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A Time-Dependent Model of the Sleep EEG

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An approach is presented for the description of sleep rhythms contained in the EEG. It is an extension of a method for automatic recognition of the sleep stages. A brief summary of the contents of this contribution follows: the sleep stage classification [2] utilizes only part of the EEG information about sleep rhythms. An example demonstrates the existence of EEG descriptors that display information in addition to the sleep stages. The computational procedure was developed from a gradual improvement in the understanding of the structure of the data.

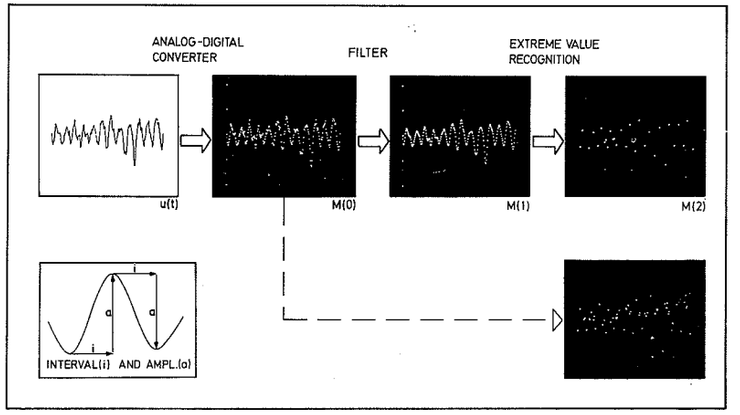

Fig. 1. Steps of the extreme value method and interval and amplitude measurement for extreme value data.

Review of a Method of Sleep Stage Classification

At the sleep congress in Würzburg in 1971 a method for automatic recognition of the sleep stages was presented by PROBST *et al.* [1]. It is an on-line, real-time program for a laboratory computer. Input data of the program is only one channel of prefiltered (70 Hz low-pass) EEG. The digitizing rate is 5 msec. The time is segmented into 30-sec epochs. The following computations are carried out:

1. Data collection and reduction by the extreme value method (fig. 1), a variation of the well-known period analysis with zero-crossing method.

2. After the analog-digital conversion, smoothing of the signal by a simple filtering algorithm.

3. Determination of the local peaks. The extreme value data are measured by the sequences of amplitude and time differences between adjacent peaks.

The joint frequency distributions of the amplitude and period parameters for every single epoch – in the following called extreme value distributions – constitute the input data for the stage recognition. The extreme value distributions show intra-stage ranges that overlap each other only partly for different stages, a property on which the stage recognition procedure is based.

Suitable values of the control parameters of the program have to be determined for every subject. This is done in a special learning phase by storing the data from a sample of visually scored, typical epochs for each sleep stage. The program is now used as a routine procedure for on-line sleep scoring in several research projects in our institute.

Our experience with this method can be summarized in the following statements.

A satisfying intra-individual stage recognition can be achieved with the data of the extreme value distribution alone. The distribution contains information about the background activity of the EEG.

More complex data like EEG patterns, or external data such as EOG or EMG, or data from more than one EEG channel are not necessary. The agreement between visual and automatic scoring is always more than 80%. Also the REM-stage can be discriminated sufficiently well from the EEG if the series of output data of the recognition procedure is smoothed along the time axis.

Present Work on a Descriptor of the Sleep EEG

Figure 2 shows an example of the extreme value distribution. The horizontal axis is the interval or frequency axis, the vertical axis is the

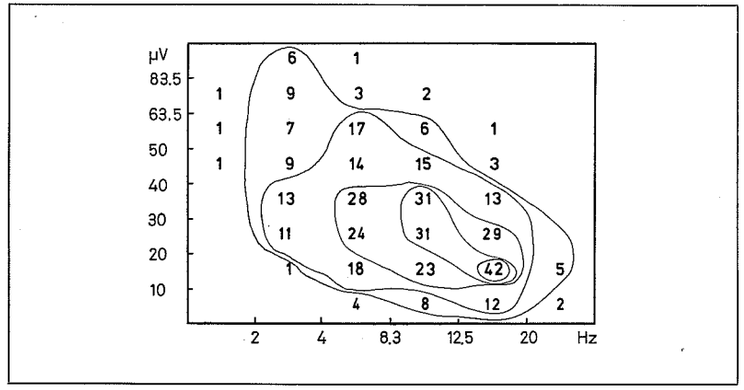

Fig. 2. Joint interval amplitude distribution of extreme value data. Integration time, 30 sec. Typical example of a unimodal frequency-amplitude distribution.

amplitude axis. The numbers represent the numbers of events during the epoch that were classified into the respective matrix fields. An event is each EEG wave discovered and measured by the extreme value procedure.

More detailed inspection of the data clarified the fact that these distributions are unimodal. The extreme value method extracts only the highest frequency component from the signal. This contributes to an explanation of the empirical finding just mentioned. Unimodal distributions can be approximately described by a few parameters. Therefore, we have computed several parameters of the distribution and plotted their values along a time axis. The resulting curves showed quasi-continuous changes of the shape of the extreme value distribution that can be described by two factors: shifts of the mean value and changes of the correlation. As a sensitive descriptor for these properties of the data we have computed a simple synchronization parameter as follows: the interval and amplitude axes are dichotomized and so the interval-amplitude space is divided into four fields; thus, each wave is classified into one of these fields. Then, the fraction of the time in which the ' slow-wave, high-amplitude ' field is occupied plus the time in which the ' fast-wave, low-amplitude ' field is occupied is the descriptor.

Figure 3 gives an example of the results obtained with the synchronization parameter.

In the upper row the visually scored pattern of a night of a healthy subject is shown. The lower row contains a computer plot of the corresponding data of the synchronization parameter. Each point represents a value of a 30-sec epoch. Obviously, the correlation between the visually scored pattern and the synchronization curve is significant. The synchronization parameter is quasi-continuous. This indicates that the sleep stages are a discrete classification scheme for a biological continuum. An advantage of the synchronization parameter is its additional information about local variations that do not show in the periods with constant sleep stages. An example is the long stage 2 period in the 5th hour. Another interesting finding is that the ascendant slopes are mostly terminated by an epoch of movement time. The main features of the approach presented here are the following:

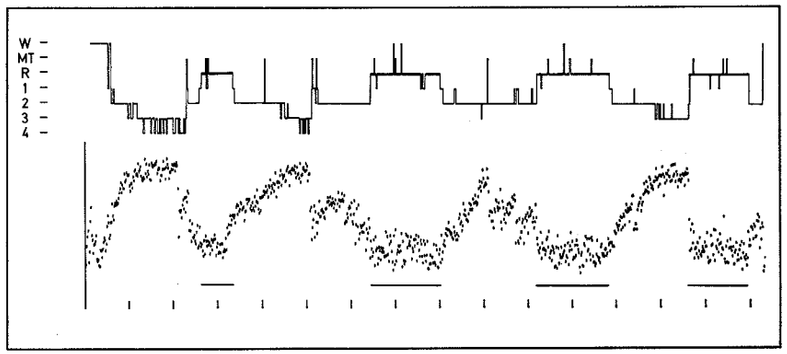

Fig. 3. Visual sleep stage scoring (upper row) and computer plot (lower row) of the synchronization parameter. Comparison of sleep stages (visual scoring) and synchronization measurement for the same night.

1. The definition of the computational procedure can be stated independently from the conventional sleep stage criteria and no learning phase is needed in computer applications.

2. By the application of more specific algorithms additional information about the sleep rhythm that does not show in the sleep stages is obtained.

References

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2 RECHTSCHAFFEN, A. and KALES, A. (eds.): A manual of standardized terminology, techniques and scoring system for sleep stages of human subjects (US Department of Health, Education and Welfare, Bethesda 1968).

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