Electroencephalography and evoked potentials: a PC-based analysis program for laboratory courses in physiology

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Illert, Michael, Harald Wiese, and Uwe Wolfram. Electroencephalography and evoked potentials: a PC-based analysis program for laboratory courses in physiology. Am. J. Physiol. 263 (Adv. Physiol. Educ. 8): S16–S22, 1992.—A computer program (EEG Analysis) was developed for the preclinical laboratory course in physiology held for medical and dental students. It offers an off-line analysis of a set of typical and frequently occurring physiological and pathological electroencephalogram (EEG) and evoked potential (EP) recordings, which are stored in an IBM-compatible personal computer (PC) system. The users are requested to measure and analyze the data sets and to work through a base of questions relevant in the frame of the particular topic. The program is structured in several exercises: calibration, pickup of non-EEG signals (eye movements, chewing), waveforms in EEG recordings from awake subjects (α-waves, β-waves), desynchronization of cerebral activity (visual activation, acoustic activation, mental activation), habituation of cerebral activity upon acoustic stimuli, EEG recordings from asleep subjects (different sleep stages, sleep-specific EEG signals), epileptic seizures, and EPs (principal of averaging, visually evoked potentials in different cortical areas). The program runs under MS-DOS and is network capable. The software structure ensures maximal flexibility for rapid changes and adaptations of the program to specific needs of a particular EEG course. The program has been used for three years, and the response from >800 students has been consistently positive.

physiology teaching; computer programs; personal computer assisted teaching

FOR MEDICAL STUDENTS the recordings of the electroencephalogram (EEG) and of evoked potentials (EPs) have become routine procedures in most laboratory courses in physiology. This reflects the importance that the underlying neurobiological concepts have in teaching and training. EEG and EP recordings offer the optimal possibility to study the activity of many cortical neurons at the same time. The EEG activity is correlated with cognitive, emotional, mental, sensory, and motor aspects of behavior, and the EEG technique is used for the study of a variety of cortical functions like arousal, wakefulness, sleep, dreaming, epilepsy, and coma. Because these subjects are all highly relevant, the wide distribution of EEG recordings in the courses in physiology is not surprising.

As in many other preclinical courses, the teaching in the EEG course is hampered by high numbers of students taking part in the classroom work. This problem is important because in the preclinical subjects the understanding of the basic theoretical concepts is dependent on active work with experimental material and on the discussion of the problems arising from interpretation of the measured data.

To improve this situation we have developed a computer program (EEG Analysis) that offers an off-line analysis of a set of typical and frequently occurring physiological and pathological EEG and EP recordings.

The recordings are stored in an IBM-compatible personal computer (PC) system. The users are requested to analyze and/or measure the different data sets and to work through a base of questions that are relevant in the frame of the particular topic. It is the aim of this interactive analysis to introduce the students into the conceptual background of integrative processes within the cerebral cortex. We have been using this program for three years and have found the laboratory exercise to be well appreciated. An abstract has been published (7). The program is one of several computer programs that have been developed in our department for computer-assisted teaching in the undergraduate courses in physiology (2, 3, 5, 6).

EEG ANALYSIS PROGRAM
Topics of Program

The program is designed as one component of the laboratory course, Integrative Processes in the Cerebral Cortex. This course deals with the technique and phenomenology of EEG recordings, the analysis of EEG signals reflecting integrative processes in the cerebral cortex, and the use of EPs as tools for testing neuronal systems. The EEG Analysis program is structured in several exercises that deal with particular aspects of these topics (Fig. 1).

Organization of Laboratory Course

The course starts with an on-line demonstration of EEG recordings from a healthy volunteer, which is followed by the analysis of prestored EEG recordings with the described program.

On-line EEG recording. EEG recordings from a companion student are observed by the whole class of ~20 students. To test the cerebral function, conventional paradigms are used (e.g., eyes opened and closed, acoustic stimuli, mental arithmetics, jaw clenching). Visually evoked potentials are induced by means of a checkerboard oscillating on a PC screen. The EEG is recorded with an analog EEG chart recorder. In case of the EP recordings the amplifier is connected to a PC equipped with an analog-to-digital converter card. Up to five channels are digitized with a sample rate of 1.2 kHz/channel and are averaged. One of the channels can be displayed in real-time like an oscilloscope trace, either showing the analog sweep or the on-line averaged data. The paper chart of the EEG amplifier and the monitor of the averaging PC are filmed with a video camera and projected onto a screen (2 x 3 m) to demonstrate the recordings to the whole class. This on-line EEG recording takes about 60–90 min.

Computer-based analysis. After the on-line EEG recording, the students split into small groups to work with the EEG Analysis program. Two or three students share one PC. The EEG and EP recordings are stored on the hard disks of the PCs or on the file server of a network. The program displays unipolar recordings from the occipital (O1), parietal (P3), central (C3), and frontal (F3) leads. The students are instructed to work through the different exercises by analyzing the data with the offered software tools (scrolling, scaling, cursor function for measuring times and amplitudes) and by answering questions.
How to Use EEG Analysis Program

Starting the program. After the program has been started the main menu with the different exercises is displayed (Fig. 1). The students are free to start with any item, but to obtain quantitative data the calibration procedure must be performed first.

Layout of computer screen. The typical screen layout is demonstrated in Fig. 2 (taken from exercise 3; see α-Waves). The screen is divided into three different windows. Window 1 (top) displays the EEG recordings, which are labeled on the right and left as to their recording sites. The small vertical marks below the occipital recording (bottom trace) give the time calibration (1 s between marks). On the PC screen 1 s is displayed by 100 points, which visualizes an overall recording time of ~6 s. This condensed display has been selected to make the students familiar with the periodicity and rhythmicity of the EEG signals. The line above the frontal recording (top trace) is used as event marker. Window 2 (middle) offers four lines of text either instructing about the next step in the program (as in the illustrated case) or posing questions to be answered. Window 3 (bottom) displays the function keys that are used in the particular part of the program. Keys not shown in this window do not perform any action in the specific situation. The only exception is the help key, F10, which is always available offering context-sensitive help.

Scrolling function. The EEG recordings stored in the exercises cover a recording period of between 20 and 80 s. Because the time displayed on the screen is only 6 s, a scrolling function has been developed to make the whole data set available for inspection and analysis. By default the recordings scroll from right to left, similar to the paper chart recorder used in the on line recording from the subject. The maximum scrolling speed is processor dependent (~4 cm/s with a 80386/20-MHz processor and 14-in. monitor). The scrolling may be stopped or restarted (space bar), and the direction may be reversed (D key). Keys B or E will start the scrolling at the beginning or the end of the recorded period. The keys controlling the scrolling are displayed in Fig. 2.

Selection of records. Window 1 displays by default the records obtained from all four cortical leads. For the detailed cursor-assisted analysis of a particular recording, the voltage scaling can be optimized by selecting that record with the key giving the location of the cortical electrode (F, C, P, and O keys for frontal, central, parietal, and occipital, respectively). The record is then displayed in isolation with an expanded voltage scale, the time scale remaining unchanged. The other recordings disappear (Fig. 3).

Cursor function. In most exercises the records must be analyzed by measuring the latencies and the amplitudes of the displayed events. This is assisted by a simple cursor function, which is illustrated in Fig. 3. The cursor reads absolute values on the x-y axes. It can be placed in window 1 by the arrow keys; the cursor speed increases dynamically as long as the arrow keys

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Fig. 1. Exercises offered in the EEG Analysis program. They are listed and can be selected from main menu, which is first screen appearing after starting program.

Fig. 2. Layout of computer screen. Hard copy from exercise 3 (see α-Waves). The screen is divided into 3 windows. Window 1 (top) displays recordings from 4 cortical leads: frontal (F), central (C), parietal (P), and occipital (O). Small vertical bars give time intervals of 1 s. Window 2 (middle) gives 4 lines of text, instructing user about next steps in analysis. Window 3 (bottom) displays the keys that are available to operate program. Keys: space bar, toggle to start or stop scrolling; T, cursor-directed placing of time period of 1 s (e.g. to measure frequency of α-waves); P1, selects displayed recording for plotting; B, D, or E, controls direction and beginning of scrolling; ESC, returns program to previous page. With color monitor, windows 1 and 3 are displayed as white areas on a cyan background (in hard copy the cyan background appears black), keys in window 3 are underplayed in yellow, and EEG recordings in window 1 are black on white.

Fig. 3. Use of cursor function to measure amplitudes and time relations of a visual EP recorded in occipital lead (averaged signal from 136 stimuli; hard copy from computer screen). The cursor (cross), which is moved with arrow keys, reads position on the time (t) and voltage (U) scales. In addition it reads differences (Δt, ΔU) between cursor and a marker (rectangle) that can be set by space bar. Cursor has red color; marker is black. For further colors see legend of Fig. 2.
are pressed. A marker (rectangle in lower left of window 1) can be set by the space bar. In addition to the absolute values, the cursor function will then read the relative x-y values between the marker and the actual cursor position. 

Printouts of records. The program offers the option to make printouts of recordings (e.g., for inclusion in the protocols). The recordings can be selected from different exercises. Selection is done by the F1 key (Fig. 2), which writes the actual content of window 1 into memory. The recordings are stored with the relevant calibrations; for documentation purposes an identification line of 60 characters can be added. The name of the exercise and the actual date are automatically inserted. The printing is done after the EEG Analysis program has been finished. Printouts from two selected recordings are displayed in Figs. 4 and 5; up to six different recordings can be selected for printing on one page.

DIFFERENT EXERCISES

Exercise 1: Calibration

The exercise explains the calibration of electrophysiological measurements by requesting the user to calibrate the EEG signals. When this calibration procedure is not performed correctly the user can proceed with the exercises, but the quantitative data given by the program will be wrong. The calibration can be repeated at any time.

Exercise 2: Pickup of Non-EEG Signals

The recordings demonstrate the pickup of remotely generated physiological signals [eye-movement potentials and electromyography (EMG) signals from jaw muscles]; artifacts due to technical problems like AC current or contact problems at the electrodes are not dealt with. The EEG recordings with eye-movement signals were obtained from a subject who rhythmically moved the eye balls (Fig. 4, left). The signals are large in the frontal recording and become progressively smaller in direction of the occipital recording. A second exercise demonstrates the pickup of EMG signals. The EEG recordings were obtained while the subject was biting at the teeth. In one sequence of recordings the strength of the bite is gradually increasing, which allows for extraction of the differences between EMG and EEG signals and the relation between interference and strength of the muscular contraction. The sequence in Fig. 4, right, demonstrates the pickup of the EMG signal during a sudden strong bite.

Exercise 3: Waveforms in EEG Recordings from Awake Subjects

α-Waves. Figure 2 illustrates typical EEG recordings in an awake subject with distinct α-waves in the occipital, parietal, and central leads. For the analysis the students are first requested to identify the cortical areas with the most and the least pronounced α-activity. Then they concentrate on the calculation of the mean frequency and the mean amplitude of the α-waves. For this purpose the user selects from the recording four epochs of 1 s each and chooses the recording with the optimal α-activity, which is then displayed with an enlarged amplitude (the records from the other cortical leads are omitted). In the selected four epochs the students count the frequency of the α-waves and calculate the mean frequency. To save some time the mean amplitudes are calculated and displayed by the computer program.

β-Waves. The analysis of the β-waves is presented in a separate exercise. For a striking illustration of the differences between the β- and α-waves, the program displays in one and the same screen three representative recordings with β-waves and one with α-waves. The students are requested to measure the frequency and the amplitudes of the β-waves and to compare the values with the data obtained by the previous analysis of the α-waves.

Exercise 4: Desynchronization of Cerebral Activity

The program displays the desynchronization of the cerebral activity in three different situations: during opening and closing of the eyes (visual desynchronization), during application of tone bursts (acoustic desynchronization), and during mental arithmetic (mental desynchronization). Figure 5 shows the desynchronization during visual (left) and acoustic stimuli (right). In both cases the subject was at rest with a pronounced α-rhythm. Opening of the eyes and application of a short tone led to a distinct desynchronization of the cerebral activity. For the analysis of these events the students are instructed to

![Fig. 4. Pickup of non-EEG signals. Laser printout of 2 recordings selected during analysis for inclusion in protocol. Top: box used for identification purposes, with name of program (EEG; left) and actual date (right) automatically inserted and with 60-character line (middle) to be used for further identification by user. Recordings: left, eye movement-related EEG artifacts during up- and downward movements of eyes (high-pass filters had been adjusted to 5 Hz, thereby cutting off DC component of movement signal); right, electromyography (EMG)-related EEG artifacts provoked by biting on teeth. In each recording, top line gives event marker. The 4 cortical recordings are displayed with identifying letters. Voltage and time calibrations and name of exercise are automatically inserted during printout.](http://advan.physiology.org/)
describe this desynchronization and its spatial distribution over the cortex and to discuss this event in relation to the preceding and following cerebral activity. Similar recordings display the desynchronization during mental arithmetics.

Exercise 5: Habituation of Cerebral Activity
On Acoustic Stimuli

Two exercises deal with habituation of the cerebral activity. In the EEG recordings of the first exercise, tone bursts have been repeatedly applied during a period of 65 s (1 tone/5 s; each tone lasted 1 s). Whereas the first tone bursts resulted in distinct desynchronizations of cerebral cortical activity, the activity habituated rather quickly after the sixth tone. A nearly complete habituation was present after the tenth tone burst. In this first exercise the recordings scroll through the screen, and the students are requested to describe the EEG changes. To facilitate comprehension of these events, the second exercise displays the cerebral activity during the first four (nonhabituated) and the last four (habituated) tone stimuli in epochs of 1 s before and 1 s after the tones (Fig. 6).

Exercise 6: EEG Recordings from Asleep Subjects

One of the modern applications of the EEG is in the diagnosis of sleep disturbances. The descriptions of EEG waves during sleep, different sleep stages, and the discussion of relevant neurobiological concepts occupy a considerable space in the modern textbooks of physiology (see Refs. 8, 9). However, the recording and analysis of EEG phenomena during sleep have only rarely found entrance into the laboratory exercises for undergraduate

Work through the questions which have been asked in the instruction booklet to this laboratory task.
medical students. We have therefore included in the program EEG recordings obtained in a sleep laboratory from a healthy volunteer. Recordings from four different sleep stages with their typical waveforms are displayed. Special exercises are devoted to the analysis of sleep-specific EEG phenomena, such as K-complexes and sleep-spicules. Because the undergraduate students have considerable difficulties in detecting these events, the relevant waveforms have been overlayed with identifying colors. The students are requested to analyze these potentials in the different leads and to measure the amplitudes and time durations. The posed questions direct the students to realize that sleep is an active process of the brain and that the sleep stages are manifestations of the rhythmicity of this process.

**Exercise 7: Epileptic Seizures**

The recordings were obtained from a patient who suffered from a grand mal type of epileptic disease. The typical characteristics of epileptic activity (e.g., spike and wave complexes, enlarged preseizure α-activity) are displayed. The students are requested to measure the pre-seizure α-activity and to compare the data with the α-activity recorded previously from a healthy subject. They are furthermore asked for a careful description of the epileptic discharge (comparison of the EEG amplitudes in different cortical areas, analysis of a spike and wave complex, etc.) and to discuss the pathophysiological aspects.

**Exercise 8: EPs**

Today the technique of recording EPs is a routine approach for testing the intactness of neuronal systems. It is critically dependent on the use of the averaging technique. When we introduced EP recording in the laboratory courses, we soon realized that the students had difficulties in understanding the important concept of averaging. Therefore a separate exercise on this topic has been developed.

**Principle of averaging.** This exercise shows the advantage of the averaging procedure by displaying from a sequence of stored original EP records in parallel the actual record (n-th stimulus) and the averaged signal (Fig. 7). For this purpose window 1 is subdivided into two further windows. In the top window the EP recordings evoked by the successive visual stimuli (oscillating checkerboard) are displayed (120 exposures at a frequency of 2/s). The start of the sweep is triggered by the change of the checkerboard illumination. The bottom window displays the average of the signals recorded up to and including the actual one (the average is obtained by adding the voltage of the actual signal to the sum of the previous signals and dividing by the number of signals). The display can be stopped and started again at will. The direct comparison of the actual records and of the averaged signal demonstrates how the averaged EP develops out of the biological noise and stabilizes in amplitude and configuration. At the same time the noise decreases.

**Visually evoked potentials.** This exercise displays the average of visual EPs recorded from occipital, parietal, central, and frontal areas with an oscillating checkerboard. Window 1 is subdivided into four windows that contain the averaged EPs from the four recording sites. The time base of the recording is rather slow (500 ms/screen; it can be expanded by a toggle to 250 ms/screen) because the main interest in this exercise lies in the intermediate and late latency components. After gross inspection of the similarities and differences of the EPs and after description of the main findings, one of the EPs can be selected for further and more detailed analysis. It is

![Image of EEG and EP recordings](http://advan.physiology.org/)

**Fig. 7. Principle of averaging technique.** Hard copy from computer screen of parallel display of actual EP record (top window, 120th stimulus) and the averaged signal (record 1-120, bottom window). For colors, see Fig. 2.
then displayed with an expanded voltage scale (Fig. 3). The cursor function assists in measuring the latencies and amplitudes of the different EP components.

SOFTWARE AND HARDWARE

Software Design

We aimed to develop a software structure that would ensure maximal flexibility for rapid changes and adaptations of the program to specific needs of the particular EEG course. We used Turbo Pascal 5.5 (Borland International) as programming language because the unit concept of this language allows well-structured programs, split into handy modules (units). Some time-critical tasks have been written in assembly language. The printout of the graphic screens was realized using the standard Hewlett-Packard Graphics Language (HPGL) format for vector graphics. Compared with hard copies from the screen, this offers a much better graphic resolution. Most pen plotters and many laser printers can be used for on-line printing, both on stand-alone systems and in a network environment. Furthermore, HPGL emulation software is available for most dot matrix, ink jet, or laser printers, which can then be used to plot the graphs offline, if the output is directed to a plot file instead of an LPT or COM device.

To allow rapid changes of important parts of the program we have stored as much information as possible outside the executable kernel program in a sample of external ASCII files. In this way these parameters can be changed with a simple ASCII editor. There are four such configuration files, each of them holding specific information. Two files comprise several parameters of the working environment. In the content file the different exercises are listed. This file allows one to select the exercises offered in the introductory main menu. The parameter file holds parameters for the internal working of the program. The amplitude of the calibration signals for the different exercises (this is important in case new EEG data sets are added) is the first parameter. Another one adjusts the speed of the scrolling function (in case computers with different clock speeds are used simultaneously). The remaining parameters deal with the organization of printing the EEG data. Parameters can be set that determine the number of printouts on a single page (default value is 6 windows/page; the size of the windows is automatically adjusted according to the no. of windows/page). The name of a plot file for later (off-line) printing or the printer device (LPTX: or COMX:) for on-line printing is set as well. The two further ASCII files hold all text appearing in the program. The message file contains the use of the function keys, the labeling of the x-y axes, and the error messages. It further includes the text appearing in window 2, which is limited to four lines with 78 characters/line. Finally, the help file stores all help screens. These ASCII texts may be of arbitrary length (scrolling is possible) and can be changed at will. They may contain program-specific help or further physiological information for the students. This set of ASCII files is completed with a documentation file (not needed for the program to run) with instructions for installation of hardware and software and a description of the four configuration files. The format of the data files containing the EEG and EP records is also explained in detail to allow an easy supplementation of the program with additional data sets.

Hardware Requirements

The program requires an IBM-PC-compatible computer with an 8088/6 or any of the 80 × 86 (Intel) series microprocessors with 512-kilobyte (kB) random-access memory (RAM). A hard disk with at least 1.5-MB is strongly recommended. The program is designed for a video graphics array (VGA) adapter and a color monitor. For printouts any device that works with HPGL is suitable (e.g., pen plotters or many laser printers).

The program runs under Microsoft MS-DOS 3.1 operating system (or subsequent releases). It works in a network environment like LAN Manager (Microsoft) or Novell 386. The executable file, the configuration files, and all data files may be stored on the network fileserver; for plotting, network plotters (or printers with HPGL emulation) can be used.

DISCUSSION

This paper describes a graphic, interactive program for IBM-compatible PCs that has been designed to supplement in courses in physiology the on-line EEG and EP recordings with a detailed analysis of the experimental data and situations. It is important in our view that an on-line recording of EEG events precede the off-line analysis of the prestored EEG and EP recordings. The off-line analysis without previous on-line recordings will prove difficult for students who have no previous experiences with the EEG technique.

The program has been designed to 1) offer the students optimal and exemplary EEG recordings that will expand the data obtained in the on-line recording, 2) offer EEG recordings that are important in physiological (sleep) or pathological (epilepsy) contexts but that are normally not available in the preclinical courses, 3) explain methodological concepts (principle of averaging), and 4) support and encourage discussions between the students on the background and relevances of the EEG recordings by guiding them through the different topics and the analysis with questions asked in the program.

When we selected the didactic approach and designed the program, we put high priority on the concept that the students should analyze the records by working through a set of relevant questions. This interactive analysis is supported by the instruction to prepare a written protocol that contains the measured data as graphs and tables, the answers to the questions asked in the program, and a printed documentation of relevant records. This concept tries to stimulate the active participation of the students. Accordingly the EEG Analysis program does not use the PCs as instruments for an automatic analysis of the EEG and EP records but rather as systems that store and display the records and offer software tools for a manual analysis. With this didactic concept it is essential that the groups are continuously supervised by an academic
teacher to discuss topics arising during the analysis of the data. Such supervision is, however, not necessary for operating the program, which is self-explanatory and very easy to work with. We have used the EEG Analysis program in our courses for three years. More than 800 medical and dental students have worked with it, and the response from the students has been positive throughout. They welcome the possibility to work in small groups while analyzing the EEG data and answering the questions asked in the program. An added advantage is that the set of records is always available and the students can go back to particular topics at any time. Students also appreciate the fact that recordings from patients and asleep subjects can be analyzed, because such recordings are normally presented only in textbooks, if at all.

The program described here is part of a series of programs that we have developed for physiology courses for medical and dental students. Following the concept of the EEG Analysis program, some of them use prestored data for the analysis of different topics (2, 3, 7). In others the PCs are used as recording systems for on-line experiments and as powerful and efficient tools for data analysis (5, 6). We have practical knowledge of five years with this kind of computer-assisted teaching, and our opinion on this approach is altogether positive (10). In particular, we share the experience reported in many papers (e.g., Refs. 1 and 4) that the students seem to really enjoy the computer-based teaching. They seem to profit from it and spend a lot of time in analyzing the data and working through the concepts offered to them with this approach.

We thank Drs. H.-H. Habler and J. Häusl for helpful advice during the development of the program, and many students for critical feedback with earlier and current versions of the program.

English and German versions of the program are available from the authors. Multiple copies of the program may be made for a department. Address for reprint requests: H. Wiese, Dept. of Physiology, Univ. of Kiel, Olshausenstrasse 40, D-2300 Kiel, Germany

Received 5 March 1992; accepted in final form 24 August 1992.

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