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THE CHARACTERISTICS OF EEG ACTIVITY AND THE SUBJECTIVE ESTIMATION OF TIME DURING DREAMS OF DIFFERENT STRUCTURE

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Recognitions of time and of space interrelationships are equally important for the organism and, apparently, these functions are closely connected. Smith (1966) has shown that the organism perceives time only to the extent that its nervous system is able to interpret time in terms of spatially-organized processes of feed-back regulation. This is all the more probable as among the sense organs in man there is no special one for "time-perceiving", and part of this, in the opinion of a few investigators beginning with Sechenov (1863), may be played by the auditory and muscle senses. In addition to these, a certain role belongs to the "visceral clock", *i.e.*, rhythmicity of vegetative functions and of the heart beat (Elkin 1966).

Wiener (1958), having advanced a hypothesis that the biological clock is imprisoned within the small range of the alpha rhythm, a phase of the alpha cycle being a "tick of a biological clock", started a search for the "time units" in which events in the central nervous system are programmed. In particular, the character of perception by man of the time interval has been shown to depend on the frequency of the EEG dominant rhythm. On speeding up of this frequency the interval becomes underestimated, on slowing down it is overestimated (Hoagland 1936; Leonov and Lebedev 1968). During sleep, it is still possible to judge the functioning of the time-counting system: in an indirect way, by the estimation of durations of sleep and dreams made by the subject when awakened.

As the time-counting of the organism is, most probably, based upon the rhythmic processes of the energy metabolism sustaining life (Hoagland 1935), the subjective estimation of time during sleep must, to some extent, reflect the speed of the physiological processes underlying the development and course of sleep and dreams. It has been shown (Lewis 1969) that, after a deep sleep (during which a number of physiological processes slow down), an awakened man underestimates the duration of the sleep.

The present studies have been carried out with the goal of studying the details of time-counting during sleep, and of the relations between the subjective estimation of the duration and structure of dreams, and the character of the bioelectrical activity.

METHODS

Three series of studies have been made:

1. Studies on normal subjects who, during natural night sleep, were presented for 10–30 sec with a weak stimulus (light touch, smell, etc.), after which the subject was immediately awakened and interrogated in detail about the character and duration of the dream, if one had occurred. When interrogating the subject, the probable connection between the dream and the presented stimulus was considered in the first place (judging both by the contents of the dream and by the subject's impression as to the moment of its occurring). If such a connection was revealed, the following characteristics were sought for: (1) details regarding the contents of the dream; (2) its modality (visual, auditory, proprioceptive, etc.); (3) the sequence of events and integrity of the dream; (4) the speed of events; (5) the total duration of the dream; (6) its emotional back-

ground. After that, working with the subject, an estimate of the total duration of events in the dream was made as though they had really occurred.

2. Studies on normal subjects during night sleep in a sound-proof chamber, whose EEG, EOG and ECG were recorded continuously. Once or twice during the night, weak light stimuli were presented by an "Alvar" photo-stimulator (10/sec frequency). In the morning, at about the time for awakening, a weak stimulus was presented to the subject. After the presentation of the stimuli the subject was awakened and interrogated (as has been described above). In individual cases when, in the EEG, a REM phase spontaneously occurred or if the subject displayed some motor unrest even without eye movements and EEG signs of the REM phase (as dreams are known to occur during slow wave sleep as well; Foulkes 1967; Berger 1969) he was then awakened and interrogated.

In all, 142 studies on two groups of 30 subjects were made. Reports on the dreams associated apparently with the timed presentation of the stimuli were obtained in 27 cases.

3. Studies in Parkinsonian patients in whom implanted electrodes were being used for treatment in the Department of Applied Neurophysiology of the Institute for Experimental Medicine of the Academy of Sciences, U.S.S.R.[1]. The method of implantation and identification of the electrodes has been described (Bechtereva *et al.* 1969). The EEG, the ESCoG (electrosubcorticogram) and, in most studies, the unit activities of neurones of subcortical structures were recorded during natural night sleep. The EEG, ESCoG and EOG were recorded on an "Orion" electroencephalograph, the impulse activity on a "DIZA" electromyograph from which the impulses were fed via a limiting device both into the oscilloscope with a camera, and to the electroencephalograph. This made it possible to record the unit activity on paper on 1 to 3 channels.

During recording the patients were presented from time to time with weak stimuli. Apart from this, some accidental effects from without sometimes occurred (recording was not done in the sound-proof chamber). Both in the case of stimulus presentation and of a spontaneous REM phase or motor unrest, the subject was awakened and interrogated about his dreams, after which he usually fell asleep again. During the night the subjects were awakened 2–8 times.

In all, in this group of 9 patients, 18 night records were obtained and over 50 comparisons of the subjects' reports with the EEG pattern were accomplished. Reports on a dream after the subject had been awakened were obtained in 20 cases (of these, in 5 cases the dream appeared to be due to the stimulus). The character of the unitary activity during the dream was studied in 14 cases.

Determination of the sleep phases was done visually from the EEG, according to the method of Rechtschaffen and Kales (1968). Analysis of the EEG changes was also made visually. Additionally, the instantaneous amplitudes of the potentials (in 5 sec epochs with 1/40 sec intervals) were collected and coded by an automatic reading device. Then, with the aid of a computer, interrelations between the electrical activities of different deep structures at the moment of dreaming were studied by means of correlation analysis (epoch $\tau = 0.75$ sec, time shift $\Delta t = 25$ msec). In all, when studying 16 cases of dreaming in 5 patients, 210 crosscorrelograms were drawn. Hypotheses on the differences between the maximal values of the correlation functions above a given threshold (0.3) in groups of well-formed dreams, insufficiently formed dreams and dreams of complex structure, were checked by the *t* criterion. The impulse activity was estimated from its mean firing rate during 10 sec, and the study of interrelations between activities of different neuronal populations belonging to different subcortical structures was accomplished by means of correlation analysis.

RESULTS

Dreams apparently associated with stimulus presentation were reported in 27 cases out of 142 or 19%. In patients, the association of the dream with a specially presented stimulus could be established in 5 cases out of 50 tests, *i.e.*, in 10%. In this study olfactory stimuli proved the most convenient; this type of stimulation does

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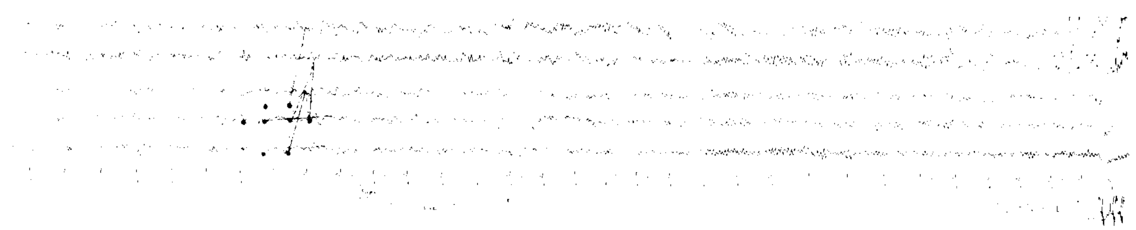

Fig. 1. EEG, ECG and EOG (*bottom trace*) of patient M prior to and at the moment of presentation of an olfactory stimulus (at arrow) followed by a complex and well-formed dream. Recording was stopped when subject was awakened.

not lead to immediate awakening and frequently enough causes dreams, particularly in the case of food items having a strong smell.

In addition to the above cases in which the absolute duration of the dream could be established according to the moment of presentation of a stimulus, the duration of spontaneously occurring dreams or those following an accidental stimulus could be estimated from the EEG and the oculographic changes.

Thus 47 dreams were studied in all, whose absolute duration, subject's estimated duration, contents, structure, and emotional background were known. In 13 cases, the EEG was recorded during a spontaneously occurring dream; in 17 cases, during a dream occurring, apparently, under some external influence.

In Fig. 1, the EEG and EOG of a healthy subject are presented. At the end of a night's sleep, at 7 a.m., she was given an olfactory stimulus (smell of cheese). This was followed by a complex formed dream (she saw herself at a party with many guests who were engaged in a complex game of the masquerade type) which lasted (according to the subject herself and to the number of events) 10–20 min. Twelve seconds after stimulation had started, rapid eye movements occurred, and 4 sec later the subject was awakened with some difficulty. As Fig. 1 shows, prior to stimulation, theta waves of moderate or large amplitude dominated the EEG and, owing to the stimulation, alpha waves with 10–11.5–12 c/sec frequency also occurred; during the rapid eye movements, the amplitude decreased. At the end of the recording artefacts appeared due to forceful awakening of the subject.

In 17 patients, the gross activity of subcortical structures was also recorded along with the EEG. It proved to be either similar to or different from the EEG during sleep. Fig. 2 and 3 show both these variants. In Fig. 2 the EEG, ESCoG and the EOG of a Parkinsonian patient are presented. At the 40th minute of her sleep she had a dream: rather obscure visual images and a sensation that someone was near her whom she should drive away. The patient moaned and moved her right arm, after which she was awakened and interrogated. The duration of the dream, according to the patient, was no more than half a minute (which corresponded to the duration of the EEG and ESCoG changes expressed, as Fig. 2 shows, by low voltage theta and alpha-like activity as well as a few sharp and fast waves occurring in all EEG and ESCoG channels).

In Fig. 3 are shown the EEG, ESCoG and EOG in another Parkinsonian patient taken at the moment of an emotionally coloured dream consisting of pleasurable pictures following each other as in TV. The dream occurred 12 min after the beginning of sleep in the evening, right after a telephone ring in the corridor. Eye movements then repeatedly reappeared during 3 min (with intermissions) after which the patient awakened. She had a sensation of a long dream (scores of minutes) because she had "seen" rather many pictures. As Fig. 3 shows, mainly theta and delta waves of moderate amplitude, with a few superimposed sleep spindles, were recorded in the EEG. The ESCoG activity in different leads was rather variable: in some channels high voltage slow and sharp waves were recorded, in others, a low voltage theta rhythm and sleep spindles.

In 14 cases, along with the EEG and ESCoG, the activity of neuronal populations was recorded during dreams. Fig. 4 presents from one patient 2 EEG channels, 2 ESCoG channels, and the impulse activity of the same neuronal populations as in the ESCoG. Under the influence of weak auditory stimulation during 10 sec (rustle of paper), at the end of sleep, about 5 a.m., obscure

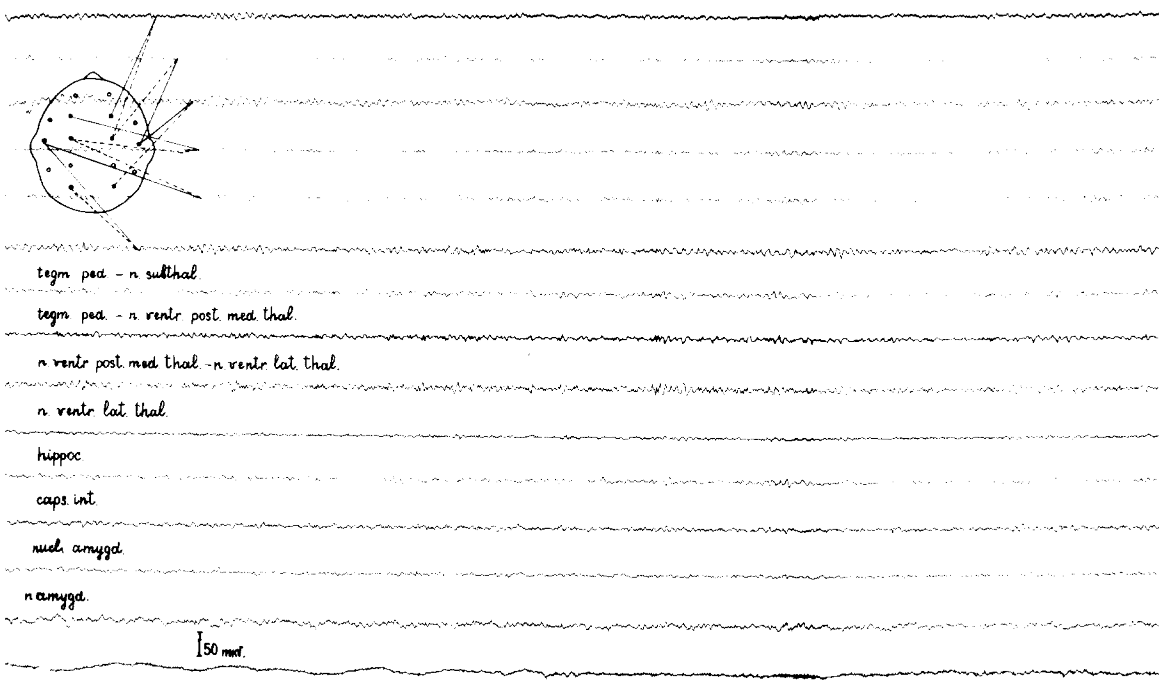

Fig. 2. EEG, ESCoG of various structures and EOG (*bottom*) of patient M (with implanted electrodes) at the moment of spontaneously occurring obscure visual images. Eye movements are not obvious. The time of dreaming was indicated by the subject moaning and moving a hand as if trying to push away something unpleasant occurring in her dream.

visual images occurred in her dream, the duration of which was no longer than 1–2 min and so was in accordance with the electrographic changes.

As Fig. 4 shows, high voltage theta and delta waves dominated the EEG, with superimposed (not very obvious) sleep spindles. In the ESCoG also, the high voltage theta and delta waves were recorded but for a shorter period compared with the EEG. In addition, deformed alpha-like waves were noted and, in one of the leads, clear bursts of sleep spindles. The character of the impulse activity in one of the leads did not change during the dream, while in another, simultaneously with slight eye movements, the firing rate considerably increased.

To study peculiarities of the time estimation at the moment of dreaming, we investigated separately the localization of the dream events within the time continuum, the speed of these events and their sequence.

1. *Relation of dream events to the time continuum*

As a rule, after being awakened, the subjects were not oriented in time and could only associate the dream events with the moment of awakening. Very infrequently, when estimating his own condition a subject could conclude that he had had a dream near the morning, as he felt he had slept well.

2. *Speed of events in the dream*

In almost half the cases (22 out of 47) the probable duration of events occurring in the dream, according both to the subject's estimate and to the experimenter's calculations, exceeded the absolute time of the dream by 2–10, 25–50 and even 100 times. The subjective perception of acceleration of the time flow was mainly noted in complex dreams peculiar for their numerous aspects, dissociated events, simultaneity of incompatible events (for instance, when the subject both sees himself as from without and also acts himself). Exceptions were nightmare dreams with a similar acceleration of the time flow, and with events proceeding quite logically but accompanied by a strong emotional reaction.

There is a certain correlation between the bioelectrical events, the speed of the dream events,

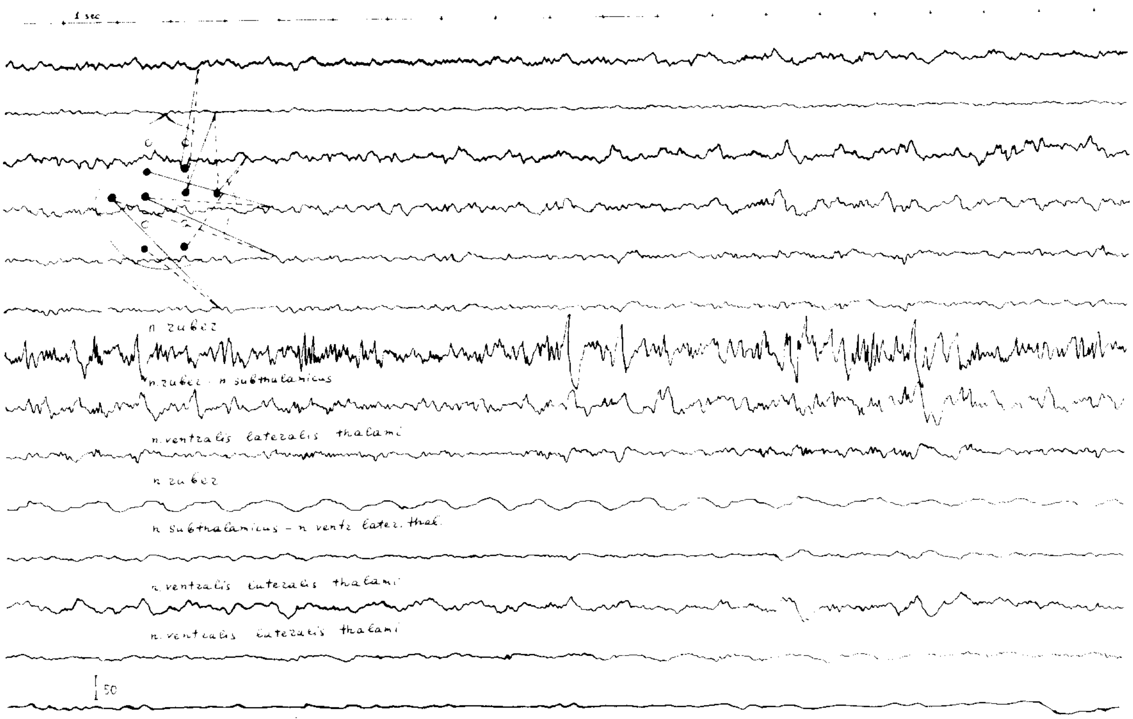

Fig. 3. EEG, ESCoG and EOG (*bottom*) of patient B. (with implanted electrodes) at the moment of a bright dream in the form of shifting pictures occurring under the influence of auditory stimulation.

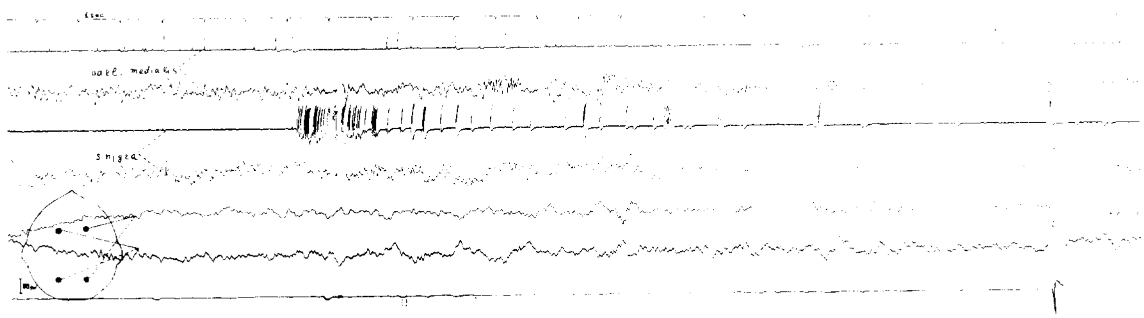

Fig. 4. Gross and unit activities from two subcortical structures, two EEG derivations, and EOG of patient K (with implanted electrodes) at the moment of occurrence of obscure visual images under the influence of auditory stimulation.

and the regularity of their structure. With simply formed (regular) dreams or insufficiently formed but unimodal dreams (*e.g.* only visual or only proprioceptive) when the time flow was ordinary (*i.e.*, 1 : 1), fast activity dominated the EEG and the ESCoG, as is typical for the REM phase of sleep (see Fig. 2).

In dreams with a complex structure, as well as in strictly logical but very emotional dreams, time obviously flowed faster and, in the activity of subcortical structures and in the EEG, high voltage (rarely, low voltage) theta rhythm appeared with superimposed alpha-like rhythm and sharp waves (rarely, sleep spindles), though the activity could vary very considerably (Fig. 1 and 3).

3. *Sequence of dream events (time relations between events)*

In a majority of the dreams either a successive procession of events in time or an instantaneous occurrence of images with no developing action was noted. In 28% (13) of dreams a complex disrupted action was noted as occurring simultaneously in two or more aspects (for instance, the subject in a dream worked in a garden and, at the same time, saw from without his own activity); the logic of events proved sometimes to be absurd (for instance, the subject, an engineer, saw herself at home but at the same time her EEG was being taken in the room and her little daughter was nearby, and the subject had to calculate "her daughter's integral").

In 5 cases of complex dreams, the reverse procession of events was noted: the subject first saw what happened afterwards and then the beginning. For instance, in a dream a schoolboy saw himself in a street-car, then he saw how, before he had boarded the street-car, he had taken his transistor radio out of a brief-case and then, still before that, how the transistor radio had been playing in the brief-case. In all such dreams a subjective perception of acceleration of the time flow was noted. The character of the bioelectric events is as described above.

When studying the relations between the bioelectric processes by correlation analysis, we found earlier that the highest correlation functions (exceeding the chosen level of significance (0.3)) were those between the ESCoG of any single structure and the ESCoG of all other structures. These proved highest during wakefulness and in the first phase of sleep (A). During slow wave sleep this value for the correlation fell and became lowest at the moment of dreaming.

There were differences between dreams of different types. Comparison of the correlation of one structure with that of each of the other structures at the moment of a dream gave the following results: the correlation coefficient value exceeded the chosen significance level (0.3) in disorderly or poorly organized dreams in 33%, in well-formed dreams with logical structure and ordinary time flow in 60%, and in dreams with a complex structure and accelerated time flow in 15% of studies. The difference between the group of well-formed dreams and the other two groups is significant ($P=0.95$); the difference between the group of unformed dreams and the dreams of complex structure is insignificant.

The mean firing rate of the neuronal population was usually considerably increased at the moment of dreaming as compared not only with the immediately preceding spontaneous activity, but with the mean firing rate of the same population during wakefulness. However, this increase was not invariable; it seemed that not all structures recorded from always participated in the formation of a dream, and the increase in firing rate depended on the location of the electrode, as shown in Fig. 4. At the moment of a disorderly indifferent dream with an ordinary time scale evoked by an auditory stimulus, the increase of the firing rate was observed only in one of the two subcortical structures under study.

Correlation coefficients of the mean firing rates recorded simultaneously from several structures showed that their changes might be either in the same or in different directions.

During wakefulness, a considerable variability of the correlation coefficients of the firing rate was noted for different structures (0.2–0.96). During slow wave sleep the correlation coefficient was low as a rule (0.08–0.1), only infrequently reaching values as high as 0.3–0.32, which showed a persistent enough absence of correlation in the neuronal activity of the structure. In well-formed dreams with logical structure, imitating the orderly perception of the environment which is characteristic of wakefulness, the correlation coefficient of the mean firing rate in different neuronal populations was as a rule very high (0.8–0.98). In disorderly dreams or disrupted dreams with "blowing up" events, with a complex illogical structure and multi-faceted simultaneous incompatible actions, the correlation coefficient of the mean firing rate in some populations can be very low while in other structures it was rather high. Table I presents the changes occurring in the EEG, ESCoG, and unit activity during dreams with different structures.

DISCUSSION

The data obtained by us concerning the subjective perception of acceleration of the time flow during certain dreams coincide both with the commonly known idea of the "relativeness of psychological time" and with the results of other studies concerning the time relations during dreams (Sehjelderup 1960). Gastaut *et al.* (1965) revealed the connection between some particular features of dreams and the character of the EEG of the sleeping brain, and found that nightmares

TABLE I

Specific features of the EEG, ESCoG and unit activity and estimation of the time flow during dreams of different structure.

Structure of dream	Ratio duration of dream to real time	EEG pattern	ESCoG pattern	Changes in neuronal activity
Disorderly	1/1	Low voltage irregular alpha rhythm; fast and sharp waves; low or high voltage theta rhythm, rarely delta waves.	Low voltage irregular alpha rhythm; fast and sharp waves; low or high voltage theta rhythm; delta waves. Patterns correlated in 33%.	Increase in firing rate inconsistent, less than in half the cases, and occurring in different structures with no correlation.
Well-formed with logical structure.	1/1 or 2–5/1	Obvious and regular alpha rhythm; obvious or weak beta activity; sometimes low voltage theta rhythm.	Alpha-like rhythm; obvious theta and delta rhythms; low voltage beta rhythm. Patterns correlated in 60%.	Increase in firing rate in all structures, high correlation.
Complex structure, full of controversies, with simultaneous existence of unrelated aspects of activity.	5–10/1 or 50–100/1	Obvious fast activity, low voltage theta and delta rhythms with superimposed alpha waves; sometimes obvious slow waves.	Obvious fast activity, high or low voltage theta rhythm with superimposed alpha-like activity. Patterns correlated in 15%.	Increase in firing rate in many structures but with no correlation.

occur against a background of diffuse alpha rhythm in the EEG. Moiseeva and Kasatkin (1968) found that emotional dreams (mainly negative) are accompanied by an obvious alpha rhythm, sharp waves and fast activity, both in the EEG and in the ESCoG. By means of correlation analysis it was further shown (Moiseeva and Beliaev 1972) that the bioelectric activity in subcortical structures during sleep does not persistently "lead" that in other structures; that the correlations between activities in these structures during sleep or at the moment of a dream are rather dynamic and variable (thus being quite different from those during wakefulness), the negative correlations prevailing over positive. Also, changes in the slow electrical processes in the deep structures during sleep (in terms of 2 parameters: change of sign and of amplitude of the oscillations) were shown to be associated, not with the sleep phases, but with the sleep cycles, and to proceed in different structures without correlations (Moiseeva *et al.* 1971b).

Finally, it was shown (Moiseeva *et al.* 1971a) that the unit activity of different structures during dreams changes in different ways. Thus, during dreams or generally during sleep, a relative independence of activity of different structures is observed.

In this study the analysis of correlations between the character of the dream and the character of the bioelectric activity provides grounds to state that, in cases of disorderly dreams on the ordinary time scale, the patterns of both the EEG and ESCoG are very variable and there is practically no correlation between the patterns of different structures. It may be suggested that, in this case, only one or a few structures get involved in the formation of the dream, which accounts for its imperfection.

The well-formed dream with a logical structure and no disorder or time or spatial relations, is followed by some ordering (appearance of regular alpha rhythm) and similarity between the EEG and ESCoG patterns, by a high correlation of the mean firing rates and a rather high correlation of the bioelectric processes in the structures under study. In such dreams time is adequately estimated. Only infrequently, when in the EEG and the ESCoG fast activity prevails, is some acceleration of the time flow noted (by 2–5 times).

Complex dreams with simultaneous actions in different aspects, both compatible and incompatible, *i.e.*, dreams with disturbed temporal and spatial relations, take place against a background of polymorphous EEG and ESCoG activity, combining prominent high voltage slow waves and fast waves. Increase in the rate of impulse activity during dreams occurs in different structures disconnectedly. The correlation between the bioelectric processes occurring in different structures is lower than during dreams with a logical structure. The duration of such dreams is greatly overestimated. Probably, owing to relatively independent processes in different structures, unrelated images simultaneously appear, which may account for the complex structure of the dream.

As to the mechanism of the subjective perception of "time flow acceleration" during dreams, with increase in frequency (appearance of beta-like waves in the REM phase), it may be similar to that with raised body temperature, which is known to cause acceleration of processes and change in time perception (Hoagland 1936; Woodrow 1951; Mann and Rutenfranz 1971). Moreover, a certain dependence was shown to exist between the body temperature and the frequency of occurrence of REM phases, and it sharply increased on administration of one of the psychotropic drugs which raise the temperature (Blum *et al.* 1972).

However, the subjective underestimation of the time flow due to the occurrence of high frequency brain waves may be by a factor of 2–5 times but not by scores of times. Apparently the instantaneous dissociated fragments of dreams, connected with the independent activity of different structures in wakefulness, are reproduced by the subject in a certain temporal order (as unidimensional time alone is natural for consciousness) which accounts for the effect of the considerable time acceleration.

SUMMARY

During dreams evoked by stimuli of a certain duration, the EEG was studied in healthy subjects and in patients with implanted electrodes (EEG, ESCoG (electrosubcorticogram), unit activity). Estimation of the temporal structure of the dream was made from the verbal account of the subject. In the case of an unformed dream the duration of the dream was shown to be adequately estimated, the EEG and ESCoG patterns to be rather variable, and correlation between the bioelectric activities of different structures to be nearly absent. Apparently, in these cases, only some of the structures participate in the formation of dreams, which accounts for their unformed character. A formed dream with logical structure, with no disorder of temporal and spatial relationships, is accompanied by certain orderly rhythms, similar EEG and ESCoG patterns, and a high correlation between bioelectric processes occurring in the structures under study. Dreams with a complex structure, with simultaneous action in different aspects and with major overestimation of their duration, are accompanied by polymorphous EEG and ESCoG patterns. Almost no correlation is observed between bioelectric processes in different structures. Apparently these dreams are associated with independent activities in different structures and, in the verbal account, the subject tends to place the events in a certain temporal order which creates the effect of considerable acceleration of the time flow.

RESUME

CARACTERISTIQUES DE L'EEG ET ESTIMATION SUBJECTIVE DU TEMPS PENDANT DES REVES DE DIFFERENTS TYPES

On a étudié chez des sujets normaux, et des patients porteurs d'électrodes implantées, l'activité électrique (EEG corticale, EEG sous-corticale (ESCoG), ECoG unitaire) concomitante de rêves évoqués par un stimulus d'une certaine durée. L'estimation de la structure temporelle du rêve était effectuée sur rapport verbal du sujet. Lors de rêves sans structure, leur durée était correctement estimée, les EEG ou ESCoG étant variables, et pratiquement sans corrélation entre les diverses structures. Apparemment, dans ces cas, seules certaines structures participent à la

formation de ces rêves, d'où leur absence de structure. Un rêve structuré, logiquement organisé dans les relations spatiales et temporelles, était accompagné de rythmes réguliers, semblables sur l'EEG et les ESCoG et à travers les diverses structures. Les rêves à contenu complexe, avec diverses modalités d'action, largement surestimées quant à laur durée, coincidèrent avec des patterns EEG et ESCoG polymorphes, sans corrélation d'une structure à l'autre. En somme, ces derniers rêves semblent associés à une activité indépendante de diverses structures; le sujet, dans son rapport verbal, tend à situer les événements dans un certain ordre chronologique, d'où accélération considérable du temps.

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