COMPUTER TECHNOLOGY

A microcomputer-based system for evoked-potential augmenting/reducing measurements

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Evoked-potential measurements can readily be implemented on a microcomputer. We present as an example a system for obtaining an evoked-potential augmenting/reducing measure using the Apple II microcomputer. Specialized features of the PASCAL program and peripheral equipment are described.

Individuals differ in their responses to stimulation at different intensities. Petrie (1960) originally described "augmenting" and "reducing" on the basis of a measure of kinesthetic aftereffects. Buchsbaum and Silverman (1968) developed a measure of augmenting/reducing that used signal-averaging techniques to obtain an average evoked-potential measure (see Donchin & Lindsley, 1969; Shagass, 1972). Individuals whose evoked-potential amplitudes increase as a function of stimulus intensity are said to be augmenters; those whose amplitudes do not increase or even diminish are reducers. For the visual evoked potential, for example, evoked potentials are obtained at four intensities of light flash, and the augmenting/reducing measure is the slope of the amplitude of P100/N140 as a function of log luminance. The measure appears to be a relatively stable individual trait. Studies using the visual evoked responses of psychiatric patients have shown differences between schizophrenia and affective disorder and between bipolar and unipolar depression (Buchsbaum, 1978). Thus, the technique appears to be promising for clinical research in the area of psychiatric diagnosis.

The laboratory system described here uses an Apple II Plus with 48K memory, language card, real-time clock, and A-to-D and D-to-A convertor. The controlling program is written in both PASCAL and assembly language. The system is described in general terms, with more

detailed discussion of two areas: (1) the relationship of PASCAL and assembly language within the program and (2) some methods of delivering stimuli at different intensities under computer control.

PROCEDURE

In the visual evoked-potential experimental session, the subject views a screen on which light flashes of 500-msec duration are repeated 256 times at 1 flash/sec, with 64 trials at each of four intensities in random order. The electroencephalogram (EEG) is recorded from the vertex, with the reference electrode at the right ear. Another pair of electrodes above and below the right eye allow monitoring of the electrooculogram (EOG) for detection of eyeblinks. The EEG and EOG are amplified by a Grass polygraph with 7P1 preamplifiers (frequency response = 0.4-40 Hz at 3-dB attenuation). The signals are sampled at 250 Hz.

A single program controls data acquisition and preliminary analysis. When the program is loaded, the light is flashed once at each intensity to check whether it is working properly. The raw EEG signal is displayed on the CRT to verify that the connections to the A-to-D convertor are intact and that the signal is within range. The light flashes are then displayed to the subject, while the EEG signal is recorded and summed separately for each intensity of flash. In addition, trials on which eyeblinks occur are deleted from the analysis. When recording is complete, the sums are divided by the number of trials, to form averages, and the peak amplitudes and slope are computed and printed. The measure of peak amplitude most commonly used, which we use also, is the "peak-to-valley" measure: For P100/N140, for ex-

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Figure 1. Typical visual evoked potential averages shown as output from printer. Highest intensity appears at top.

ample, the program finds the maximum voltage between 76 and 112 msec, and the minimum between 116 and 156 msec. The program displays the evoked potential with the peak and valley marked, so that the operator can override these limits manually if the peak or valley appears to be outside them. The program also calculates the peak amplitudes as the mean absolute deviation from baseline, where baseline is the mean of all time points in the average, as described by Buchsbaum (1976). The slope is calculated from the peak amplitudes by regression. Thus, data acquisition and calculation of summary statistics for each subject are completed on line in a single session; only group comparison and analysis remains to be performed at a later time. The evoked-potential averages themselves can be transferred to a printer (Figure 1).

SOFTWARE METHODS

The program is written in UCSD PASCAL, except for certain routines in assembly language. PASCAL was used because it appeared likely that the program would require modification from time to time (as indeed turned out to be the case). The language has "self-documenting" features that facilitate inspection and revision. Variables and subroutines have eight-letter names, which can be used to suggest their functions. Moreover, the flow of control in the program is easy to follow: (1) English keywords are used, such as IF... THEN or REPEAT... UNTIL, instead of numbered GOTO statements, and (2) the main program always appears last, after the subroutines (or procedures) it refers to, and, in turn, each procedure is preceded by the procedures it refers to (see Eckerman, 1981). The PASCAL segments of the program handle operator interaction, disk file and record assignment, and calculation (Figures 2 and 3).

The assembly language routines are necessary for input/output with nonstandard peripherals and for greater speed. VOLTSIN, VOLTSOUT, and READ-TIME (see Appendix) are examples of assembly language routines used for access to nonstandard devices (the A-to-D and D-to-A convertors and the clock, respectively). In the Apple and other 6502-based computers, external devices are assigned locations in memory, and these absolute addresses are not readily specified in PASCAL. Moreover, to specify them in PASCAL makes the resulting PASCAL source program dependent on the specific machine used. If reference to absolute addresses is confined exclusively to the assembly language routines, the host program can, in theory at least, be implemented on any machine for which a UCSD PASCAL compiler exists; only the assembly language routines need be rewritten.

The other routines, WAIT and FLASH, are written in assembly language for speed of execution. In the case of WAIT, which causes a delay of specified length, the improved speed is merely to improve accuracy of timing. FLASH, the data-sampling routine, was originally written in PASCAL, but a test program showed that this would operate too slowly. The test program read the clock, called VOLTSIN, added the resulting value to a two-dimensional array, read the clock again, and displayed the two clock readings: These were either 4 or 5 msec apart, indicating that the correct elapsed time was between these values and longer than our sampling interval.

After these routines are assembled into object code, they can be placed in a library for linkage to the host program each time it is executed, or they can be linked to the host program once when it is compiled (or recompiled). The assembler, linker, and library utility programs are included in the UCSD PASCAL operating system supplied by Apple Computer, Inc.

HARDWARE

The system includes the Apple II microcomputer with 48K of memory, language card, disk drives, printer, real-time clock, and A-to-D and D-to-A convertor (clock and convertor from Mountain Computer). We use three disk drives; however, the system will work as well with two. Operation with a single drive is feasible, but the small amount of disk space available requires frequent recopying of data if permanent storage is desired. The clock has a resolution of 1 msec, the minimum required by the system. The A-to-D convertor is a 16-channel, 8-bit successive-approximation type, which requires 16 microsec per conversion. Both the A-to-D and D-to-A convertor have voltage ranges of -5 to $+5$ V.

The other major component of the system is the interface to the stimulus generator. Because we were interested in replicating Buchsbaum's (1978) work as closely as possible, we required a light source with a brief (<3 -msec) rise time so that it would be on continuously during

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PROGRAM SLOPEEC;

FUNCTION VOLTSIN (CHANNEL: INTEGER): INTEGER;
EXTERNAL;
(* READS A-TO-D CONVERTER *)

PROCEDURE VOLTSOUT (VALUE, CHANNEL: INTEGER);
EXTERNAL;
(* SENDS OUTPUT TO D-TO-A CONVERTER *)

FUNCTION FLASH (INT: INTENS): BOOLEAN;
EXTERNAL;
(* TURNS LIGHT ON, SAMPLES EEG, ADDS TO SUMS. *)
(* FUNCTION RESULT IS TRUE IF NO EYEBLINKS. *)

PROCEDURE READTIME;
EXTERNAL;
(* READS CLOCK INTO HITIME (0-15.9 SEC) AND LOTIME (0-99 MSEC) *)

PROCEDURE WAIT (DELAY: INTEGER);
EXTERNAL;
(* CAUSES DELAY (IN TENTHS OF SEC) FROM LAST CALL TO READTIME *)

PROCEDURE LIGHTSEQ;
(* INITIALIZES ARRAY CONTAINING SEQUENCE OF INTENSITIES *)

PROCEDURE TESTSTIM;
(* DISPLAYS FLASH AT ALL INTENSITIES AS A TEST *)

PROCEDURE DISPEEG;
(* DISPLAYS ANALOG SIGNAL ON CRT AS A TEST *)

PROCEDURE INTERRUPT;
(* DISPLAYS OPTION MENU AFTER OPERATOR INTERRUPTS EXPERIMENT *)

PROCEDURE CALCULATE;
(* DIVIDES SUMS TO GET AVERAGES.
  * FINDS PEAKS, CALCULATES PEAK AMPLITUDES.
  * PRINTS RESULTS.
  *)

PROCEDURE DISPLAY;
(* DISPLAYS AVERAGES ON CRT SO THEY CAN
  * BE DUMPED TO PRINTER.
  *)

PROCEDURE NEWFILE;
(* STORES DATA AT END OF EXISTING DISK FILE.
  * IF NONE EXISTS, STARTS A NEW ONE.
  *)

(* MAIN PROGRAM *)
BEGIN
  GOTOXY (10, 12); (* TAB TO CENTER SCREEN *)
  WRITELN ('EVOKED POTENTIALS');
  GOTOXY (9, 14);
  WRITELN ('AUGMENTING/REDUCING');
  VOLTSOUT (0, MINUSSCH); (* SET DUMMY CHANNEL TO -5 V *)
  TTLOUT (0, TRUE); (* TURN LIGHT OFF *)
  VOUT[0] := VOUT0;
  VOUT[1] := VOUT1;
  VOUT[2] := VOUT2;
  VOUT[3] := VOUT3;

  LIGHTSEQ;

  GOTOXY (5, 18);
  WRITELN (HITRETURN, 'TEST LIGHT BOX');
  READLN;
  TESTSTIM;
  DISPEEG;

  PAGE(OUTPUT);
  WITH E DO
    (* SET UP ID FOR RECORD *)

  BEGIN
    WRITE ('ENTER 3 CHAR SUBJ CODE: ');
    READLN (NAME);
    WRITE ('ENTER GROUP CODE: ');
    READ (GROUP); WRITELN;
    WRITE ('ENTER OCCASION CODE: ');
    READ (OCCASION); WRITELN;
    CHECKSTRING := 'EVO';
    GF := GAIN;
    END;

    (* INITIALIZE COUNTERS AND SUMS *)

    FOR INT := 0 TO 3 DO
      BEGIN
        NDONE[INT] := 0;
        FOR SAM := 0 TO NSAMPLE DO
          SUM[INT, SAM] := 0;
        END;

        WRITELN (HITRETURN, 'BEGIN EXPERIMENT');
        WRITELN ('HIT Q TO HALT');
        READLN;

        READTIME;
        WAIT(1); (* INIT CLOCK *)
        FOR I := 1 TO MAXTRIAL DO

          BEGIN
            INT := SEQ[I];
            VOLTSOUT (VOUT[INT], LIGHT);
            IF FLASH (INT) THEN NDONE[INT] := NDONE[INT] + 1;
            IF KEYPRESS THEN
              BEGIN
                READ (KEYBOARD, RESP);
                IF (RESP = 'Q') THEN INTERRUPT;
              END;
            END;
            WAIT(10);

          END;

          CALCULATE;
          DISPLAY;
          E.AVE := SUM;
          NEWFILE;
          CLOSE (EVOK, LOCK);
          WRITELN ('THAT'S IT FOR NOW, FOLKS!')

        END.
      END.
    END.
  END.

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Figure 2. Listing of main program and description of subroutines.

the sampling period. The rise time of incandescent bulbs was too slow, on the order of 100-200 msec. With an incandescent bulb, the observed evoked potential would be a response to the bulb turning "on" at an intensity that, in most cases, would be much smaller than the eventual maximum intensity specified by the investigator. A system of shutters and filters was considered, but was rejected as too noisy.

Instead, we used a fluorescent light source, which required a special interface so that the computer could switch the light on and vary the light's intensity. Since the interface was no longer available from the vendor (Iconix) that had supplied Buchsbaum's laboratory, it had to be custom-designed.¹ Briefly, the interface consists of two circuits: (1) a 1500-V pulse is generated at the onset of the light flash and is applied to a wire running alongside the fluorescent tube to force it into a conducting state; and (2) a steady dc voltage is applied to the ends of the tube for the duration of the flash. The dc voltage is the output of an operational amplifier, whose (+) input is an analog voltage generated by a D-to-A converter controlled by the computer, and whose (-) input

is proportional to the current through the tube, since the current is approximately linearly related to the light intensity.

An alternate approach is the use of a stroboscopic flash photostimulator, which has the required rapid rise time; since the flash is brief, however, the resulting evoked potential is theoretically a combination of an "on" and an "off" response. There are no systematic data comparing the augmenting/reducing measures obtained using a strobe flash with those using a longer flash. If this approach is acceptable, it can be implemented more easily, since stroboscopic flash stimulators that can be triggered by an external signal are available (e.g., from Grass Instruments). The intensity is controlled by a manual switch, which switches capacitors of different sizes into the circuit; this would have to be replaced by a set of electronic switches, such as power MOSFETs, one for each intensity.

We also wished to obtain auditory evoked potentials, and again we were aware of no commercially available stimulators whose intensity could be controlled by the computer. However, integrated circuits that make the

Figure 3. Flow chart of main program.

design of such a stimulator a good deal easier than for the visual modality are available. We did not require a flat frequency response, since only one frequency (1 kHz) was used. The choice of a rise time is more problematic. A fast rise time is desirable for the reasons given above; if the rise time is too fast, however, the subject hears a click at the onset of the tone. A device with a rise time of 15-20 msec is shown in Figure 4. Briefly, it accepts a signal from a sine-wave oscillator or function generator (not shown), which is attenuated by a voltage-controlled attenuator (Motorola HEP C6009P) and then amplified (National Semiconductor LM383). The attenuator is controlled by output from the D-to-A converter. The output ranges from -5 to $+5$ V, and the attenuator control voltage ranges from $+3.5$ to $+6$ V. The 741 operational amplifier is used to scale the D-to-A

Figure 4. Schematic of auditory stimulus control device. Connection to D-to-A converter requires two converter channels, one at -5 V, the other varied between -5 and $+5$ V.

output to the correct range: One channel of the D-to-A converter is held at -5 V and the other is varied, with the resulting output from the 741 ranging from 0 to $+6$ V. The rise time can be changed by using a different value for the capacitor from Lead 2 of the attenuator to ground.

Program listings are available at no charge from W. Braden, Butler Hospital, 345 Blackstone Boulevard, Providence, Rhode Island 02906. For program copies on a 5.25-in. diskette, send a blank diskette or \$5.00.

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NOTE

1. Details of the interface and stimulus unit are available from the third author.

Appendix

The following assembly language routines are declared as EXTERNAL procedures and functions in the PASCAL host program:

FUNCTION VOLTSIN (CHANNEL: INTEGER): INTEGER

When invoked, causes the A-to-D converter to sample the voltage on the specified channel and to return the value as the function result.

PROCEDURE VOLTSOUT (VALUE, CHANNEL: INTEGER)

Outputs the specified value on the specified channel of the A-to-D converter. This allows computer control of stimulus intensity on each trial.

PROCEDURE READTIME

Reads the real-time clock into two locations: LOTIME contains the lowest clock register (0-99 msec), and HITIME, the next lowest (0-15.9 sec).

PROCEDURE WAIT (DELAY: INTEGER)

Causes a delay lasting the number of tenths of seconds specified by the argument, starting from the time of the last call to READTIME or WAIT. Thus, READTIME must be called at least once to initialize the timing locations before WAIT is called for the first time.

FUNCTION FLASH (INTENSITY: 0..3): BOOLEAN

Samples the voltage from the EEG channel every 4 msec and

saves the values in a buffer. At the same time, the EOG channel is sampled to detect an eyeblink, defined as a change of more than 200 microV occurring in any 48-msec period. If an eyeblink is detected, the data is discarded and the function returns a value of FALSE; otherwise, the EEG values are added to

the array of sums for the appropriate intensity and the function result is TRUE.

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