

A NEW QUANTITATIVE APPROACH TO THE ASSESSMENT OF STAGES OF VIGILANCE AS DEFINED BY SPATIOTEMPORAL EEG PATTERNING¹

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Summary.—Electroencephalographically oriented research on vigilance needs valid measures for assessing the level of vigilance between wakefulness and sleep. When studying different psychologically, psychopathologically, and pharmacologically induced states, special attention has to be paid to minor alterations of the level of vigilance which are reflected, essentially, in topographical changes of alpha-activity (Stage A). Since vigilance is a dynamic process, brief fluctuations in the range of a few seconds must also be recorded. In our opinion existing methods of quantification do not fully meet these demands. We have, therefore, developed a relatively simple procedure which can be characterized as an attempt quantitatively to reconstruct visually, i.e., spatiotemporally defined patterns of vigilance. The usefulness of this method, which also has certain limitations, has been demonstrated in psychopharmacological studies.

The topic to be treated here requires a short explanation of what we mean by the term "vigilance," a term originally coined by Head (1923). In psychology "vigilance" is usually used in the context of research on attention and connected with concepts such as activation, selectivity, attention, motivation, etc. In this research "vigilance" appears as a multifactorial phenomenon which is investigated in the domain of observable behaviour. As Matejček (1982) pointed out, the relationship between the individual determinants of vigilance can only be interpreted in a meaningful fashion if all the factors can be related to a common basis, i.e., to the neurophysiological level of description.

A number of EEG studies are based on the premise that the quality of an individual's interaction with his environment is a function of the dynamic state of his central nervous system and that this dynamic state is directly reflected in his EEG. Therefore, the EEG is considered to be a highly sensitive indicator of vigilance in the sense of Head.

In this connection it should be pointed out that a linear relationship between drowsiness as a subjective psychological phenomenon and declined vigilance as determined by the EEG cannot be assumed. As shown by Matoušek and Petersen (1983) there is a high variability of self-rating scores of drowsiness in relation to data based on measurement of EEG vigilance.

Head's concept of vigilance was applied to the human EEG by Lairy and Dell (1957). The concept was further developed by Bente (1964a, 1964b, 1979) who concentrated on the time course and topography of the EEG and

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attempted to relate various (visually defined) EEG patterns to the momentary functional state of the brain.

Electroencephalographic changes of vigilance are reflected by a complex *spatiotemporal* process, first pointed out by Loomis, *et al.* (1937, 1938) and by Davis, *et al.* (1938). These authors distinguished two EEG stages, A and B, between resting wakefulness and sleep. Stage A was refined into substages by Bente (1964a) and Stage B by Roth (1961). It need not be emphasized that a valid quantitative measurement of the level of vigilance is of utmost importance for electroencephalographically oriented research, since otherwise we can only base our investigations on visual evaluations which are characterized by varying interrater reliability depending to a large extent on the training

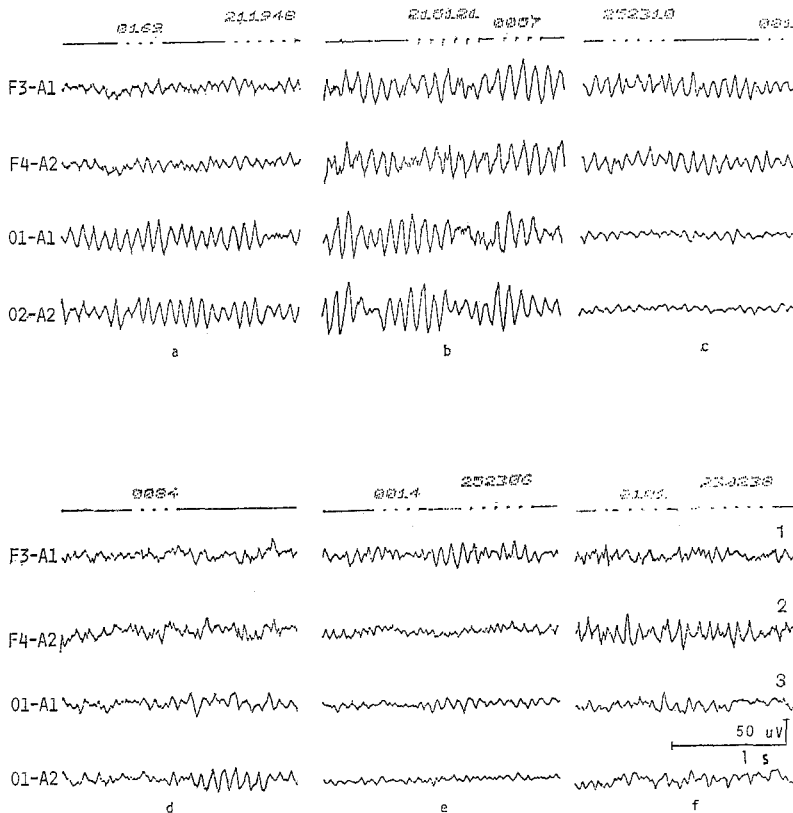


FIG. 1. Stage A as subdivided by Bente (1964a, 1979). a: Stage A₁ —, b: Stage A₂ —, c: Stage A₃ —, d, e, f: incompletely developed stages occurring as transitional forms

and the experience of the investigators. Two kinds of measures are required, (a) measures for assessing the level of vigilance and (b) measures reflecting the time course of vigilance. Since we are dealing with topographical relations, the analysis must consider more than only one derivation. Furthermore, temporal variability must be preserved.

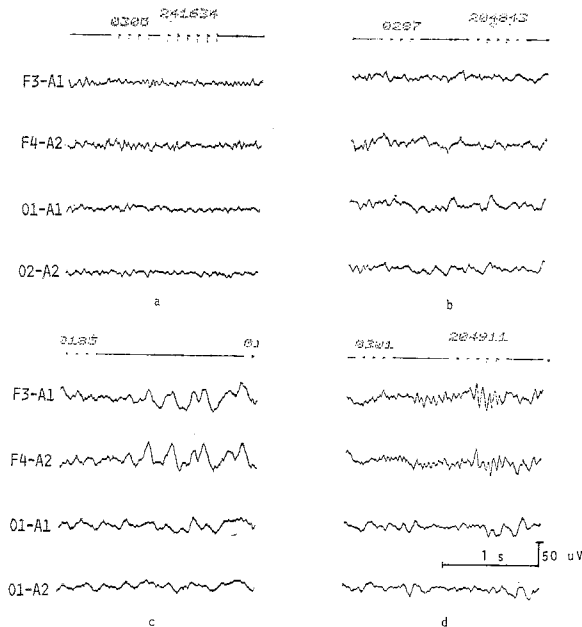


FIG. 2. Stage B and Stage C, Stage B as subdivided by Roth (1961). a: Stage B₁ —, b: Stage B₂ —, c: Stage B₃ —, d: Stage C

METHOD

Four referential (or source-) leads are recorded, an anterior and a posterior lead from corresponding points of each hemisphere (e.g., F3/A1-F4/A2-O1/A1-O2/A2). A recording of 10 min. is stored on FM-tape. The examinations are done with the subjects in a semirecumbent position with the eyes closed. The subject is left undisturbed and allowed to fall asleep. For comparability, reexaminations must be carried out at the same time of day.

The recordings are converted from analogue to digital and segmented into 300 2-sec. epochs. The aliasing effect is prevented by the choice of a high-sampling frequency (260 cps) and by digital filtering to eliminate all spectral coefficients above 32 cps. For our investigations of the time course, it is neces-

sary to forego the elimination of artifacts. As a precaution against artifacts resulting from the recording process or from A/D-conversion the digitized EEG is plotted (D/A-conversion). Markedly disturbed recordings are excluded from further analysis.

For each epoch the absolute power spectrum is estimated by means of fast Fourier transform (FFT, spectral resolution: 0.5 cps, frequency range: 0 to 32 cps). The resulting sequences of 300 periodograms represent the data base for all subsequent operations.

For each epoch the percentage of alpha-power (8 to 13 cps) relative to total power (0 to 32 cps) is calculated. This step is the prerequisite for automatic differentiation between epochs considered to be Stage A from all other epochs.

The algorithm of decision between Stage A and Stage nonA is derived from the criteria governing our visual evaluation (Table 1). A nonA stage is present when no single lead shows a definite alpha-rhythm. As the criterion for definite alpha-rhythm we determined a minimum of 50% alpha-power (8 to 13 cps) relative to total power (0 to 32 cps).

TABLE 1
SUBDIVISION OF STAGES A AND B OF LOWERED VIGILANCE*

A ₁	Alpha-spread to anterior regions. Synchronization, regularization and slight slowing of alpha-rhythm.
A ₂	Shift of alpha-voltage maximum to anterior regions. Diminution of occipital alpha-amplitude. Enhanced modulation of occipital alpha-amplitudes.
A ₃	Anterior shift of maximum of alpha-rhythm. Discontinuous dissolution and fragmentation of alpha-rhythm in the occipital regions. Enhanced frequency variation of resting rhythm and appearance of faster alpha-waves in marginal portions of alpha-spindles (appearance of fast activity).
B ₁	Generalized low-voltage activity.
B ₂	Low-voltage activity with interspersed diffuse irregular 4-7 cps activity (appearance of irregular fast activity).
B ₃	Low-voltage activity. 3-5 cps slow activity of increasing amplitude predominant in the precentral regions (appearance of spindle-like fast activity in fronto-precentral regions).

* (Loomis, *et al.*, 1937). The criteria for the Substages A were given by Bente (1964a), for Substages B by Roth (1961) (from Bente, 1979).

Fig. 3 shows 2-sec. epochs from the original recording with the corresponding alpha-percentages. As can be seen (an example is given for each 10%-step) some alpha-waves, but no alpha-rhythm, can be found in the epochs with an alpha-percentage < 50. Furthermore shades can hardly be recognized in this range.

To record the increase of nonA epochs which is expected along with

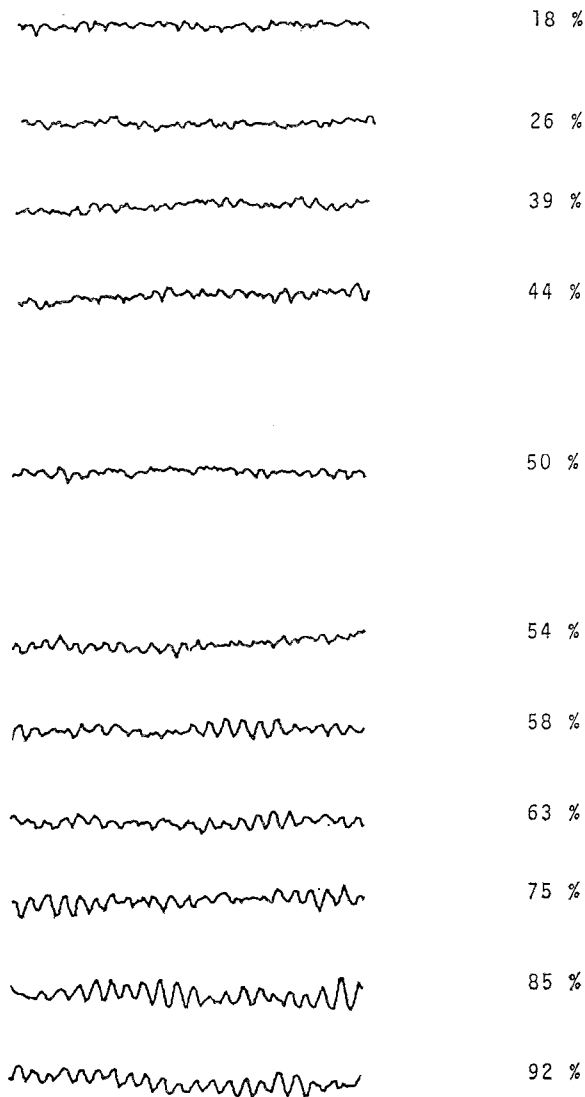


FIG. 3. 2-sec. epochs and their corresponding alpha-percentage (8-13 cps) relative to total spectral power: Derivation $O_2 - A_1$ of the EEG of a healthy volunteer without medication

physiologically declining vigilance in the time course, the rate of nonA epochs is determined for each of the 10 min. of the recording period separately.

The objection that a nonA epoch may correspond not only to lowered

vigilance but also to an arousal state seems to be irrelevant in consideration of the recording conditions (see above).

The determination of the time-dependent decline of vigilance, i.e., the

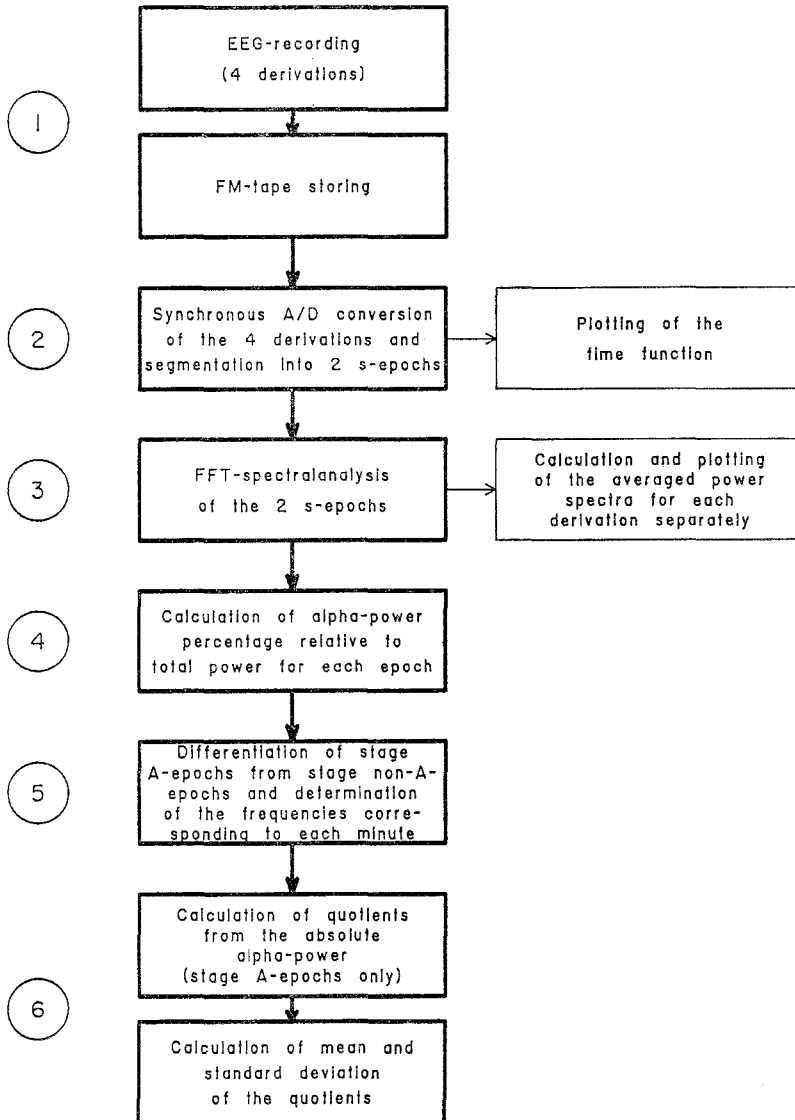


FIG. 4. Assessment of vigilance by computerized EEG: successive steps of data processing

dynamics of vigilance, is based upon a rough differentiation between A and nonA epochs. For a refined assessment of the mean vigilance *level* we need a subdivision of Stage A; see Table 1. This subdivision is founded upon the anterior-posterior relation of alpha-power. Two quotients of anteriorization, alpha-power of the anterior derivation/alpha-powers of the anterior + posterior derivations, can be calculated for each Stage A epoch, one for the left (AQ_1) and one for the right hemisphere (AQ_r). In addition, we calculate 2 quotients of lateralization, alpha-power of the left derivation/alpha-powers of the left + right derivations, which reflect left-right relations over the anterior (LQ_{anterior}) and over the posterior region ($LQ_{\text{posterior}}$).

The calculation of quotients of lateralization is based on the hypothesis that changes of vigilance are reflected in both the anterior-posterior and the left-right dimension. It has been speculated that the function of lateralized neural arousal systems is to regulate the cognitive contributions of the hemispheres differentially (Tucker, 1981). We agree with Tucker (1983) when he emphasizes that the consideration of the *interaction* of caudality with laterality may prove helpful theoretically.

Finally, we calculate mean values and standard deviations for all epochs taken into consideration.

Fig. 4 graphically summarizes the method.

DISCUSSION

From our point of view all former attempts at electroencephalographic measurement of vigilance have two shortcomings in common. On the one hand, topographical information is not taken into account. On the other hand, the periods analysed seem to be too long for determination of dynamic variability in the range of a few seconds.

Although we are aware that the proper length of epochs for FFT is controversial (e.g., with regard to spectral resolution or the stationarity of the signal), we feel that physiologically occurring fluctuations of vigilance in the range of a few seconds should not be treated as disturbing "random" variability or noise but rather as a source of information. In contrast to hypotheses denying a direct correlation of shortlasting attenuations of alpha-rhythm (Elul, 1967) to vigilance, there is evidence that such shortlasting attenuations are accompanied by a loss of precision in the adaptive reactions to environmental conditions (Bente, 1964a; Kugler, 1981; Matoušek & Petersen, 1983).

The two best-known procedures are discussed briefly. One was proposed by Matejček and Devos (1976) for the evaluation of the time-dependent effects of psychoactive drugs. From 3-min. sections of the derivation O2-CZ, the Hjorth-parameters were calculated at several time points (the so-called normalized slope descriptors: activity, mobility, complexity). For example, from an increase of complexity ("range of frequencies") coincident with a decrease of

mobility (average frequency) a lowering of vigilance is inferred. This is without doubt a useful procedure for certain questions. Its applicability, however, seems very restricted since topographical information and short fluctuations of vigilance are lost. In addition it must be stressed that very different spectra may yield the same Hjorth-parameters (Denoth, 1975).

The other method proposed by Matoušek and Petersen (1983) was developed on the basis of visual evaluation like ours. A number of parameters derived from the power-spectra of 5-sec. epochs are validated by visual evaluation of the corresponding original record. For the visual evaluation only one posterior lead is considered. Quantitative parameters are absolute and relative powers of certain frequency bands and their ratios. The visual evaluation follows the staging given by Dement and Kleitman (1957), which includes Stages A and B of Loomis, *et al.* within Stage I. A finer subdivision, especially of Stages A₁, A₂, and A₃ which are decisively defined by topographical information, is not attained. The authors' claim that they have developed a method for continuous measurement of *slight* vigilance fluctuations changing from *full alertness* to *slight drowsiness* seems to us to be inadequately fulfilled. A further serious objection concerns the imputed linearity of scales of the various parameters with regard to vigilance.

Whereas these methods try to extract vigilance-relevant parameters by means of complicated and sophisticated techniques, including the total frequency range, our relatively simple quantitative approach attempts to reconstruct visually, i.e., spatiotemporally defined patterns. There are two reasons for considering the alpha-band only. On the one hand, various cognitive and emotional processes reflect themselves essentially in topographical changes of alpha-activity, i.e., within Stage A of Loomis, *et al.* (Glass, 1984; Glass, *et al.*, 1984). On the other hand, Stage A and its subdivisions have proven to be decisive for electroencephalographic characterization of psychoactive drugs, a fact emphasized by Bente (1961, 1979).

The practical applications of our approach are based on the following considerations. (a) Drugs which "promote" vigilance may be expected to affect the maintenance of an initial (higher) level of vigilance in such a way that the subvigilant EEG-stages, which are characterized by a disappearance of the alpha-rhythm (nonA epochs) occur considerably later and are fewer in number than without drug administration. Sedatives, on the other hand, shorten the time which elapses until the occurrence of such subvigilant stages and increase their number. (b) Since a refined characterization of the Substages A₁ to A₃ can be obtained from quotients calculated from absolute alpha-power, hemispherical differences of vigilance-regulation can be ascertained. (c) Since vigilance parameters are determined for each 2-sec. epoch of each single EEG, intra- and interindividual variability is essentially preserved. These parameters can be

used for pre- and postcomparisons of certain groups as well as for repeated measurements on the same individual.

Of course, this approach also has its limitations. In its present form, it is only applicable to subjects whose EEGs meet the criteria of the staging illustrated by Figs. 1 and 2, i.e., essentially to adults. Subjects with a low-voltage or a pathological EEG with predominating theta- and delta-activity cannot be dealt with. Furthermore, the method is restricted to EEGs which were recorded under resting conditions. Whether the procedure can be adapted for investigations under waking conditions, for example, for the investigation of the vigilance-dependence of task-related asymmetric hemispherical functioning, has to be studied. In spite of these limitations and other possible objections, we are confident that our method is a useful and relatively simple tool for answering certain questions. This confidence has been substantiated by the hitherto obtained results from various drug studies (Ulrich, *et al.*, in press a; Ulrich, *et al.*, in press b; Ulrich & Suchy, in press c).

In conclusion, we would like to quote a statement by Max Fink (1975): "Personally I feel that the skepticism . . . in methodological disputes can only be overcome by the presentation of clear and convincing results."

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