Microcomputer-based scalp topography mapping of event-related potentials

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A microcomputer-based technique to evaluate the scalp topography of event-related potentials is described. This technique uses only four electrode locations and produces a 24×24 element color matrix of the topography of scalp electrical activity across time. The program also displays the coordinates, latency, and value of the maximum point within the matrix. The program is implemented on an Apple II+/IIfx computer and is adaptable to other computers with graphic capabilities.

Topographical analysis of human EEG has been used for many years to provide investigators with information about the locus of cortical activity (Remond & Offner, 1952). Relatively recent advances by Duffy and colleagues (Duffy, Burchfiel, & Lombroso, 1979) have produced color brain electrical activity maps (BEAMs). These maps are useful in the detection of cortical impairments (Duffy, Bartels, & Burchfiel, 1981) and are used to map the spatiotemporal evolution of the P300 wave in schizophrenics and normals (Morstyn, Duffy, & McCarley, 1983). In this paper, I describe the implementation of a similar technique on a general-purpose microcomputer.

The event-related potential (ERP) scalp topography mapping program uses four data files produced by a microcomputer-based ERP data-collection system (Lorig, 1985). This data-collection system has been adapted to record activity from four electrode locations (F7, F8, T5, and T6; Jasper, 1958) during stimulus administration. Each data file contains 256 data points recorded every 4 msec from stimulus onset. After the files are read into the computer memory, the user specifies the temporal window to be displayed (in milliseconds), the time increment between successive displays, and the polarity of the ERP wave within the window. The program calculates an adjusted mean and standard deviation for the data points specified and divides a range of ± 3 standard deviations into 12 color divisions. After making these calculations, the program switches into the Apple's low-resolution graphics mode and displays a color index and an oval representing the subject's head viewed from the top with a triangle indicating the nose. A 24×24 point rectangular matrix is then established within the oval.

SCALP DISTRIBUTION MODEL

Calculation of each point within the matrix is based on several assumptions regarding the scalp recording of brain

potentials. It is assumed that isolated brain potentials will be recorded all over the scalp due to conduction properties of the tissue. Maximal potentials will, however, be found at the scalp location with least impedance to the generator source. This location is typically above the neural generator, except in cases of dipoles parallel to the scalp's surface (Towe, 1979). Thus, it is assumed that the scalp area with maximal potential is located closest to the source of the brain potential and that much of the voltage recorded at other scalp areas is attributable to conduction of the source potential with decrement due to impedance properties of the tissue. Although this is not a new or controversial assumption, it is important to this program since points within the matrix must be adjusted according to the decrement expected to occur a given distance from an electrode.

To establish a value for this decrement constant, it is necessary to observe a voltage that is the result of a localized generator. By knowing the distance and voltage loss between the electrode site and the generator, the decrement or space constant can be calculated. Because it is difficult to specify the exact source of a neural generator, a discrete nonneural source was used to obtain the decrement constant for this program. Eye-blink potentials were recorded at Fz and Pz and were compared to determine the voltage loss between electrodes 24 matrix elements apart. Since voltage loss is nonlinear and follows the inverse square law, the decrement constant was established by dividing the percent voltage loss (24%) by the square root of the distance (24 matrix elements).

Calculation of the matrix elements proceeds in several steps, which are outlined in Table 1. Initially, the length of the hypotenuse from the matrix element to each electrode (matrix corner) is determined. Since a generator located 24 elements from an electrode site would be expected to decrease by 24% before reaching the electrode, the value of the generator may be estimated by dividing the observed electrode value by one minus the expected voltage loss. This would produce an estimate of the value of a matrix element a given distance from an electrode. Because estimates of matrix elements may be established

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Table 1
Formulas Used for Matrix Element Calculation

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e	= electrode
C	= decrement constant
C	= $.24/\sqrt{24}$
d_e	= distance from electrode to matrix element
i_e	= inverted distance
i_e	= $24 - d_e$ (if $d_e > 24$ then $i_e = 0$)
D	= total of inverted distances
D	= $\sum_{e=1}^4 i_e$
V_e	= observed value
E_e	= estimated value
Mv	= estimated matrix element value
E_e	= $V_e / (1 - (\sqrt{d_e})C)$
Mv	= $\sum_{e=1}^4 E_e (i_e / D)$

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using all four electrodes, estimates based on individual electrodes are weighted according to their distances from the element. Electrodes closest to the element provide the best estimate and are given the most weight. Electrodes that are 24 or more elements away from the element in question provide poor estimates and are given no weight. The four weighted estimates are then totaled to represent the expected value at the matrix element.

The resulting element value is then scaled into one of 12 colors and displayed. Peak activity, whether positive or negative, is displayed in red, pink, or orange. Smaller potentials are displayed in black, violet, or blue. This entire process is repeated for each matrix element.

Given this set of assumptions and parameters, the program places the locus of the generator at the vertex if the same potentials are recorded at each electrode site. This is because only a source potential at the vertex dissipates equally at all four electrode locations. A source potential with a left frontal lobe locus produces a pattern of high left frontal activity with concentric rings of lower activity spreading across the scalp. These rings represent the conduction loss associated with tissue impedance. Asymmetry or rapid degeneration of these rings represent processes other than conduction loss which influence the recorded voltages.

After the matrix has been drawn, the time is displayed and the user is prompted to continue (C). Pressing C initiates the drawing of the next time selection. After all matrices have been drawn, the latency, the left-right and anterior-posterior coordinates, and the value of the maximal matrix element are displayed. The Applesoft BASIC program listing is presented in Table 2.

PROGRAM EVALUATION

To test this program, visual ERP data were collected from a single subject at 15 electrode sites (F7, F3, Fz, F4, F8, T3, C3, Cz, C4, T4, T5, P3, Pz, P4, and T6). All active electrode locations were referenced to linked mastoids and amplified using a Beckman Accutrace 200A electroencephalograph. Single trial waveforms from F7, F8, T5, and T6 were stored on-line using an Apple II+ microcomputer (Lorig, 1985). One trial with "classic" ERP morphology was selected (see Figure 1) and used in the analysis. The N1 component of this ERP peaked at 140 msec poststimulus and tended to be maximal over the posterior electrodes. The amplitude of this component was determined manually (baseline to peak) for each of the 15 electrode locations. A scalp topography map was then generated for the 140-msec time period using only the four electrode sites digitized during data collection. Matrix elements corresponding to the 15 scalp locations were identified and compared to the actual electrode values obtained manually. A Pearson product-moment correlation coefficient indicated a significant relationship between the actual and predicted values ($r = .90$, $N = 15$, $p < .001$). The half-tone reproduction of this scalp topography map (STM) is presented in the upper half of Figure 2. The lower half of Figure 2 contains the STM for the P180 component. This component was scored similarly to the N1 wave and also revealed a significant relationship between observed and predicted values ($r = .86$, $N = 15$, $p < .001$).

DISCUSSION

This program offers investigators several advantages over previously mentioned techniques. It can be implemented on a small, readily available microcomputer and uses only four electrode locations, thus reducing the amount of data and equipment necessary for data acquisition and processing while retaining a strong relationship to actual observed electrode values. Because the program makes predictions about the passive spread of scalp-recorded potentials, deviations may represent active processes, such as simultaneous multiple generator sources within the brain.

Caution must be used in the extrapolation of scalp-recorded potentials to underlying cortical sources since these potentials may not always accurately depict cortical activity (Picton, 1980). Gevins (1984) found ambiguities in localization of source potentials using up to 60 electrode sites.

Another problem of interpretation concerns the relationship between the functional significance of an ERP component and its anatomical topography. Functionally distinct components may not be represented by anatomically distinct neuronal aggregates (Donchin, Ritter, & McCallum, 1978), but instead by broad patterns of acti-

Table 2
Program Listing

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10 D$ = CHR$(4)
20 HOME : INVERSE
30 PRINT "
40 PRINT "
50 NORMAL : PRINT "      ERP SCALP TOPOGRAPHY MAPPING
60 INVERSE
70 PRINT "
80 PRINT "
90 NORMAL
100 DIM A(4,256),F$(4),C(12)
110 VTAB 12
120 PRINT "INPUT FILE NAMES IN ORDER
130 PRINT "(F7,T5,F8,T6)
140 FOR I = 1 TO 4
150 INPUT "FILE NAME ";F$(I)
160 NEXT I
170 HOME : VTAB 12
180 INPUT "INSERT DATA DISK AND PRESS RETURN";Z$
190 HOME : VTAB 12: PRINT "      LOADING DATA
200 MX = 0:MN = 255
210 FOR X = 1 TO 4
220 PRINT D$;"OPEN";F$(X)
230 PRINT D$;"READ";F$(X)
240 FOR I = 1 TO 256
250 INPUT J
260 A(X,I) = J
270 NEXT I
280 PRINT D$;"CLOSE"
290 NEXT X
300 REM MATRIX DIMENSION
310 Z = 24
320 Z1 = Z - 1
330 HY = SQR ((Z ^ 2) * 2) + .1
340 REM RATIO CONSTANT
350 RK = 2
355 RJ = 1
360 OC = ((48 - Z) / 2) - 1
370 RO = ((48 - Z) / 2) - 1
380 REM DECREMENT CONSTANT
390 DC = .24
400 C = DC / SQR (2)
410 HOME
420 INPUT "SEARCH FOR NEGATIVE(1) OR POSITIVE(2)      WAVES? ";W
430 AX = 0
440 PRINT "SEARCH RANGE IN MSEC (EX.200,500)?
450 INPUT BG,ED
460 INPUT "INCREMENT BETWEEN STEPS (MSEC)? ";SP
470 GOSUB 1110
480 GOSUB 970
490 GOSUB 880
500 FOR I = BG TO ED STEP SP
510 MN = OM:ST = OS
520 GOSUB 660
530 INPUT "PRESS RETURN TO CONTINUE";J$
550 NEXT I
560 TEXT
570 HOME : PRINT "      SUMMARY DATA
580 VTAB 4: PRINT "FOR FILES:"
590 FOR P = 1 TO 4: PRINT F$(P): NEXT P
595 PRINT : PRINT "SEARCH RANGE="BG" TO "ED" STEP="SP
600 PRINT : PRINT "PEAK="AX
610 PRINT : PRINT "LATENCY="LX" MSEC
620 PRINT : PRINT "L-R VALUE="RX
630 PRINT : PRINT "A-P VALUE="CX
640 END
650 REM DRAW MATRIX
660 FOR RW = 0 TO Z1
670 FOR CL = 0 TO Z1
675 REM DETERMINE DISTANCE
680 K1 = SQR (RW ^ 2 + CL ^ 2)
690 K2 = SQR ((Z1 - RW) ^ 2 + CL ^ 2)
700 K3 = SQR (RW ^ 2 + (Z1 - CL) ^ 2)
710 K4 = SQR ((Z1 - RW) ^ 2 + (Z1 - CL) ^ 2)
719 REM ESTABLISH ESTIMATES
720 SA = A(1,I) / (1 - (SQR (K1)) * C)
721 SB = A(2,I) / (1 - (SQR (K2)) * C)
722 SC = A(3,I) / (1 - (SQR (K3)) * C)

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Table 2 (Continued)

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723 SD = A(4,I) / (1 - (SQR (K4)) * C)
729 REM ESTABLISH WEIGHTS
730 K1 = Z1 - K1: IF K1 < 0 THEN K1 = 0
731 K2 = Z1 - K2: IF K2 < 0 THEN K2 = 0
732 IF K3 > Z1 THEN K3 = Z1
733 K3 = Z1 - K3: IF K3 < 0 THEN K3 = 0
734 K4 = Z1 - K4: IF K4 < 0 THEN K4 = 0
735 KS = K1 ^ RJ + K2 ^ RJ + K3 ^ RJ + K4 ^ RJ
739 REM WEIGHT ESTIMATES
740 V1 = ((K1 ^ RJ) / KS) * SA
741 V2 = ((K2 ^ RJ) / KS) * SB
742 V3 = ((K3 ^ RJ) / KS) * SC
743 V4 = ((K4 ^ RJ) / KS) * SD
770 VT = V1 + V2 + V3 + V4
780 GOSUB 1060
790 PLOT CL + OC, RW + RO
800 IF VT > AX THEN GOSUB 1420
810 NEXT CL
820 NEXT RW
830 HOME : VTAB 24
840 PRINT I * 4" MSEC"
850 FOR RR = 1 TO 500: NEXT RR
860 RETURN
875 REM DRAW HEAD
880 R = (Z / 2) + 4: COLOR= 15
890 FOR CT = 0 TO 6.283185 STEP .01745329
900 X = 23: Y = 19
910 CX = R * COS (CT)
920 CY = R * SIN (CT)
930 PLOT (Y - CY), (X + CX)
940 NEXT CT
950 GOSUB 1470
960 RETURN
965 REM DRAW COLOR SCALE
970 GR
980 FOR I = 1 TO 12
990 READ W
1000 COLOR= W
1010 PLOT 36, 16 + I: PLOT 37, 16 + I
1020 C(13 - I) = W
1030 NEXT I
1040 RETURN
1050 DATA 1,9,11,13,12,4,10,7,6,2,3,0
1060 FOR CO = 1 TO 12
1070 IF VT > (MN + ST * (CO - 1)) THEN CR = C(CO)
1080 NEXT CO
1090 COLOR= CR
1100 RETURN
1105 REM CALC MEAN & S.D.
1110 BG = INT ((BG / 4) + .5): ED = INT ((ED / 4) + .5): SP =
      INT ((SP / 4) + .5)
1120 IF W = 2 THEN GOSUB 1280
1130 N = 0
1140 KH = SQR (((Z / 2) ^ 2) * 2)
1150 SS = 0: SU = 0
1160 FOR KQ = BG TO ED STEP SP
1170 FOR KB = 1 TO 4
1180 U = A(KB, KQ) / (1 - (SQR (HY / 2) * C))
1185 UY = A(KB, KQ)
1190 N = N + 2
1210 SU = SU + U
1220 SS = SS + U ^ 2
1222 SU = SU + UY
1223 SS = SS + UY ^ 2
1225 NEXT KQ
1230 ME = SU / N
1240 SJ = SQR ((SS - ((SU ^ 2) / N)) / N)
1250 OM = ME - (3 * SJ)
1260 OS = ((3 * SJ) + ME - OM) / 12
1270 RETURN
1280 FOR KA = 1 TO 255
1290 FOR LA = 1 TO 4
1300 A(LA, KA) = 256 - A(LA, KA)
1310 NEXT LA
1320 NEXT KA
1330 RETURN
1340 NN = 255: NX = 0

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Table 2 (Continued)

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1350 FOR FA = 1 TO 4
1360 IF A(FA,I) > NX THEN NX = A(FA,I)
1370 IF A(FA,I) < NN THEN NN = A(FA,I)
1380 NEXT FA
1390 NX = NX * (1 + (C * (HY / 2)))
1395 NN = NN * (1 + (C * (HY / 2)))
1398 MN = NN
1400 ST = (NX - NN) / 12
1410 GOTO 520
1420 AX = VT
1430 LX = I * 4
1440 RX = CL
1450 CX = RW
1460 RETURN
1470 HV = 0
1480 FOR HR = 3 TO 7
1490 PLOT 19 + HV,HR
1500 PLOT 19 - HV,HR
1510 HV = HV + 1
1520 NEXT HR
1530 RETURN

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vation rather than localized areas of high activity. Also, similar patterns of scalp activity may represent different functional components of the ERP (Fabiani, Gratton, Karis, & Donchin, 1986).

These are important concerns which must be taken into account. The scalp-recorded locus of a particular ERP component may not correspond exactly to the cortical source generating the wave. Simultaneous bilateral generator sources of similar potential would produce a maxima along the midline because of overlapping zones of conduction. Typically, however, there is great similarity between the location of the generator and the corresponding scalp topography (Towe, 1980). Thus, these studies may produce a generally accurate image of cortical activity during information processing.

Attaching functional labels to the various generator sources identified with scalp topography mapping techniques may also be difficult since an ERP component is not synonymous with a peak in the waveform (Fabiani et al., 1986). Identification of functional ERP components can only be accomplished by comparing neural generators under different experimental conditions (Donchin et al., 1978). Although it is true that different functional components of the ERP may be represented by similar patterns of scalp-recorded activity, heterogeneous patterns must originate from different sources or must

Figure 1. ERP waveforms following the visual stimuli (letters).

Figure 2. Scalp topography maps of the development of the N140 (top) and P180 (bottom) components of the ERP (halftone reproductions of the color display).

represent differential activation of the same source (Picton, Wood, Stuss, & Campbell, 1978). Scalp topography mapping techniques may offer a method for better understanding these sources and their relationship to psychological constructs.

REFERENCES

- DONCHIN, E., RITTER, W., & MCCALLUM, C. (1978). Cognitive psychophysiology: The endogenous components of the ERP. In E. Callaway, P. Tueting, & S. H. Coslow (Eds.), *Event-related brain potentials in man* (pp. 349-411). New York: Academic Press.
- DUFFY, F. H., BARTELS, P. H., & BURCHFIEL, J. L. (1981). Significance probability mapping: An aid in the topographic analysis of brain electrical activity. *Electroencephalography & Clinical Neurophysiology*, **51**, 455-462.
- DUFFY, F. H., BURCHFIEL, J. L., & LOMBROSO, C. T. (1979). Brain electrical activity mapping (BEAM): A new method for extending the clinical utility of EEG and evoked-potential data. *Annals of Neurology*, **5**, 309-321.
- FABIANI, M., GRATTON, G., KARIS, D., & DONCHIN, E. (1986). The definition, identification, and reliability of measurement of the P300 component of the event-related potential. In P. K. Ackles, J. R. Jenkins, & M. G. H. Coles (Eds.), *Advances in psychophysiology* (Vol. 2). Greenwich, CT: JAI Press.
- GEVINS, A. S. (1984). Analysis of the electromagnetic signals of the brain: Milestones, obstacles, and goals. *IEEE Transactions on Bio-medical Engineering*, **31**, 833-850.
- JASPER, H. H. (1958). The ten-twenty electrode system of the International Federation. *Electroencephalography & Clinical Neurophysiology*, **10**, 371-375.
- LORIG, T. S. (1985). Event-related potential data acquisition using the Apple II+/Ile. *Behavior Research Methods, Instruments, & Computers*, **17**, 479-483.
- MORSTYN, R., DUFFY, F. H., & MCCARLEY, R. W. (1983). Altered P300 topography in schizophrenia. *Archives of General Psychiatry*, **40**, 729-734.
- PICTON, T. W. (1980). The use of human event-related potentials in psychology. In I. Martin & P. H. Venable (Eds.), *Techniques in psychophysiology* (pp. 357-395). Chichester, England: Wiley.
- PICTON, T. W., WOOD, D., STUSS, D., & CAMPBELL, K. (1978). Methodology and meaning of human evoked potential scalp distribution studies. In D. Otto (Ed.), *Multidisciplinary perspectives in event-related brain potential research* (pp. 515-522) (EPA-600/9-77-043). Washington, DC: US Government Printing Office.
- REMOND, A., & OFFNER, F. (1952). A new method for EEG display. *Electroencephalography & Clinical Neurophysiology*, **7**, 453-460.
- TOWE, A. L. (1979). Electrophysiology of the cerebral cortex. In T. Ruch & H. D. Patton (Eds.), *Physiology and biophysics* (Vol. 1, pp. 563-588). Philadelphia, PA: Saunders.

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