

REPRESENTATION OF SPATIAL PATTERNS IN THE ELECTRICAL ACTIVITY GENERATED BY THE BRAIN

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ABSTRACT

The Karhunen-Loeve transformation is used for the representation of spatial patterns present in the EEG. Three eigenimages are shown to be sufficient to represent more than 92% of the variance in a 2.5 s segment of both a normal and an abnormal EEG. These images, interpolated to form topographic maps, reveal what appear to be important fundamental patterns in the EEG. These patterns may be reflective of independent generators within the brain. The results suggest that the method may be extremely valuable for the reduction of the data collected during electroencephalography.

Keywords: Karhunen-Loeve transform, electroencephalography, topographic mapping, pattern representation, data compression.

INTRODUCTION

The electrical activity of the human brain can be recorded using electrodes attached to the scalp. Known as the electroencephalogram or EEG, these recordings have been used extensively to study both the normal and the abnormal functioning of the brain. Specialization of the regions of the normal brain for performing various cognitive functions has, for example, been observed through lateralized variations in the EEG. Changes in the patterning of the EEG have been correlated with mental disease and with drug induced states. The locations of tumors and epileptic foci have also been determined from recordings of the EEG (1-3).

An emerging method for the presentation of the EEG is topographic mapping (4). This method involves the interpolation of the potentials recorded at discrete sites on the scalp to form surfaces which are then displayed as color coded maps on a television monitor. These maps serve to assimilate the spatially dependent potentials from the various regions of the scalp and enable the overall character of the EEG to be more easily visualized. From these maps, potential asymmetries reflecting cognitive activity or potential spikes indicating the location of an epileptic focus can be discerned.

One difficulty in the topographic mapping of the EEG is the representation of the temporal variations present. Brain potentials from

the normal brain contain variational components extending up to perhaps 30 cps and epileptiform potentials can contain components to near 100 cps. Therefore, topographic maps which represent the potential distribution over the scalp at discrete instants in time change very rapidly and individually may seem to lack any definite character. Solutions to this problem have been to cartoon the maps or to display several maps at once in a sequence to represent the temporal variations. Neither of these approaches have been entirely satisfactory since the extraction of patterns which include the temporal variations must still be done by the observer.

The approach which we have adopted to the solution of this problem is the Karhunen-Loeve transformation (KLT) (5). This transformation allows the spatial and temporal patterns in the EEG to be represented by a parsimonious set of eigenimages. An arbitrary interval of time can be represented with these eigenimages and a measure of the significance of each obtained from the associated eigenvalue. In addition and probably most importantly, eigenimages relate directly to some persistent spatial patterning of the EEG.

METHODS

The EEG was recorded using the 31 electrode shown array in Fig. 1. A left-ear reference was used for the recordings. To facilitate the interpolation method, 4 additional points, X_1 , X_2 , X_3 and X_4 were assumed to exist at the corners of this array to complete a 5×7 grid. Samples of the potential variations at each of the 31 electrodes were obtained at the rate of 120 per second using a 12 bit analog-to-digital converter. Potentials at the corner points were computed at each sampling instant by linearly interpolating the potential values from the nearest 3 electrodes. Interpolation of interelectrode potentials for topographic mapping was obtained using the method of bicubic splines (6). The boundary condition used for the splines was the so-called clamped slope and a value for this was estimated from the potential at each boundary and nearest interior electrodes.

The KLT of the EEG was obtained by representing the array of samples (a potential image) from the scalp electrodes at each instant

in time as a vector $p_i = (p_{i,1}, p_{i,2} \dots p_{i,N})^t$ where $N = 31$ the number of electrodes in the array, i is the instant in time and t is the transpose operator. The data to be transformed was represented by the potential matrix P of dimension $N \times T$ where T is the number of samples collected from each of the 31 electrodes. The eigenvectors (eigenimages) of P in the KLT are the columns of the $N \times N$ matrix B in the equation

$$P = B K$$

where K is an $N \times T$ coefficient matrix. B is computed from the autocorrelation matrix R where

$$R = 1/T P P^t.$$

A matrix of eigenvectors U can be found such that

$$R = U \lambda U^t$$

where λ is a diagonal matrix of corresponding eigenvalues. If the eigenvalues are arranged in descending order the correspondingly reordered eigenvectors in U form the eigenvector matrix B .

When properly normalized, the eigenimages which form the columns of B define an orthonormal space. A property of this space is that when the original matrix P is reconstructed using only the first m eigenimages and associated coefficients, the mean squared error is the minimum possible for any N dimensional space. Furthermore, the corresponding eigenvalues represent the proportion of the variance in the original data contributed by the first m eigenimages. Therefore, the mean squared error in the reconstruction is the sum of the corresponding eigenvalues of the $N-m$ unused eigenimages. If this error is small, m can be viewed as the intrinsic dimension of P and the unused images as noise. In this work eigenimages are considered as feature images which represent some persistent pattern in the EEG over the time interval considered.

Eigenmaps were computed from the eigenimages B by first calculating values for the corner points and then interpolating to determine the interelectrode values.

RESULTS

Figures 2 and 3 show topographic maps corresponding to 9 instants in time in each of 2 recordings of the EEG. The EEG in Fig. 2 is from a normal individual and is dominated in the posterior regions of the scalp by the alpha rhythm (8-13 cps). Before mapping, this rhythm was extracted from the EEG by bandpass filtering. The interval from which the maps were constructed is high-lighted in red on the tracings and is about one half the alpha period. The maps indicate that the alpha rhythm tends to be focussed in the left posterior region although the maps in the center row seem to indicate a second focus in the right posterior region as well. Maps in the bottom row of Fig. 2 are approximately reversed from those in

the top row confirming that a half period of the rhythm has been mapped.

Figure 3 shows topographic maps of abnormal delta (1-4 cps) activity in a second EEG. The maps were constructed at points equally spaced in the high-lighted interval using only filtered delta activity. They indicate a more variable patterning of this activity with perhaps a tendency for it to be strongest in the frontal regions.

Figures 4 and 5 show topographic maps corresponding to the first 9 eigenimages resulting from the KLT of the entire EEG shown on each left panel (2.5 s). In both cases the first 3 eigenimages can account for more than 92% on the variance seen in the respective EEG. For this analysis, the EEG was not filtered into any particular band so that individual maps do not necessarily represent the patterning of a single rhythm.

For the normal EEG, Fig. 4 indicates that the first eigenimage, which can account for about 65% of the variance, contains a focus of activity in the left posterior region. The activity level is negative over the entire scalp suggesting a synchronized component of activity over the entire scalp. The magnitude of this activity decreases with distance from the focus.

The second eigenimage in Fig. 4, which can account for about 24% of the variance in the EEG, indicates a component with focus in the right posterior region. This component, however, is reversed over the frontal region. The third eigenimage in Fig. 4, which accounts for only 3% of the variance in the EEG indicates a second focus in the right posterior region but one which tends to reverse in the left frontal region.

For the abnormal EEG, Figure 5 indicates that, the first eigenimage, which can account for about 56% of the variance in the interval shown, contains a focus which extends over a large portion of the right frontal region. The activity level is negative everywhere suggesting a synchronized component over the entire scalp. The magnitude of this activity is smallest at the site of the reference electrode.

The second eigenimage in Fig. 5, which can account for about 31% of the variance in the EEG indicates a focus in the mid-frontal region. This component is reversed and more diffuse over the posterior region. The third eigenimage in Fig. 5 which accounts for about 6% of the variance in the EEG suggests a focus in the right central region.

DISCUSSION

Application of the KLT to a 2.5 s interval of both a normal and an abnormal EEG has shown that a large proportion (more than 92%) of the variance present can be produced by a weighted sum of only 3 eigenimages. This is in contrast to possibly 300 topographic maps which could be constructed from the sample points in the interval. Therefore, through the KLT, a large reduction in the volume of data has been possible without a significant loss in information content. The eigenimages, interpolated to form

topographic maps, reveal what seem to be the foci for the dominant rhythm in each EEG. These foci may well be indicative of independent generators operating within the brain.

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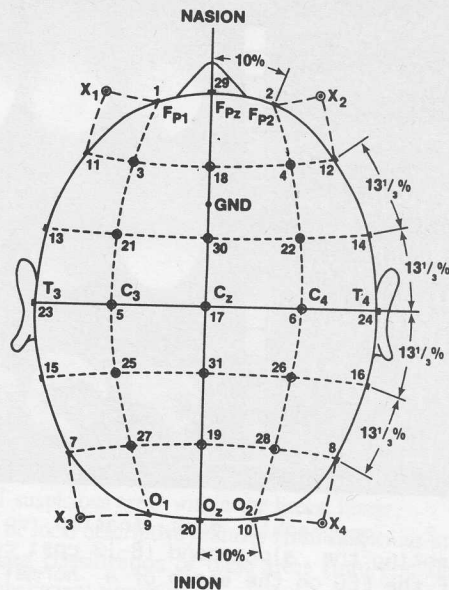


Figure 1. The location of 31 electrodes used to record the EEG. An additional electrode placed on the left ear was used as the reference. The locations FP1, FP2, T3, C3, Cz, C4, T4, O1 and O2 are those specified by the International 10-20 Standard. The non-scalp points X1, X2, X3 and X4 were used to complete a 5 x 7 recording grid.

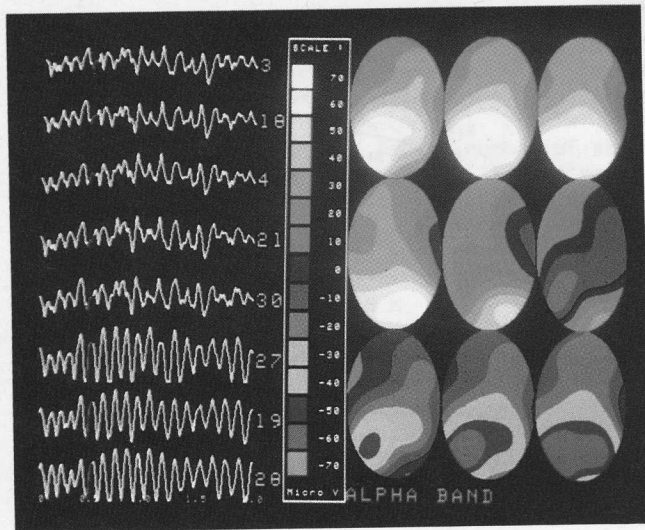


Figure 2. Topographic maps (nasion up) representing the alpha-band (8-13 cps) component of the EEG on the scalp of a normal subject at 9 discrete instants in time in a 75 ms interval. The interval mapped is shown high-lighted in red on the EEG traces to the left of the maps. The traces themselves are 2.5 s in duration. The numbers to the right of the traces correspond to the electrode positions given in Fig. 1. The maps are in sequence from top left to bottom right.

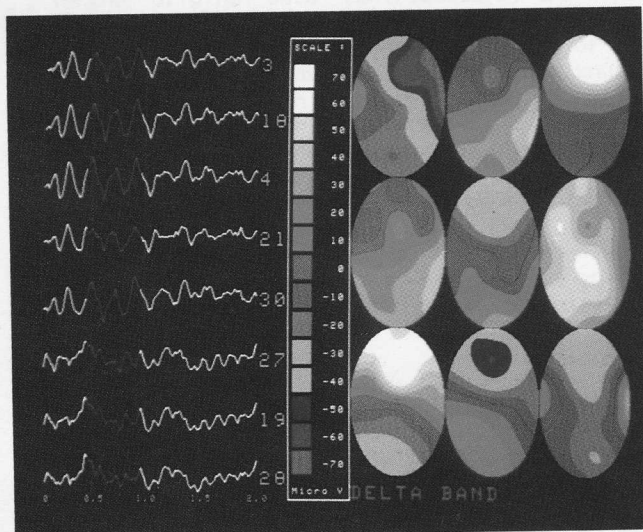


Figure 3. Topographic maps representing the delta band (1-4 cps) component of the EEG on the scalp of a neurologic patient at 9 discrete instants in time in a 500 ms interval. The interval mapped is shown high-lighted in red on the EEG traces. The colors blue to white represent positive excursions of the potential at each site with respect to the reference while the colors green to red represent negative excursions.

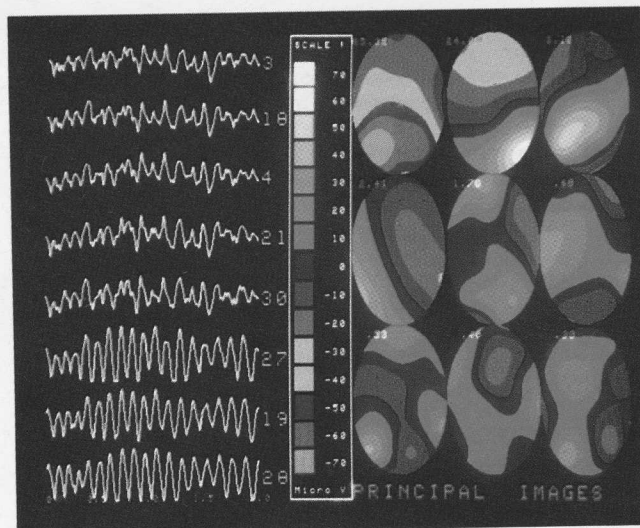


Figure 4. Topographic maps derived from the first 9 eigenimages resulting from the Karhunen-Loeve transformation of a 2.5 s interval of a normal EEG. 8 of the 31 traces involved in this transformation are shown on the left. The numbers to the right of the traces correspond to the electrode positions given in Fig. 1. The eigenmaps are in sequence from left to right and top to bottom and represent respectively 65.3%, 24.1%, 3.1%, 2.4%, 1.7%, 0.7%, 0.5%, 0.5% and 0.3% of the variance in the EEG over the interval.

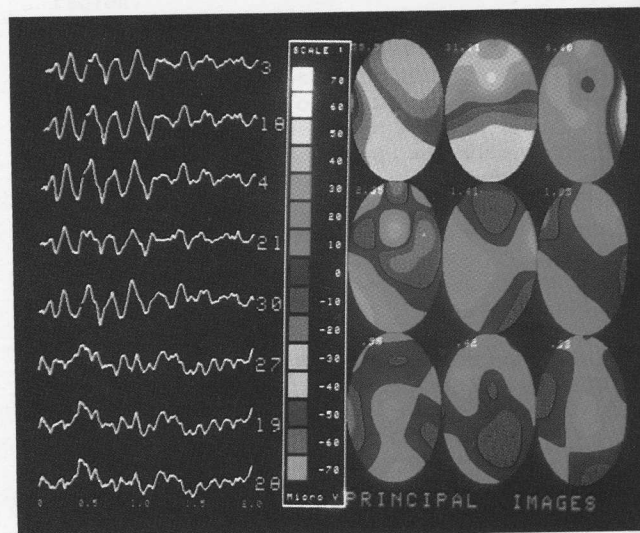


Figure 5. Topographic maps derived from the first 9 eigenimages resulting from the Karhunen-Loeve transformation of a 2.5 s interval of an abnormal EEG. 8 of the 31 traces involved in this transformation are shown on the left. The eigenmaps are in sequence from left to right and top to bottom and represent respectively 55.5%, 31.1%, 6.4%, 2.4%, 1.4%, 1.1%, 0.6%, 0.4% and 0.3% of the variance in the EEG over the interval.