Normal Sleep Pattern Analyzed Statistically and Studied by Color “Dormograms”

Lars Philipson, Ann-Marie Risberg, and David H. Ingvar

Department of Clinical Neurophysiology, University Hospital, Lund, Sweden

Summary: Polygraphic sleep recordings were made from 46 healthy adult volunteers during 159 nights and evaluated visually. Sleep stages for each 30 sec epoch were entered into a computer data base from which plots of individual nights, as well as color “dormograms” and/or statistical parameters for a set of nights, could be produced. The total mean dormogram in which all the nights were synchronized at sleep onset revealed a dominant sleep pattern, which was found to be very stable even for subgroups. Synchronizing at the beginning of the second REM period allowed the pattern for the last half of the nights to appear more clearly. A large number of different sleep parameters were calculated for each night and statistically analyzed. On the basis of these results a normal “mean” sleep pattern could be reconstructed and related to other studies of normal sleep patterns. Key Words: Polygraphic recordings—Electrocardiogram—Sleep stages—Computer—Color display.

There is at present no computerized method for automatic evaluation of polygraphic sleep recordings, including electroencephalograms (EEG), that gives results as accurate and consistent as the analysis made by a well-trained human observer. However, even if the tedious sleep stage evaluation must still be done manually, a computer may be used with advantage to identify and visualize patterns in the large amount of data obtained from the manual classification of sleep records.

In our laboratory several series of sleep studies, mainly pharmacological studies in normal subjects, have been performed during the past eight years (Risberg et al. 1972, 1974, 1975a—c, 1977). They all included drug-free control nights (following adaptation nights). The EEG findings in 159 such nights form the basis for the present evaluation of normal sleep pattern. Our series is substantially larger than those previously presented, and a large number of different sleep parameters are reported. Therefore, the present results may be useful as a reference in the interpretation of normal and abnormal sleep.

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Address reprint requests to L. Philipson at Department of Clinical Neurophysiology, University Hospital, S-221 85 Lund, Sweden.
The amount of data and calculation involved in large sleep studies have led us to develop a special computerized sleep data base system. With the aid of this system we have developed a graphical display technique to present our results in a comprehensive form that we term "dormograms."

**MATERIAL AND METHODS**

**Material**

The investigation is based on sleep records from 46 adult subjects (37 males and 9 females, aged 20–31 years, mean 24.0) with a total of 159 recordings (120 from the males, 39 from the females). Figure 1 shows the age distribution for the whole group. All subjects were normal, healthy volunteers not taking any medication at the time of the study. All recordings were done during night sleep in the laboratory following at least two adaptation nights. The conditions in the sound-proof sleep laboratories were held constant with regard to temperature, light, and sound.

**Data Recording**

Polygraphic recordings were made using standard EEG equipment (Siemens-Elema Mingograph). The EEG, electromyogram (EMG), electro-oculogram (EOG), and sometimes the electrocardiogram (EKG), blood pressure, bed movements, etc., were recorded simultaneously with conventional techniques. Throughout the study bedtime was held constant and as close as possible to its occurrence in the normal sleep/wake cycle of each subject. For practical reasons bedtime was limited to between the hours 2200–2330. The total recording time was 8 hr from lights out.
Sleep stage classification was made visually from the EEG, EMG, and EOG records according to international standards (Rechtschaffen and Kales, 1968). Each 30 sec epoch was classified as belonging to a certain sleep stage. Precautions were taken to maintain continuity and reproducibility of the classification in the laboratory. One of us (A-M. R.) was involved in the classification of all the records included. During the period of data collection, the one other person involved in the scoring had been trained by and worked very closely with A-M. R. The scoring was discussed and from time to time both scorers classified the same records, a procedure which showed a high agreement between the scorers.

**Sleep Data Base**

The classification of each sleep record gave a list of all the epochs during which a sleep stage transition occurred. Such lists, together with personal data, etc., were entered manually into the computer data base by means of an alphanumeric video terminal. From then on, all data handling, calculation, and result displays were made by the computer. Any single night or set of nights was retrievable from this data base. (In accordance with Swedish law concerning computerized registers containing personal data, this sleep data base was officially approved.)

A minicomputer (Varian V73) with 32 K word core memory and 12.5 megabytes disk memory was used to handle the data base and all calculations. The primary data base was stored on magnetic tape and searched sequentially. The calculated sleep parameters could then be stored in a secondary data base on disk, which increased the speed of statistical calculations based on subsets of nights or individuals. Special software was developed to make it possible (in an interactive manner) to select nights on a search-key basis and to perform different statistical calculations on any parameters for given subgroups.

An electrostatic printer/plotter (Varian Graphics, Statos) was used to produce graphic presentations of single nights and lists of calculated parameters. A special color TV display system including extensive basic software was also used to generate color pictures from the computer (Philipson and Wottrich, 1977).

Figure 2 shows a graphic printout obtained from the data base of the sleep stages during a single night, together with basic data about the subject. It also contains histograms showing the relative amounts of each sleep stage during each third of the night and during the whole night. This is the standard way of describing sleep.

Several other sleep parameters can be automatically derived from the sleep stage curves in the data bases (see Table 1). These, together with the graphic representation of individual nights, are presently used in our laboratory and in clinical sleep investigations of patients (Afzelius et al., 1980).

**The Dormogram Technique**

Having obtained a set of sleep curves like the one in Fig. 2 recorded in a group of subjects under similar conditions, the problem arises of calculating an "average" sleep curve. There is no accepted standard for deriving such a curve, which should represent a reliable summary of the whole set. We have chosen a method...
FIG. 2. Graphical printout from the sleep data base showing sleep stages during one night together with basic data about the subject. Histograms at bottom show relative distribution of different sleep stages for each third of the night and for the whole night. Direct copy of an actual printout from the computer on the electrostatic printer.
by which both predominant tendencies and variations are displayed in a single picture, a "dormogram," from which relevant quantitative data can also be directly derived.

The basic idea is to take a set of individual sleep curves of the type shown in Fig. 2, superimpose them, and by means of image processing and a color display technique, visualize the result in a comprehensive way. To make the result meaningful, the individual curves must first be synchronized relative to a given moment during the sleep, e.g., sleep onset. Any other well-defined moment may also be used for this purpose. The final dormogram is then calculated in steps as follows.

**Step 1**

For each 30 sec epoch (counted from sleep onset, for example), a histogram was calculated giving the number of subjects in each sleep stage during that particular epoch. In other words, the distribution of sleep stages in the whole population was calculated for every epoch, which resulted in about 1,000 histograms. Altogether, these can be represented as a rectangular array of numbers with five rows (sleep stages) and about 1,000 columns (epochs).

**Step 2**

Because of the limited spatial resolution of the TV screen, the number of columns had to be reduced to about 250. An additional slight low-pass spatial filtering was applied in the horizontal direction to eliminate occasional local transients in the data. A convolution with a suitable weight-function was applied, which resulted in an array consisting of five rows and about 250 columns.

**Step 3**

Using the smooth curve-fitting algorithm of Akima (1972), a smooth envelope of each of the new histograms was then calculated (Fig. 3). This curve-fitting algorithm is devised in such a way that the resulting curve will pass through all the given data points and, to a human observer, appear smooth and natural. A portion of the curve between a pair of given points is represented by a third-degree polynomial, determined by the coordinates and the slopes at these points. An ad hoc method is used to calculate the slope locally by the coordinates of five successive data points.

**Step 4**

Each value of the smoothed histogram curve is then translated into color and transferred to a graphical color TV display system (Semigraph 220 from SRA, Stockholm). All the color-coded histogram curves, put close beside each other on the screen, then form a three-dimensional picture of the sleep stage distribution during the night for all the nights included in the dormogram (Fig. 4).

The color code is normalized in such a way that 100% represents the total number of nights involved in the dormogram. The color code was chosen so that the reddish colors corresponded to the case where a majority of the group (i.e., more than 50% of the nights) showed the same sleep stage at that moment. The
FIG. 3. If one considers the dormogram as a topographical map of a "landscape" with peaks and valleys, this figure shows one vertical cross section in such a landscape, corresponding to a certain epoch during the night. It illustrates how the smooth curve fitting technique is used to produce the dormogram. Bars correspond to the underlying histogram of sleep stages for all the nights during the epoch in case. The curve-fitting results in the solid, continuous curve, which is then color coded. Using a bar instead of a single data point to indicate the amount of each stage before the curve fitting, results in a dormogram where the majority stage will be visualized very clearly by a band, which changes not only in color but also in width. The color scale was calibrated to correct for the overshoots caused by the algorithm, so that the color always indicates the actual percentage of the whole group and not the interpolated overshoot value.

bluish colors represent the distribution of stages represented less frequently at each moment. All the numerical values can also be printed out numerically in selectable epoch lengths.

The basic principle behind the dormograms and the color display technique is similar to the one used for cerebral "ideograms," color displays of cerebral blood flow distribution in normal subjects and patients (Ingvar and Philipson, 1977). The reason for using a color display is clearly demonstrated in Fig. 5, which is based on exactly the same information as Fig. 4A but represented as a gray scale. It is not possible to discriminate a sufficient number of gray tones to be able to identify the course of the dominant stage peak during the night.

RESULTS

The mean values, medians, and standard deviations for the numerical parameters of all the recordings are summarized in Table 1. Standard deviations are given as percentages of the corresponding mean value in order to indicate the normal range of each variable. It should be noted that some of the variables had rather asymmetrical distributions. In these cases the SD is unreliable as a measure of normal variation. The rather small variation in total time in bed, total sleep period, and total sleep time was due to the fact that the subjects were awakened after approximately 8 hr in case they were still sleeping at that time.

Figure 6 shows the actual distribution for the latencies from sleep onset to different sleep stages. These histograms were produced directly from the computer by means of the statistical routines. There were also, of course, variations in the total distribution of the sleep stages during the nights. These variations are illustrated in Fig. 7.

The dormogram in Fig. 4A is based on all 159 nights, synchronized at sleep onset. It shows a predominant standard pattern of sleep during the first half of the

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FIG. 5. Same data as in Fig. 4 but represented in a 16-step gray scale instead of in color.

night and a more diffuse pattern later in the night. Figure 8A shows an enlarged version of the first 4 hr of the dormogram in Fig. 4A.

In order to investigate the stability of the pattern for the 159 nights (Fig. 8A), the entire group was randomly divided into two subgroups of 79 nights each. The corresponding dormograms for these two subgroups are shown in Fig. 8B and C, respectively. As seen, the pattern for each subgroup was almost identical to that of the whole population. Several different subgroups were investigated with the same result.

The more diffuse pattern shown in the last half of the night (cf. Fig. 4A) might be due either to temporal dispersion of the individual patterns or to a more genuine absence of common characteristics in the second half of the nights. In order to determine which was the case, a dormogram was produced in which the individual nights were synchronized not by sleep onset, but by the start of the second REM period (Fig. 4B). One can see that a common pattern was also a feature of the second half of the night.

Using the quantitative data from all the nights (Table 1) and the qualitative view of the sleep pattern shown in Figs. 4 and 8, it becomes possible to construct a hypothetical average of all 159 nights. Due to statistical variations, this can of course be done in different ways. Figure 9 shows our reconstruction. Each sleep parameter in Table 1, when calculated for this hypothetical night, has the same value as the corresponding mean value for all the 159 nights. Also, the percentages of the different sleep stages for each third of the night (shown in Fig. 9) correspond to the means for all 159 nights. The dormograms shown in Figs. 4 and 8 have been
FIG. 4. Color dormograms (see text) for all the 159 nights included in the present investigation, reproduced directly from the color TV screen. The color scale at the right-hand side shows the correspondence between color and percentage of the total number of individual nights included. A: Synchronization at sleep onset. B: Synchronization at the start of the second REM period (defined as the first REM sleep occurring in the 170–260 min interval after going to bed). C: Synchronization at center of gravity of second REM period (defined as the time center of all REM sleep occurring in the interval 170–260 min after going to bed).
FIG. 8. Dormograms showing the first 4 hr of the night synchronized to sleep onset for all 159 nights (A), for a randomly selected subgroup of 79 nights (B), and for another subgroup of 79 nights (C) consisting of the rest of the nights except one. Note the remarkable similarity of the sleep pattern in both groups during this first part of the night.
### Table 1. Mean values and standard deviations for the calculated sleep parameters

| Sleep parameters                                      | Mean value | Median | SD of mean (%) |
|-------------------------------------------------------|------------|--------|---------------|
| Distribution of stages during total sleep time (period) |            |        |               |
| Stage REM (%)                                         | 21.3       | 21.8   | 22.4          |
| Stage 1 (%)                                            | 8.4        | 8.0    | 44.1          |
| Stage 2 (%)                                            | 51.1       | 51.7   | 13.2          |
| Stage 3 + 4 (%)                                        | 19.2       | 18.4   | 34.0          |
| Number of stage transitions ‡                        | 49.0       | 47.0   | 53.0          |
| Number of stage transitions/hr                        | 6.6        | 6.4    | 29.9          |
| Stage awake                                            |            |        |               |
| Sleep latency b (min)                                   | 22.1       | 16.0   | 92.5          |
| Latency to stage other than 1 b (min)                  | 25.6       | 20.0   | 82.3          |
| Time awake after sleep onset (min)                     | 16.7       | 13.5   | -----         |
| Number of awakenings ‡                                  | 4.3        | 3.0    | 46.3          |
| Number of awakenings/hr total sleep time               | 0.60       | 0.49   | 94.5          |
| Stage REM                                              |            |        |               |
| REM latency d (min)                                     | 86.7       | 71.5   | 38.7          |
| Stage REM during total sleep period (min)              | 93.8       | 96.5   | 22.3          |
| Stage REM of total sleep time (%)                      | 21.3       | 21.8   | 22.4          |
| Number of distinct REM periods e                       | 4.0        | 4.0    | 22.3          |
| Average duration of REM periods ‡ (min)                | 23.5       | 23.3   | 31.2          |
| Stage 3 + 4                                            |            |        |               |
| Latency to stage 3 + 4 d (min)                         | 19.7       | 17.5   | 48.5          |
| Stage 3 + 4 during total sleep period (min)            | 84.3       | 81.0   | 34.2          |
| Stage 3 + 4 of total sleep time (%)                    | 19.2       | 18.4   | 34.0          |
| Total sleep                                            |            |        |               |
| Total bed time (min)                                   | 481.3      | 483.5  | 2.25          |
| Total sleep period a (min)                             | 456.6      | 461.0  | 5.76          |
| Total sleep time a (min)                               | 439.3      | 447.5  | 8.40          |
| Sleep efficiency index (%)                             | 91.3       | 93.1   | 8.15          |

| ‡ If the same stage appears again within 5 epochs the transition is not counted. |
| b Latency counted from bedtime to sleep onset. |
| c Stages 2–4 or REM must recur between awakenings to be counted as different awake periods. |
| d Latency counted from falling asleep. |
| e To be distinct, two REM periods must be separated by at least 20 min of non-REM sleep. |
| f If the total sleep period ends during a REM period, it is not included in the calculation of the average duration of REM periods. |
| a Total sleep period = time from falling asleep to final awakening = total time in bed — (sleep latency + final awake period). |
| b Total sleep time = total time in nonawake sleep stages = total sleep period — time spent awake after falling asleep. |

Standard deviations are given as percentages of the mean value to indicate the relative individual variations for the different parameters.

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used as guidelines for the quantitative appearance of the reconstructed night. Even with these restrictions, there is considerable freedom to choose various reconstructions of different details. In such cases our choice was guided by our general impression of the printouts of all the individual nights. This means that the reconstructed night shown in Fig. 9 is not the average night, but an average night based on the data from our material.
FIG. 6. Histograms of latencies from sleep onset to different sleep stages, redrawn directly from computer plots. Sleep onset (A) is usually so rapid that no peak can be seen in its distribution. In the case of latency to stage 2 (B) and stage 3 + 4 (C), there are peaks in the distribution corresponding to the mean values of the corresponding parameters. Note the two peaks in the distribution of REM latency (D)—see text for discussion. Time scale in A and B starts at going to bed, in C and D at sleep onset.

FIG. 7. Histogram showing the mean distribution of sleep stages during the nights. The dots indicate the variation of the distribution of the entire series of recordings. Each dot represents 5 nights with the indicated percentage of the particular sleep stage.
DISCUSSION

Even if sleep stage classification from polygraphic records is performed manually, our computer system has proven very useful for storing and retrieving large amounts of data from several series of investigations, for calculating different sleep parameters for individual nights, for making statistical evaluations of sleep parameters, and for displaying the results in a number of comprehensive forms.

The dormogram technique has been shown to be a very powerful tool by which to reveal and directly visualize common patterns in a data base consisting of a great number of recordings of individual nights, patterns that would not have been perceived with conventional statistical analysis of the same data. In a strict sense, a dormogram does not, of course, contain any information other than the raw data on which it is based. Nonetheless, it has proven to be a useful method of facilitating the detection and comparison of the properties of large sets of sleep data. The advantages of the dormogram technique may be especially valuable in studies of abnormal sleep, in which there is often little or no previous knowledge of existing deviations from a normal sleep pattern.

In the present study the dormogram technique has provided further evidence of the existence of a highly stable, normal sleep pattern that seems to be synchronized at sleep onset. The stability and synchronicity of the pattern also present in subgroups of the population (Fig. 8B, C) is striking. The dormograms for the group reported here confirm many of the details of the normal sleep pattern reported previously.

After sleep onset, the dormogram shows a very short period of stage 1, followed
by a distinct period of stage 2 sleep. This ends very sharply, and a 15–50 min period of deep sleep (stage 3 + 4) follows, gradually changing to stage 2.

The first period of REM sleep has a latency of $87 \pm 34$ min from sleep onset. The REM period is rather short and may be completely missing, as in the example shown in Fig. 2. The distribution of the first REM period latency (Fig. 6D) contains a second, smaller peak at approximately twice the time to the first, main peak. This second peak appears in cases where the first REM period is absent. It is interesting to note that the late REM periods, corresponding to the second peak, appear at the same time as the second REM period normally occurs. Thus an underlying sleep rhythm seems to exist irrespective of, in this case, a manifest sleep stage, namely, the first cycle REM period. From the histogram in Fig. 6D, we can calculate that this was the case in approximately 15% of the 159 nights.

With the end of the first period of REM sleep, the first sleep cycle during the night is complete. A night usually contains four complete cycles, all of which have very much the same course. The main difference is that the time spent in deep sleep (stage 3 + 4) decreases during each successive cycle; concomitantly, the time spent in stage REM increases correspondingly in each successive cycle during the night.

The values given in Table 1 represent the quantitative statistical counterpart to the graphical information of the dormograms. They show that approximately half of the time was spent in stage 2, that approximately the same amount of time was spent in deep sleep (stage 3 + 4) as in stage REM, and that on average there were about 50 stage transitions and four to six awakenings during each night.

Many sleep studies have been made with young healthy subjects of about the same age as our subjects, and we note an overall agreement with our results. Feinberg et al. (1967) found the following stage percentages in his study of 15 young normals: 22.7% stage 1A and 22.6% stage 3 + 4. The higher percentage of SWS might be due to the short total sleep time in their subjects and differences in the scoring technique. Young adults showed a 22.1% REM in a study by Roffwarg et al. (1964). Williams et al. (1964) studied 16 healthy normals and found 24.1% REM and 20.9% stage 3 + 4. The distribution of the different sleep stages over the night is in accordance with the present results.

No attempts were made to find statistical correlations or other relations between the different sleep parameters, even if routines for such calculations are included in the statistical package used. The great number of variables, many of them intricately interrelated, makes such an investigation so complex that it is outside the scope of the present study.

One remarkable aspect of the sleep pattern shown by the dormogram is that the phase of REM cycling seems to be synchronized by sleep onset. This evidence appears to speak against the hypothesis (Kleitman, 1963) that there exists an endogenous, 24 hr “REM” cycling, i.e., during both sleep and wakefulness. As the cycle time of such a rhythm should be very short compared to the circadian rhythm, there is no reason why it should be “in phase” between individuals. If, therefore, the appearance of REM periods had been directly related to such an ongoing cycling, there should have been little or no relation between sleep onset and the phase of the REM cycles. The dormograms, however, show that there is
obviously a close relationship between sleep onset and the start of the first REM period. This finding might nonetheless be compatible with the existence of an underlying REM rhythm or tendency for such a rhythm, provided that it may easily be phase-shifted, e.g., by sleep onset. (Other known biological rhythms, like the circadian, are, however, rather phase stable, which makes this alternative less probable.)

The dormogram technique used in the present series has additionally demonstrated the homogeneity of a group of nights in young normals (Fig. 8). Hence, it may be used to investigate inhomogeneity in other sleep recording series. This may be done by dividing the whole group of nights into subgroups according to possibly significant differences in the characteristics of individual subjects or nights and then producing dormograms for each subgroup. If such dormograms reveal any differences, they can then be quantitatively investigated by making appropriate statistical calculations on the sleep parameters using the sleep data base programs. The dormograms then serve both as a guide for a general intuitive interpretation and as a means for visualizing statistically demonstrable differences. We have applied this use of the dormogram technique successfully in an on-going large study of sleep in night workers (Risberg et al., 1979).

The hypothetical average sleep pattern shown in Fig. 9 has been reconstructed from the data only to give a visual image of the mean values in Table 1. To facilitate comparisons, the reconstructed night is presented in the same form that is used for individual nights. It must be stressed, however, that the normal variations are rather large, necessitating the arbitrary choice of several of the features of the reconstructed night. This means that the sleep curve presented here as a normal average must not be used as a template that is imposable directly on plots of individual nights in order to classify all discrepancies as abnormalities. Such investigations must be based not only on visually detectable differences in patterns, but also on quantitative evaluation of sleep parameters.

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