COMPLEMENTARITY OF DIFFERENT ANALYSIS METHODS[1]

W. STORM VAN LEEUWEN

Neurophysiology Department, Institute of Medical Physics, T.N.O., and EEG Department, Neurological Clinic, University Hospital, Utrecht (The Netherlands)

In the previous communication Grey Walter demonstrated that, with different forms of analysis of the EEG, different aspects of the signal may be extracted. Thus the notion of complementarity of the different methods of analysis was developed. In the present communication an example of this notion is presented. The example concerns an investigation which has been carried out on the occurrence and spread of alpha rhythms over the head in normal subjects.

For this investigation three forms of analysis have been applied.

1. Continuous frequency analysis (Bekkering *et al.* 1958; Storm van Leeuwen and Bekkering 1958).

2. Auto- and cross-correlation (Brazier and Casby 1952; Barlow *et al.* 1959).

3. Topographic analysis (Petsche and Marko 1955).

METHODS

The investigations have been carried out in fifteen subjects from whom alpha rhythms could be recorded. In one of these subjects all three forms of analysis have been carried out. The electrodes were conventional silver–silver chloride discs, stuck on the skin with collodion. The electrode positions in the various investigations are indicated in the diagrams. Sixteen channel EEG instruments constructed by Van Gogh, Grass and Offner, have been used. In all investigations 0.3 sec time constants have been used. The subjects reclined in a comfortable chair or couch in a dimly lit room. Care was taken to prevent the subjects from sleeping during the recording.

In the investigations with auto- and cross-correlation analysis a 7-channel Ampex tape recorder has been used. In the other investigations the data were tape recorded with the 8-channel EEG magnetograph (Bekkering *et al.* 1957, 1958).

RESULTS

The results obtained with the continuous frequency analyser have been described by Bekkering *et al.* (1957). They may be summarised briefly as follows. In different areas of the scalp alpha rhythms may be recorded the frequencies fluctuate around a main frequency. In some areas these frequency fluctuations occur simultaneously, the frequency distribution in time being similar. In other areas the frequencies of the alpha rhythms fluctuate differently, although the dominant frequency may be the same (Fig. 1). On the basis of these data, areas where alpha rhythms show an identical frequency distribution in time have been distinguished from areas where the frequency distribution in time is different. In some of the subjects three areas on each side of the head were found, in others four areas were distinguishable.

It has been possible to carry out auto- and cross-correlation studies of the different alpha rhythm producing areas, thanks to the aid of Dr. Brazier and her collaborators (Massachusetts General Hospital, Boston, Mass.) and Professor Rosenblith and his collaborators (Massachusetts Institute of Technology, Cambridge, Mass.). The results have been described briefly by Storm van Leeuwen (1961). They can be summarised as follows.

In each of the subjects considerable auto-correlation of the alpha rhythms was observed. This is in agreement with many previous investigations by Brazier and Casby (1952), Brazier and Barlow (1956) and Barlow *et al.* (1959). Moreover, marked cross-correlation of alpha rhythms occurring in various areas was encountered, even in those areas differing in the frequency distribution in

[1] Report on: The analysis and display of EEG information.

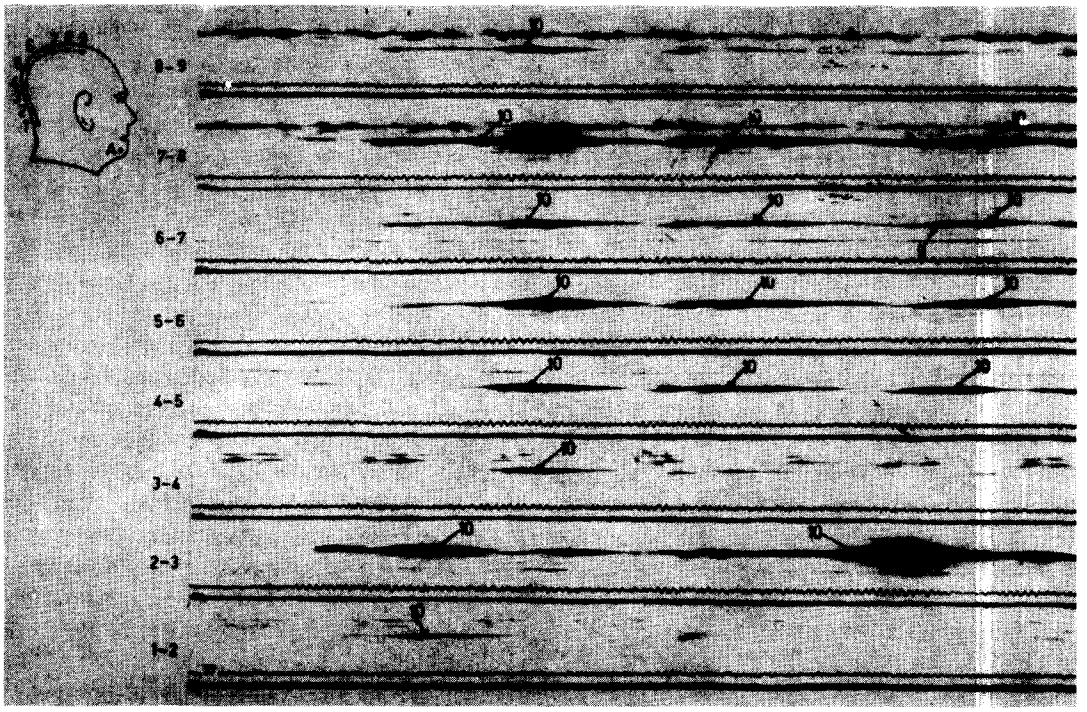

Fig. 1
Continuous frequency analysis of alpha rhythms occurring in eight areas. Leads are indicated in diagram (bipolar linkage). In various places the frequency 10 (c/sec) is marked. Note that the frequency distributions in the areas covered by electrodes 4–9 are similar. The frequency distributions in the areas covered by electrodes 1–3 are also similar but different from the previous.

time, as shown with continuous frequency analysis.

In a series of bipolar leads 2 cm parallel to the midline and in a series of leads in an occipito-temporal direction 2 cm above the ear, gradual phase shifts are observed (Fig. 2). These phase shifts seem to indicate that, averaged over $2\frac{1}{2}$ min, a fronto-occipital "sweep" of alpha waves takes place. This finding is in accordance with observations by Cooper and Mundy Castle (1960) obtained with the use of a spiral-scan toposcope, with observations by Petsche and Marko (1955) with the multivibrator toposcope, and with early observations by Darrow *et al.* (1955), obtained without automatic analysis. The cross-correlation data indicate that the area over which the phase shift takes place differs from one subject to another. In some subjects the phase shift occurs in the occipito-parietal region, in others in the posterior part of the occipital area. A phase shift was noticeable in all subjects investigated.

We have been able to carry out topographic analysis of the alpha rhythms according to Petsche.

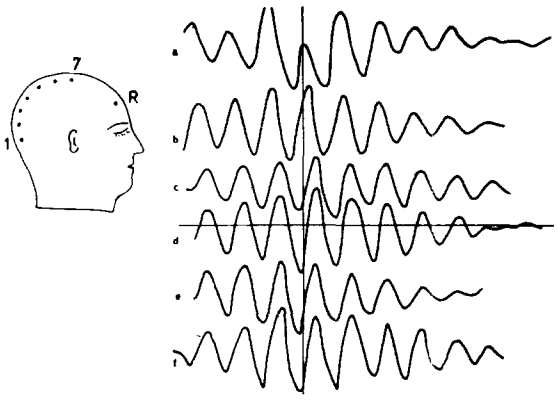

Fig. 2
Cross-correlation analysis of alpha rhythms in seven areas. Leads are indicated in diagram (common reference on forehead). Average of a $2\frac{1}{2}$ min period. Note gradual phase shift, the central areas leading over the occipital areas.

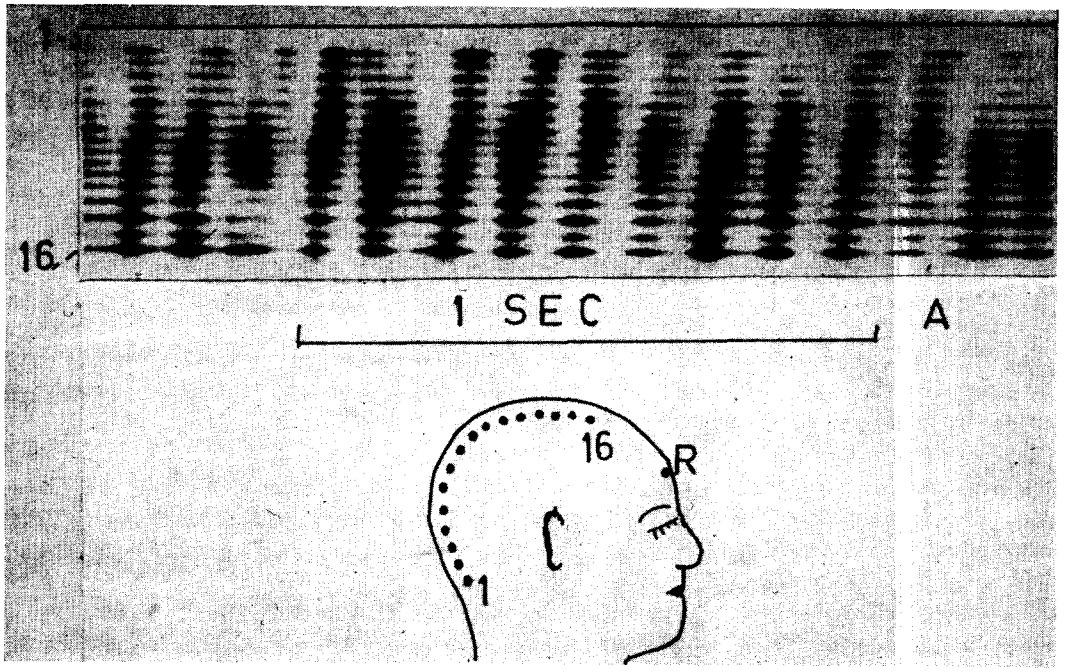

Fig. 3
Topographic analysis (Petsche) of alpha rhythms occurring in sixteen areas (same subject as in Fig. 2). Leads indicated in diagram (common reference on forehead). Note gradual phase shift in fronto–occipital direction in most, but not in all waves.

TABLE I

Comparison of the value which the three analysis methods and the primary EEG have for studying the different aspects of the alpha rhythms*

	Amplitude	Phase relations	Wave form	Frequency	Integration period
Continuous frequency analysis	poor	poor	poor	good	1 sec
Correlation analysis (Brazier *et al.*)	poor	good	good	good	2½ min
Topographic analysis (Petsche)	poor	good	poor	poor	none
Primary EEG	good	poor	good	poor	none

* In the last column the integration period is added.

A similar gradual shift of phase could be observed for each separate wave (Fig. 3), as was found with cross-correlation averaged over a period of 2½ min. However, the direction of the shift, though mainly fronto-occipital (in agreement with the cross-correlation data) is sometimes reversed, occipito-frontal, whereas on other occasions the waves appear simultaneously in all areas (Fig. 3, 5th wave from the left).

The observations with the three forms of analysis indicate the following:

1. Different areas on the scalp may be discerned where alpha rhythms occur with frequency distributions which are not always identical (continuous frequency analysis).

2. These areas nevertheless show considerable cross-correlation when averaged over a period of 2½ min. This suggests "loose coupling" between these areas, as described by Wiener (1958) (correlation analysis).

3. "Sweeping" of alpha waves appears to occur over the scalp in a mainly fronto-occipital

direction (correlation analysis), but sometimes in the opposite direction (topographic analysis).

4. The "sweeping" often occurs synchronously and in the same direction on both sides of the head.

5. Some alpha waves appear to occur, without "sweeping", simultaneously in all areas on both sides of the head, where alpha waves can be detected (topographic analysis).

These conclusions demonstrate how information which is rejected by one form of analysis is selected by another method. As shown in Table I, one of the differences of the three analysis methods used in this investigation is the value of the integration period. With the correlator the integration period is $2\frac{1}{2}$ min; the cross-correlation data reveal rhythmic phenomena occurring synchronously—possibly with phase differences—averaged over this period. With continuous frequency analysis changes occurring in the order of 1 sec can be detected. (The build-up and die-away characteristics of the filters, although not the same as in auto- and cross-correlation, can be regarded as an integrating time.) In the topographic analysis no integration is applied; mutual relations of each separate wave occurring in different areas can be studied.

The above comparison indicates that the combination of data obtained with various forms of analysis may yield an insight into the phenomena under investigation beyond simple addition or, in other words, that different forms of analysis may be complementary.

SUMMARY

The spread of alpha waves over the scalp in normal subjects has been investigated with three forms of analysis: 1. continuous frequency analysis; 2. auto- and cross-correlation analysis; 3. topographic analysis.

The data obtained with these analyses indicate that different alpha rhythms may be discerned in different areas, that the alpha rhythm-producing structures are probably loosely coupled, and that alpha waves appear to "sweep", usually in a fronto-occipital direction.

The analysis data are shown to be complementary.

REFERENCES

BARLOW, J. S., BRAZIER, M. A. B. and ROSENBLITH, W. A. The application of autocorrelation analysis to electroencephalography. *Proc. 1st nat. Biophysics Conf., 1957.* Yale University Press, New Haven, **1959**: 622–626.

BEKKERING, D. H., KAMP, A. and STORM VAN LEEUWEN, W. The EEG spectrograph. *Electroenceph. clin. Neurophysiol.*, **1958,** *10*: 555–559.

BEKKERING, D. H., KUIPER, J. and STORM VAN LEEUWEN, W. Origin and spread of alpha rhythms. *Acta physiol. pharmacol. neerl.*, **1957,** *6*: 632–640.

BRAZIER, M. A. B. and BARLOW, J. S. Some applications of correlation analysis to clinical problems in electroencephalography. *Electroenceph. clin. Neurophysiol.*, **1956,** *8*: 325–331.

BRAZIER, M. A. B. and CASBY, J. U. Cross-correlation and auto-correlation studies of electroencephalographic potentials. *Electroenceph. clin. Neurophysiol.*, **1952,** *4*: 201–211.

COOPER, R. and MUNDY CASTLE, A. C. Spatial and temporal characteristics of the alpha rhythm: A toposcopic analysis. *Electroenceph. clin. Neurophysiol.*, **1960,** *12*: 153–165.

DARROW, C. W., WILCOTT, R. C., SIEGEL A. and STROUP M. Instrumental evaluation of anterior–posterior EEG phase relationships. *Electroenceph. clin. Neurophysiol.*, **1955,** *7*: 472–473.

PETSCHE, H. und MARKO, A. Ueber die Ausbreitung der Makrorhythmen am Gehirn des Menschen und des Kaninchens auf Grund toposkopischer Untersuchungen. *Arch. Psychiat. Nervenkr.*, **1955,** *193*: 177–198.

STORM VAN LEEUWEN, W. Comparison of EEG data obtained with frequency analysis and with correlation methods. In: M. A. B. BRAZIER (Editor), *Computer techniques in EEG analysis. Electroenceph. clin. Neurophysiol.*, **1961,** *Suppl. 20*: 37–40.

STORM VAN LEEUWEN W. and BEKKERING, D. H. Some results obtained with the EEG spectrograph. *Electroenceph. clin. Neurophysiol.*, **1958,** *10*: 563–570.

WIENER, N. *Non-linear problems in random theory.* John Wiley, New York, **1958,** 131 p.

Reference: STORM VAN LEEUWEN, W. Complementarity of different analysis methods. *Electroenceph. clin. Neurophysiol.*, **1964,** *16*: 136–139.