ACTA NEUROBIOLOGIAE EXPERIMENTALIS

Acta Neurobiol. Exp. 1995, 55: 307-315

PC based EEG mapping system

Piotr Walerjan and **Remigiusz Tarnecki**

Department of Neurophysiology, Nencki Institute of Experimental Biology, 3 Pasteur St., 02-093 Warsaw, Poland,
email: piotrwa@nencki.gov.pl.

Technical communication

Abstract. A PC based program has been designed for analysis of EEG data using brain electrical activity mapping technique. It operates under control of MS-DOS operating system and can be used as a stand alone program or incorporated into a digital EEG system. The program can apply different map interpolation algorithms from nearest neighbours methods to spherical spline functions. It performs analyses in the time and frequency domain. It applies different mapping parameters like amplitude, spectral values and a new one - first time derivative of amplitude. The program is being successfully used in clinical tests of epilepsy and Parkinson disease in our laboratory.

Key words: EEG mapping, signal processing, digital EEG, epilepsy

Raw EEG traces belong to those bioelectrical signals the interpretation of which is difficult, especially as far as spatiotemporal relations are concerned. Some problems related to visual EEG inspection and interpretation have been significantly reduced owing to the brain electrical activity mapping technique introduced by Duffy (Duffy 1986). However, there are certain new problems specific to this modern technique, such as choice of parameters used for generation of maps or evaluation of a standard population map.

Computer analysis of EEG data has also other advantages. Registration of a digitally sampled signal may yield a very high time resolution, which cannot be obtained in standard analog paper recordings. It also allows after acquisition recalculations such as new reference electrodes or computation of new parameters (e.g., spectral values). Finally, the storage of digital data is more convenient, requires less room and gives better and faster access to the data stored. To make use of all the advantages of the digital analysis of EEG we have put into service a new PC based system that collects and stores EEG data. The software of the system produces analysis of data and maps in time and frequency domains.

Data acquisition procedures are important for performance of the system because they determine parameters of the sampled data which cannot be changed later on. To acquire the data we use a 16 channel EEG machine connected to an additional separating unit. This unit is linked to an analog to digital converter (ADC) card inside an IBM PC 386 compatible computer. The converter has Sample & Hold amplifiers on each of its 16 channels to ensure that no time shift occurs. It has a maximum sampling frequency of 10 kHz with 12 bit accuracy. Our standard acquisition procedure works with a 128 Hz sampling frequency, but if we find fast components in the signal (e.g., spike and wave complex) we can switch to 1024 Hz. The EEG data are transmitted to computer through DMA (Direct Memory Access) channels and displayed and stored on a hard disk drive. The length of the EEG sample is limited only by the capacity of the hard disk. The EEG is recorded from monopolar derivations. The reference electrode is usually linked ears.

Selection of the number of electrodes that is one of major problems, in our case was implied by the 16 channel EEG machine we have in our laboratory. All of the software we apply is independent on a number of electrodes (provided that sensible values are used) and may be very easily modified to fit into any particular EEG unit. Also, the ADC card may be altered to support a greater number of channels.

The key idea of the mapping process is to calculate values at all possible points in a map based on the points whose values are known; these points are electrode sites and the values are measured during acquisition. There are a number of available methods owing to which interpolations can be made and maps produced. The question is, however which of them should be elected. Another problem related to map generation is selection of the geometrical projection that transforms the three dimensional skull surface into a two dimensional image. A correct solution to these two basic problems and placement of a sufficient number of electrodes, usually determined by the requirements of the available EEG unit, should result in generation of adequate and satisfactory maps.

The need for exact topographic projections results from the purpose of mapping itself. If only rough focal activity or changes in time are to be shown, maps can follow only mild aesthetic requirements. But if maps are expected to localize spectral foci (e.g., epileptic activity), then the projection applied should follow strictly anatomical criteria and lead to no distortion and misinterpretation. Transformations that preserve interelectrode arc distances minimize image distortions. The one that saves arc lengths between *Cz* and other electrodes (Desmedt and Bourguet 1985) is used by the program.

There is a very close connection between the problem of topographical projection of a 3D skull to a 2D image and the electrode placement system. As a standard, the program uses the international 10-20 system, but the operator can easily change the placement. The coordinates of electrodes can be entered in two or three dimensions. The shape of the

image can also be changed from circular to rectangular. Up to 8, defined by the operator, electrode configurations can be saved on the hard disk.

As mentioned above, the mapping process requires calculation of values on the whole map, that is among the electrodes. There are many available methods that solve this problem. All of them have certain advantages and disadvantages, that will be referred to later on.

Currently, the most popular interpolation methods are those using the nearest neighbours. They take into account values from electrodes nearest to the searched point (neighbours). The calculated value is proportional to the value and distance between the point and its neighbours. Let W(x,y) be the calculated value at point P(x,y), z_i be the measured value at the i^{th} electrode, q_i be the weighting coefficient and n denote the number of nearest neighbours entered into the computations. The value W is given by:

$$W(x,y) = \sum_{i=1}^{n} z_i * q_i \qquad (1)$$

There are lots of available options of these methods. They differ as to the number of nearest electrodes (the most popular are 3 and 4) and the degree of interpolation (the most popular are linear, quadratic and cubic interpolation). These methods as a whole are computationally fast and efficient. The weighting coefficients depend on map geometry only and thus they can be computed and stored before map calculations are made. Moreover application of integer arithmetic gives a resolution which is good enough and it yields very fast computations without using a floating point processor. The main disadvantage of the method is the localization of extremes (minimum and maximum) on the electrode site always. This makes the results of the interpolation slightly unreliable. Figure 1A presents the EEG data interpolated with the 4 nearest neighbours quadratic method.

Currently, there is a new family of algorithms available delivering good, reliable results, and locating the extremes independently of electrode sites. All of these algorithms use spline functions as a basis. The first one applies thin plate spline functions (Harder and Desmarais 1972, Perrin et al. 1987). Let W(x,y) be the calculated value at the point P(x,y), z_i be the measured value at the i^{th} electrode, i=1..n. The spline formula is:

$$W(x,y) = \sum_{i=1}^{n} p_i * k_{m-1}(x-x_i, y-y_i) + q_{m-1}(x,y) \qquad (2)$$

The method presented above requires floating point arithmetic and that is why it may be significantly slower then the nearest neighbours method. Except for this disadvantage, the method provides very good pictures. The extremes are not combined with electrode sites, which makes the method reliable.

Another algorithm of the same family applies spherical spline functions (Wahba 1981, Wahba 1982, Perrin et al.1989). Using the above notation and assuming S to be a spherical projection of P(x,y) and E_i to be a spherical location of i^{th} electrode, the m^{th} degree spherical spline formula is of the following type:

$$W(x,y) = c_o + \sum_{i=1}^{n} c_i * g(\cos(S,E_i)) \qquad (3)$$

This method gives slightly better results then the previous ones, especially when the number of electrodes is small, i.e. when spatial undersampling occurs. Figure 1B shows the same data as the previous figure, however interpolated with the spherical spline function method.

To make the calculations faster it is possible to compute values of some constant arrays first. For the thin plate spline method one can create array of function $k_m()$, because it depends on the electrode location only. For the spherical spline functions the only constant array is that of the g(x) coefficients, because it depends on the the degree of spline function only and can be calculated for values between -1 and 1.

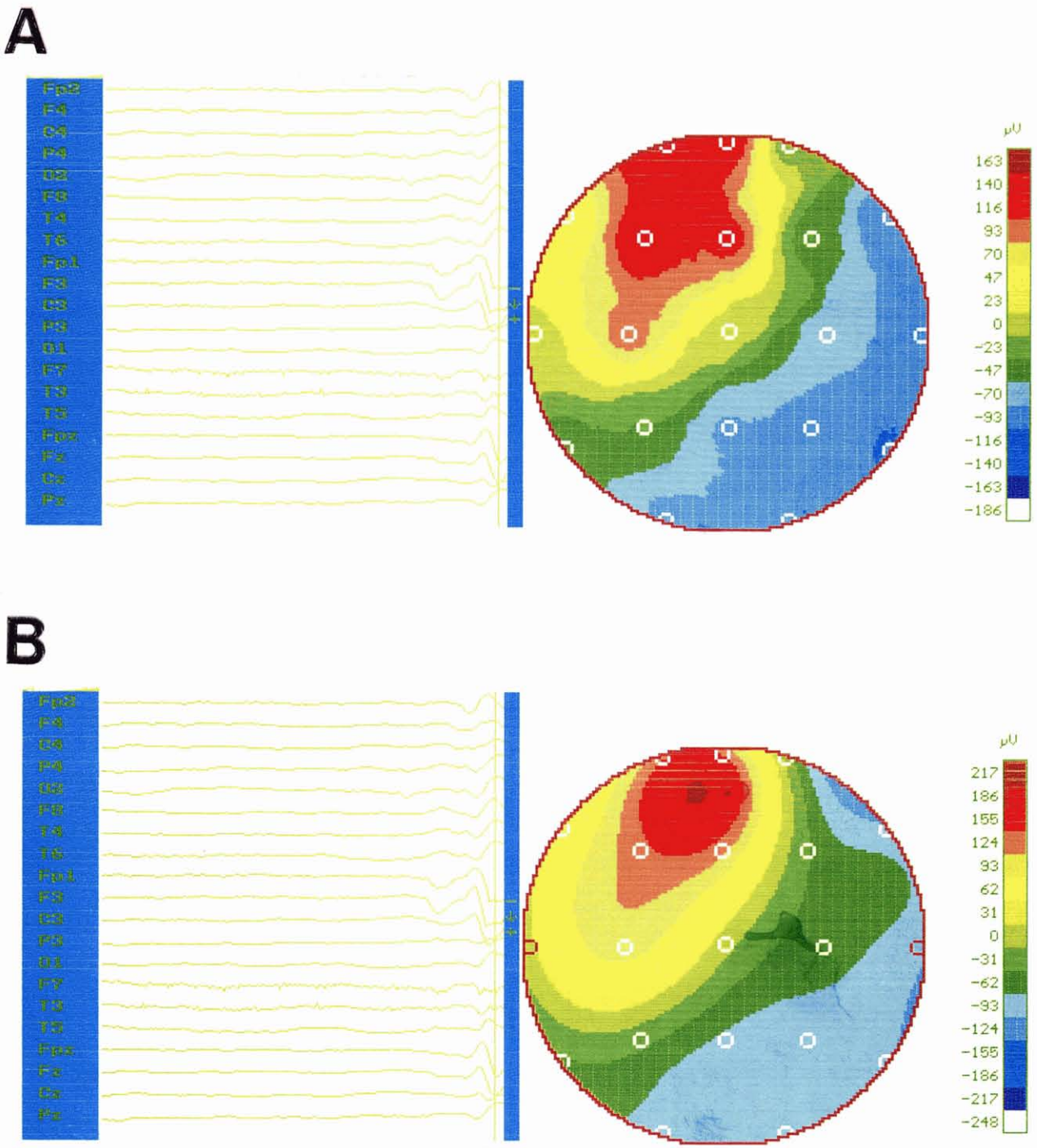

Fig. 1. A, the EEG data interpolated with 4 nearest neighbours quadratic method. The positive extremum is localized under Fp1 electrode. B, the same data interpolated with the spherical spline function method. The positive extremum is now localized among Fp1, Fpz, F3 and Fz electrodes.

We have tested and compared maps illustrating the same sets of data, calculated using different interpolation algorithms, including the ones mentioned above and the other options with various number of neighbours, coefficients and degrees. Subsequent to the testing process we have found that the methods using spline functions have always resulted in better and more reliable results then those of nearest neighbours, no matter which coefficient and neighbours we applied. The differences in localization between the nearest neighbours and spline functions methods that can be observed on power maps are barely acceptable. The usage of nearest neighbours methods should be avoided when calculating maps of amplitude, because a precise physiological localization is required in this type of mapping. The nearest neighbours methods are also unacceptable during the animation of potential maps, because the sequences of images are inconsistent and their interpretation is impossible. On the contrary, maps calculated using spline functions give continuous images that can be animated and interpreted to result in a good analysis of propagation of discharges. According to our data and experience we believe, that nowadays, when powerful computers are available, the spline function methods are worth using and the time needed for calculations is not such a critical factor as three or four years ago.

There are lots of various parameters that are used to generate maps. At present, the most popular are the amplitude, the spectral values such as amplitude, power and coherence or other parameters that have no connection with physical values e.g. significant probability (Duffy et al. 1981). The program applies two standard parameters, including amplitude and spectral amplitude, and one new parameter, that is, the first time derivative of amplitude.

The new parameter related to the time domain analysis is the time derivative of amplitude (Walerjan et al. 1991). This quantity is proportional to the velocity of signal changes or its slope. The largest values of the time derivative follow spike discharges. The smaller ones follow sharp waves and the smallest result from slow waves. Based on the well known fact that human skull acts like a low pass filter we suppose that the maximum time derivative values are located close to the epileptic foci when analyzing spikes or sharp discharges.

The value of the time derivative is calculated according to the Stirling interpolating equation:

$$[df/dx]_{x=x_o} = \frac{1}{h}\left[\frac{df_o + df_{-1}}{2} - \frac{1}{6} * \frac{d^3f_{-1} + d^3f_{-2}}{2} + \ldots\right] \quad (4)$$

where

$$h = x_{i+1} - x_i \quad (5)$$

$$df_i = df(x_i) = f(x_i + h) - f(x_i) \quad (6)$$

$$d^2f_i = d^2f(x_i) = df_{i+1} - df_i \quad (7)$$

and so on.

We make an attempt to localize the foci using this new technique. Our results show that there is a good correlation among maps, the time derivative and the current source density (CSD) maps. In some cases, the diagnosis was also confirmed by neuroimaging techniques.

Figure 2A shows EEG containing spike and wave complex, Fig. 2B presents maps of amplitude of the spike. Figure 3 shows first time derivative of amplitude and CSD maps of the same fragment of EEG containing an epileptic spike.

We use mainly analysis of propagation of potentials in our study. As an additional tool we check the results of propagation analysis using the time derivative of amplitude and CSD maps. We think that potential maps are the best for analysis of discharge evolution from noninvasive records on the surface of the head. However, in case of generalized spikes it is good to verify the results of potentials mapping, that may be unclear, using the time derivative algorithm, which reduces slow waves and eye movement artifacts and makes better visible and more focal rapid changes. Nevertheless how fast the EEG is changing it is always good to try making CSD analysis. However, we found that CSD mapping

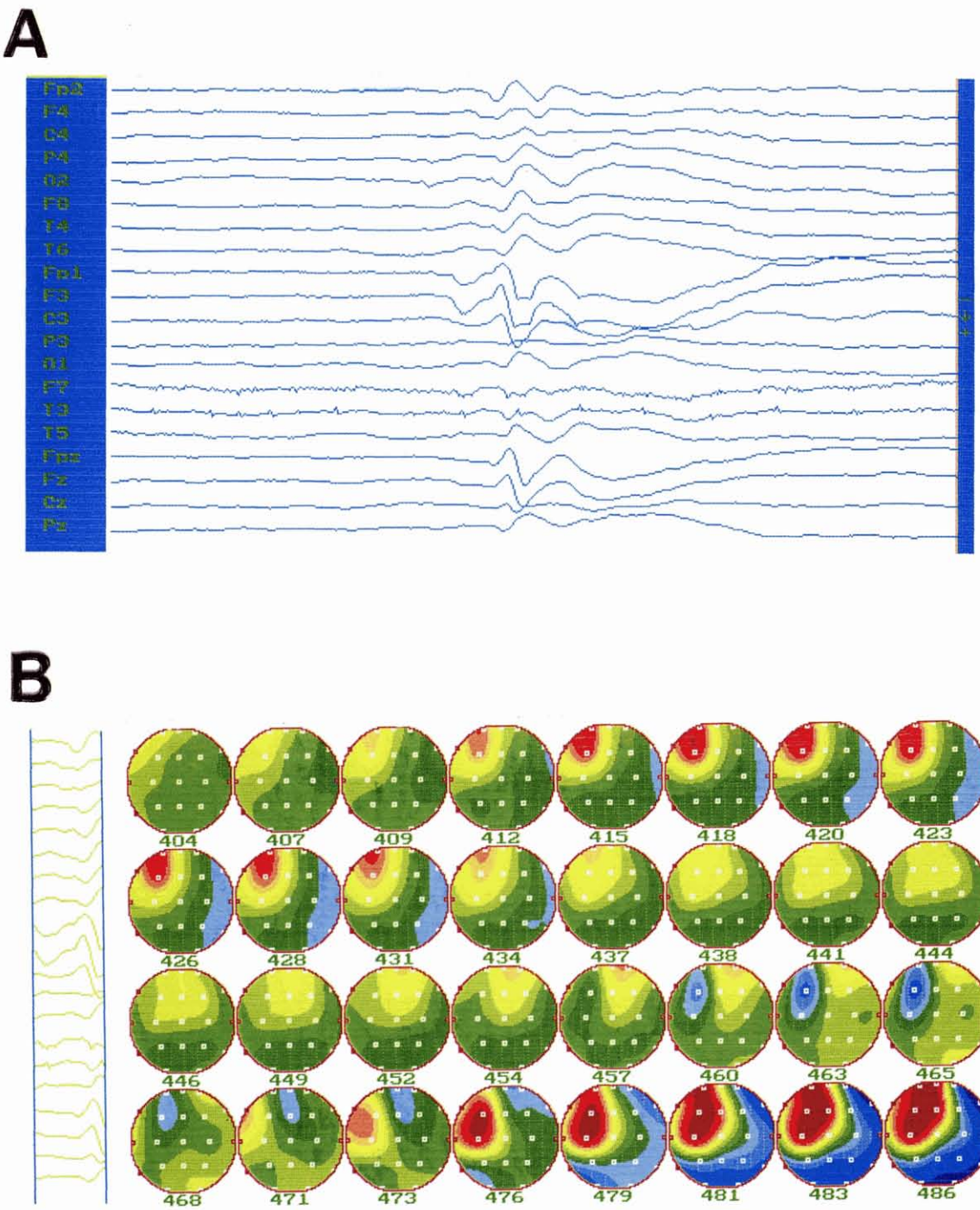

Fig. 2. A, the EEG containing spike and wave complex. B, maps of amplitude of the spike. The markers are set at 404 ms (left) and 486 ms (right) from the beginning of the segment.

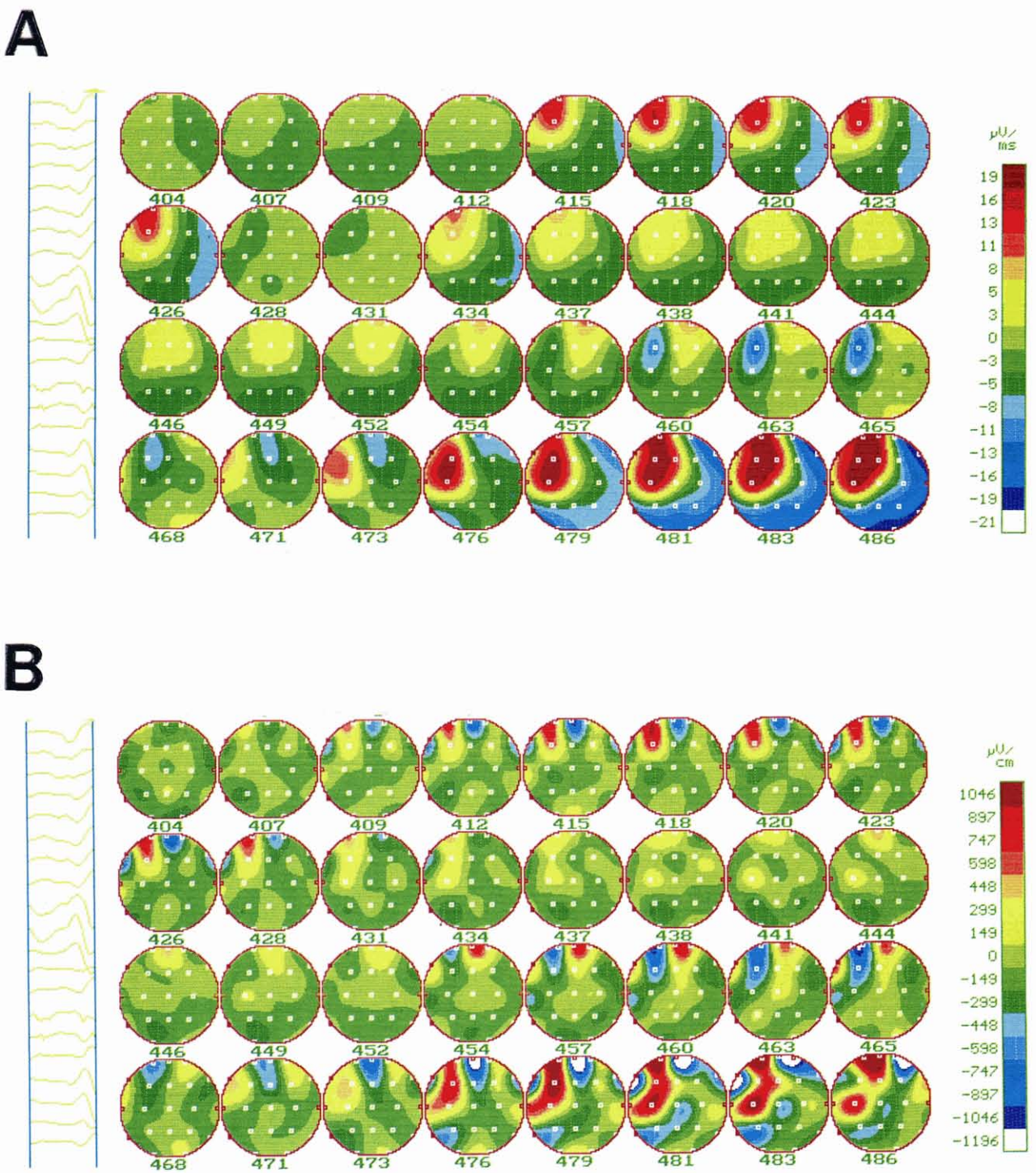

Fig. 3. A, first time derivative of amplitude maps of the same EEG containing epileptic spike. B, CSD maps of the same fragment of EEG with epileptic spike.

that is very good for analysis of cortical sources, gives poor results when applied for propagation analysis and image animation due to its properties, that discard far potential fields and enhance cortical generator.

The mapping program applies all of the modern brain electrical activity mapping technique. It can be used as a stand alone program or can be incorporated into a digital EEG system. The program is menu driven, and it implements dialog windows to get input from the user. A four second EEG segment is always displayed on the screen. Information concerning the patient and program options is also on the display.

The program allows for reference electrode recalculation. The EEG data that have been recorded using a common reference (e.g. linked ears) can be reconfigured to the average reference. The EEG data file can be cut off to eliminate artifacts. Any epoch can also be written to the disk to save only selected interesting events and discharges. The amplitude of the signal can be measured with a marker and displayed. The program can also apply high and low pass digital filters. The user can set some standard typical for EEG apparatus frequencies and time constants or define his own values. There is an electrode overlay editor that can change positions of electrodes on the scalp or make a new overlay for a specific purpose. The user can also select one of the interpolation algorithms described above.

There are two types of analyses that can be used: one in the time and one in the frequency domain. In the time domain, it is possible to make maps of amplitude, the first time derivative of amplitude and current source density. In the frequency domain, the program draws standard power maps of four basic rhythms: delta, theta, alpha and beta as well as maps of any user selected frequency range. It can also display power spectra of any electrode signal.

The time domain analysis allows a user to make an amplitude and time derivative map for the time position selected by the marker. As it is usually not sufficient to observe one map only, the program can make 4, 9, 16 or 32 maps of the EEG epoch selected by two markers. The selected signal period is divided into equal intervals, with each of them described by a map. To enhance the study of discharge propagation, the maps can be animated. The speed of animation is set by the user.

The frequency domain analysis allows a user to divide the EEG into spectral components. The spectrum is calculated using the Fast Fourier Transform (FFT) algorithm. The constant part of the signal is cut off before FFT. The signal is also smoothed using a Hanning window in the time domain. The program applies different display modes. It can scale maps in absolute values in $\mu V/Hz$ or in terms of the percent of the maximal value to make better comparisons. The user can also display any selected spectra, and make maps of spectral ranges selected by two markers.

The program can provide both a short and a long period spectral analyses. A short period analysis means the power spectra calculated for the current segment or a part of it, selected by markers. A long period study means the computation of power spectra for the whole data file or for the list of selected segments and then averaging over the spectra.

The maps are calculated using the above mentioned algorithms. These are the nearest neighbours methods for three and four electrodes with linear and quadratic interpolation among them, the second and third degree thin plate spline functions methods and the fourth degree spherical spline functions method.

The program has been written using Turbo Pascal compiler. There are some big subroutines, that are critical for the processing time written in Turbo Assembler. The program is rather fast now, i.e. on 486DX 50 MHz machine it takes 1 s to calculate 32 amplitude maps using the four nearest neighbours method with a quadratic interpolation and 4 s to calculate 16 maps of amplitude using thin plate spline function method. The computation of FFT for 4 s epoch takes about 1 s.

The program is now being used to study parkinsonian and epileptic patients. Our experience shows that it is best to use spectral analysis for Parkinsonians. Especially the possibility to present and compare spectra enables reliable analysis of Parkinsonian

patterns of EEG. The analyses in time and frequency domain are useful for epileptic EEG. As the maps of power spectrum give results that might be obvious in some cases, the time domain analysis may lead to some important conclusion concerning epileptic focus localization. The possibility to make map cartooning and the analysis of the time derivative is of a great importance for analysing the discharges and their propagation. If the propagation is similar while analysing many fast transients, like spikes, the epileptic focus may likely be found, but these findings should always be compared with other clinical data.

This work was partially supported by KBN grant PB/374/P2/03.

Desmedt J.E., Bourguet M. (1985) Color imaging of parietal and frontal somatosensory potential fields evoked by stimulation of median or posterior tibial nerve in man. Electroencephalogr. Clin. Neurophysiol. 62: 1-17.

Duffy F.H., Bartels P.H., Burchfield J.L. (1981) Significant probability mapping: an aid in the topographic analysis of brain electrical activity. Electroencephalogr. Clin. Neurophysiol. 51: 455-462.

Duffy F.H. (ed.) (1986) Topographic mapping of brain electrical activity. Butterworths, Boston.

Harder R.L., Desmarais R.N. (1972) Interpolation using surface splines. J. Aircraft 9: 189-191.

Perrin F., Pernier J., Bertrand O., Giard M.H., Echallier J.E. (1987) Mapping of scalp potentials by surface spline interpolation. Electroencephalogr. Clin. Neurophysiol. 66: 75-81.

Perrin F., Pernier J., Bertrand O., Echallier J.E. (1989) Spherical splines for scalp potentials and current density mapping. Electroencephalogr. Clin. Neurophysiol. 72: 184-187.

Wahba G. (1981) Spline interpolation and smoothing on the sphere. SIAM J. Sci. Stat. Comput. 2: 5-16.

Wahba G. (1982) Erratum: spline interpolation and smoothing on the sphere. SIAM J. Sci. Stat. Comput. 3: 385-386.

Walerjan P., Purska-Rowińska E., Tarnecki R., Mempel E. (1991) New mapping program for PC computer. In: Knowledge, information and medical education (Eds J.H. van Bemmel and J. Zvárová). Elsvier Science Publishers B.V.(North-Holland) IMIA, p. 141-149.

Received 6 March 1995, accepted 16 October 1995