments, and compared the two sets of data. Starting from an average VBF baseline

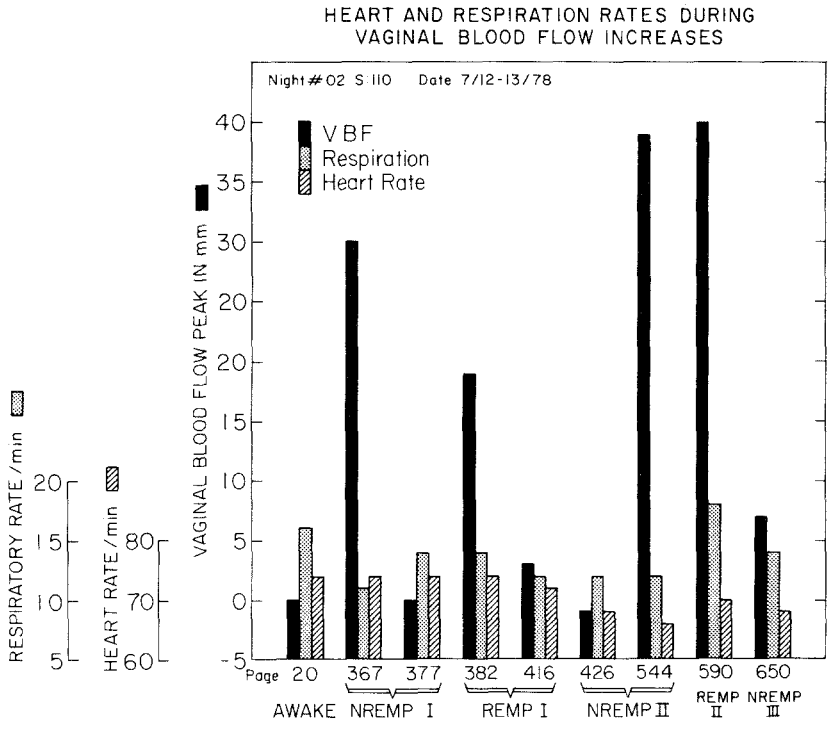

Fig. 10. Same subject as in Fig. 6 showing minimal increases in heart and respiratory rates during two NREM-REM complexes associated with REMP I and II.

of -5 mm, the nonerotic affects showed a mean fluctuation around the baseline of -3 mm to +5 mm, nonsignificant variations. The baseline heart rate was 75.9/minute, which fell during the administration of the affects to 73.8/minute. The corresponding figures for sexual memory and fantasy were a heart rate of 71/minute and a VBF increase of 7.6 mm; for the erotic tape, 72.8/minute with a VBF increase of 21 mm; and for the erotic film, 71.6/minute and a VBF increase of 20.3. It can be seen that there were consistent but small falls in heart rate (from 1.2 to 4 beats/minute) during

Table III. Relationship between Presleep VBF Increases and Heart Rate

	VBF in mm	Heart rate/min.
Baseline	−.5	75.9
Affects	−3 to +5	73.8
Memory/Fantasy	+7.6	71.0
Tape	+21	72.8
Film	+20.3	71.6

the experiments that evoked sexual arousal, associated with significant increases in VBF, especially during exposure to the tape and film (see Table III).

DISCUSSION

Differences and Similarities between REM Erections and VBF

The findings confirm earlier work of Cohen and Shapiro (1970, 1971) that episodes of vaginal vascular engorgement are associated with 95% of REMPs, similar to the percentage of erections in the male. Abel *et al.* (1979) found that pressure pulse increases were associated with two-thirds of REMPs. The average total duration of erections in minutes per night is about 2½ times that of REM VBF increases in comparable age groups. The average duration of individual VBF increases is about 8 minutes, a large majority (70%) occurring in the first half of any given REMP and a much reduced frequency in the second half.

Looked at from a different point of view, however, the combined mean values of the total number of minutes per night of REM and NREM VBF equals 82 minutes, that is, 31 plus 51 minutes. In males of comparable age, the figure for simultaneous NPT and REM is 87 minutes (Karacan *et al.*, 1976). These figures indicate that the duration of VBF increases is equivalent to the duration of REM erections but that the former are distributed differently, having a much greater incidence in NREM sleep.

VBF increases occur in a series of two or more wave-like patterns, the mechanism of which is obscure but probably involves differences in hemodynamics and the nature of the tumescent tissues. In the male, erections are built up by a series of pulsations caused by the blood-pumping action of the bulbo- and ischio-cavernosus muscles (Karacan *et al.*, 1978; Wagner and Green, 1981). Tumescence then attains a maximum and may continue at this level for periods as long as an hour.

Differences between REM and NREM VBF

It has been shown that the frequency and relative durations per unit of time of the REM VBF increases are much greater than the NREM, and these differences are highly significant statistically. The mean amplitudes show nonsignificant differences, but in the highest ranges, 30-45 mm, there are somewhat more NREM increases. Of REMPs, 95% are associated with VBF increases, but this is true of only 66% of NREMPs.

Differences between NREM Erection and NREM VBF

The linkage between REMPs and VBF episodes is much looser than that between REMPs and erection. There are four times as many NREM VBF increases as there are NREM erections. NREM-REM complexes take place at the interface between the end of a NREM period and the beginning of the succeeding REMP, an accummulation of NREM VBF increases accounting for more than a third of the total NREM episodes and merging with a similar accumulation of REM VBF increases in the early part of the REMPs. These NREM-REM complexes may form functional units.

One of the most striking findings is that masturbation to orgasm did not produce maximum VBF increases any greater in magnitude than those associated with REM and NREM sleep, namely about 45 mm, and in one instance orgasm occurred with a 25-mm rise. It is suggested that maximum vascular engorgement in both male and female is *finite and limited by anatomy.*

Another important finding is that there are only minor cardiorespiratory fluctuations during REM and NREM sleep, even when erection is maximum and VBF increases reach levels as high as sometimes occur during masturbation to orgasm. Careful analysis has revealed that in most awake subjects during exposure to erotic tapes and movies there is even a distinct decrease in heart rate of several beats and often a slight decline in respiratory rates. This can occur when the VBF response to these stimuli is as great as 25 to 30 mm and fairly high ratings of subjective feelings of sexual arousal are reported. Jovanovic (1972) reported that in men the largest erection of the night occurs between 4 and 6 AM, when the heart rate is at the lowest level.

A specific cognitive and motivational pattern may be at work associated with VBF increases during REM and NREM sleep, or when one is awake passively viewing an erotic movie or listening to a tape. A quite different pattern is set in motion when one masturbates with the intention of reaching orgasm or has a dream orgasm. Only in the latter conditions are cardiorespiratory changes massive. The difference is that with masturbation there is direct manual manipulation of the genital and a more intense degree of excitement, a striving to attain orgasm associated not only with cardiorespiratory increases but also with other autonomic responses such as sweating, flushing, and all those total body reactions, vascular, secretory, and contractile associated with the orgasmic phase of the sexual response cycle described by Masters and Johnson (1966). In dream orgasm the hallucinated events of the dream are experienced as real and are capable of producing the same physiological responses as in waking orgasm.

The difference in physiological events in active and passive sexual arousal involves a difference in autonomic system response. During passive arousal there is parasympathetic activation leading to erection or vaginal engorgement associated with a mild decrease in heart rate. In active arousal parasympathetic erection and vaginal engorgement continue, but the sympathetic division of the autonomic nervous system is simultaneously activated leading to the above-described cardiorespiratory increases, sweating, flushing, etc., followed by a massive overflow into the voluntary nervous system with convulsive body movements.

The fact that waking VBF increases appear to be evoked only by erotic stimulation does not necessarily imply that VBF increases during REM sleep are aroused by sexual content of dreams. As with erections in the male, the VBF responses in the female occur in such a high percentage of REMPs, and have a fairly defined temporal patterning, that it is improbable that each increase is evoked by erotic dream content. Like the erections, they may be primarily neurophysiological in origin, produced by release of the sexual areas and circuits in the lateral hypothalamus from higher limbic system and cortical inhibition during REM sleep. Only 15% of dreams derived from REM awakening are manifestly sexual.

It has been suggested that at least some erections, and some VBF responses as well, may be nonerotic in nature. It has been shown (Fisher, 1966), however, that some REM erections *are* associated with erotic dreams; this is also true of dreams with nocturnal emission. In an ongoing experiment,[7] we have been waking our female subjects during different phases of VBF responses (sudden rises or falls, or during portions of REMPs free of VBF increases) and making corresponding awakenings during NREM periods. We have been examining the dream and other content elicited during such awakenings. Preliminary results indicate that 50% of awakenings in a series of 22 VBF REM increases were associated with overtly sexual dreams and more than 80% with symbolic sexual content, while awakenings made during REMPs associated with decreases in VBF, or flat records, showed very little sexual content. Awakenings made during all phases of VBF NREM responses were associated with even less erotic content. These results indicate that REMPs assocaited with VBF increases have the best chance of being linked to dreams with erotic content.

The endogenously arising REM erections and VBF increases may provoke sexual dreams, but, on the other hand, psychically produced sexual content may interact with the erections and VBF responses and facilitate or inhibit them, depending on anxiety or other factors. It has been shown that anxiety can inhibit REM erection or results in sudden detumescence of an

[7]This experiment is being conducted by Barbara Furman and Jerry Cunningham.

ongoing erection (Fisher, 1966; Karacan, 1965). Both the alternative explanations given may be true. The most plausible formulation is that there is a reciprocal interaction between psychic content and the REM sexual excitation in both the male and the female. The physiological sexual arousal is ontogenetically primary, present at birth, and only later, when psychic structure formation matures, does the dream arise, interact with, and be acted upon by the somatic aspects of the sexual drive.

Another factor that threw doubt on the possible connection between REM erection and VBF responses and the sexual content of dreams was the virtual absence of clear-cut cardiorespiratory increases associated with the dreams, which we mistakenly took as evidence that the latter were nonerotic in nature. However, since our findings demonstrate that in the waking state sexual arousal of considerable intensity in response to erotic stimulation from tape or film is not accompanied by cardiorespiratory increases and can even be accompanied by slight reductions, it seems likely that VBF increases may be similarly associated with erotic dream content and sexual arousal in the absence of autonomic change.

Our subjects were observed for VBF changes during the ovulatory phase of the cycle because of the possibility that they would show greater arousability during this phase. However, recent work as well as the bulk of the literature (Schreiner-Engel *et al.*, 1980) indicate that arousability is not at peak during this phase. Schreiner-Engel *et al.* (1980), who used the photoplethysmograph to record pulse pressure and also carried out endocrine assays, found that arousability is significantly less during the ovulatory phase than during postmenstrual and midluteal phases. Abrams *et al.* (1972, 1978) investigated vaginal blood flow during the menstrual cycle, utilizing a thermo-conductance device similar to our VBF sensor, and also failed to observe increased arousability during the ovulatory phase. However, our subjects showed considerable arousability both by subjective report and VBF increases.

Abrams *et al.* (1978) emphasized that the design and operating characteristics of vaginal probes are important variables in relation to vaginal size, amount of secretory activity, distance between blood vessels, etc., and that further research is needed on these variables.

Possible Function of REM Erections, VBF, and REM Sleep

Many functions of REM sleep have been proposed, phylogenetic, ontogenetic, the consolidation of memory and the facilitation of learning, information processing, etc. These theories are not mutually exclusive. It is unlikely that a complex organismic state such as REM sleep has only one function, anymore than waking has one function.

A few investigators in the field of sleep research have presented evidence for a motivational theory of REM sleep. Dement *et al.* (1970, 1967) reported that cats, rats, and rabbits who had been REM-deprived for as long as 70 days developed a state of CNS hyperexcitability during waking. Cats demonstrated a dramatic development of compulsive sexual behavior with persistent attempts of males to mount other males and females. They showed increased hunger, doubled the rate of eating, would cross an electrified grill for food, and would eat out of a dish with a burning candle, contrary to normal behavior. Rats showed hypersexuality, grooming, and aggression. It was concluded that REM sleep deprivation produced an increase in drive-motivated behavior, while REM sleep reversed the motivated behavior caused by such deprivation.

Ellman and Steiner (1968a, 1968b), Ellman *et al.* (1978), and Steiner and Ellman (1972) came to much the same conclusions as Dement as a result of their studies of the effects of REM deprivation on the rates of intracranial self-stimulation (ICSS) in the rat hypothalamus. The areas in the limbic system from which high rates of bar pressing for stimulation can be elicited, such as the hypothalamus, are the same as those from which drive behaviors such as sex and hunger are evoked. They found that REM deprivation lowers hypothalamic thresholds and increases ICSS response rates. They showed that there is a reciprocal relationship between REM sleep and ICSS, that is, in some way the latter facilitates motivational states and provides a type of periodic drive discharge. They postulate that during REM sleep elements of the ICSS or positive-reinforcement neural network are activated. They speculate that the reason why REM deprivation is effective in alleviating endogenous depression is because it lowers ICSS threshold. One can view depression as a raising of thresholds for a variety of drives, sex, aggression, hunger, and pleasure seeking, all of which are decreased in depression. The lowering of ICSS thresholds activates and intensifies waking drive behavior and presumably has a therapeutic effect on the depression.

Vogel (1979) also infers a motivational function of REM sleep from the observations that REM sleep deprivation in animals and in depressed humans increases drive-motivated behavior. Since REM sleep reverses this effect of REM sleep deprivation, it follows, and this is the crux of the motivational theory, that REM sleep normally decreases waking drive-motivated behavior. The motivational theory, paraphrasing to Vogel, suggests that

> drive reduction by REM sleep should have an adaptive value in all placental mammals and primates. One possible value might be that REM sleep tames and modulates drive oriented behavior so as to permit higher organisms behavioral flexibility in the presence of drive motivations. This flexibility would include a capacity to delay drive gratification in order to respond with adaptive variability to

> environmental exigencies. The presence of REM sleep allows higher organisms to be less driven, less relentless, less stereotyped and more adaptively specific in response to primitive drives or instinctual motivation, pp. 145-146.

Vogel concludes, "Thus it may be that modern sleep research on laboratory animals and human depressives has supported the old, occasionally derogated, psychological view that dreams discharge instinctual tensions (Freud, 1953)," p. 146.

The psychoanalytic concept of instinctual drive refers to the psychic representation of the somatic drive, whereas Ellman's and Vogel's formulations of motivational theory is in terms of the somatic, physiological, and neural concomitants. The relationship between the psychological and somatic aspects of drives is very complex and cannot be discussed here, but it is important to bear in mind the basis on which these authors have formulated their motivational theories.

Vogel's motivational theory has some bearing on the possible function of REM erections in the male and VBF increases in the female. It has not been obvious why so much erection in the male and vaginal engorgement in the female occur during REM sleep, or what adaptive function they serve. As Vogel has suggested, the great amount of sexual excitation at night during dreaming sleep may serve to modulate and reduce sexual drive during the day and, through the dream, discharge instinctual tensions. The close connection between dreaming and sexuality was stressed by Freud. Not only might REM erection and vaginal vasocongestion reduce daytime drive pressure through sexual dreams, perhaps even in the absence of dreams, but they could have a more direct effect through dreams with seminal emission and orgasm in the male and orgastic dreams in the female. Such orgastic dreams serve as outlets during states of deprivation, or other causes, especially in adolescence, but at all ages to a lesser degree. Orgastic REM dreams are an extraordinary occurrence, being the only dreams in which real gratification takes place, as opposed to wish-fulfilling, hallucinatory, nonsexual dreams.

Abel *et al.* (1979), using vaginal photoplethysmographic recordings, demonstrated consistent findings of decreases in relative blood volume with increases in pulse pressure within the vagina during two-thirds of the REM periods of 10 subjects. They concluded that these vascular changes are similar to the phasic shifts of blood flow in the penis during REM sleep. They did not report data on the duration of the pulse amplitude increases, but their graphic representation of such an increase shows it to be 4 or 5 minutes in duration, comparable to that we have reported. They did not investigate the relative distribution of VBF increases in the different

[8]We thank Dr. Gene Abel for his courtesy in providing us with a photoplethysmograph.

portions of the REM periods or, although aware of NREM responses, the number and distribution of NREM increases and their interrelationships with REM increases.

We have had occasion to compare the VBF sensor with the photoplethysmograph,[8] in several subjects who inserted both devices so that simultaneous recordings could be compared. We found that the AC portion of the photoplethysmograph, which measures pulse pressure, gives a recording that runs parallel to that of the VBF sensor. It appears to measure the same physiological processes as the VBF sensor. However, it produces just as large but more prolonged body movement artifacts as the VBF sensor. It has the additional disadvantage that for nocturnal recordings it is more difficult and takes a much longer time to score.

The results that we have reported confirm the original findings of Cohen and Shapiro's (1970, 1971) pilot study in which two subjects slept in the laboratory for three nights, each for a total of 20 REM periods. In 19 of these, VBF increases were present, variable in duration, beginning with the onset of REM periods or displaying some lead, lag, or discontinuity. We confirm their finding of a comparable number of NREM VBF episodes not distinguishable from those observed during REM. They noted that the incidence of VBF increases during REMPs is of the same order of magnitude as that of REM erections reported by Fisher *et al.* (1965) and Karacan (1965). The authors conclude that the similarity in the VBF changes to those of penile erection demonstrate activation of a peripheral physiological system during REM sleep in both sexes.

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