SESSION III
RESEARCH TOOLS
FOR MACINTOSH COMPUTERS

Jon Vaughan, *Presider*
Hamilton College

Using the Macintosh computer in psychophysiological research: Programs for stimulus presentation, data collection, and response quantification

TERRY D. BLUMENTHAL and JOSEPH A. COOPER
Wake Forest University, Winston-Salem, North Carolina

In this paper, we describe two Turbo Pascal programs, one for the control of stimulus presentation and measurement with peripheral devices (BLINK) and another for off-line stimulus reduction and analysis (SCORE). The programs can be applied in a wide variety of research settings. The programs do not use all of the interactive features of the pull-down menus found in the Macintosh, which increases the degree to which they can be modified for local use. They do not require familiarity with programming.

The programs described here were developed to assess the auditory startle response in adult human subjects. The startle response is a brainstem reflex found in a wide range of animals (including humans), at a wide range of ages (from before birth into old age) (Hoffman & Ison, 1980). The neurological pathways and neurochemical sensitivities of the response have been identified in animal models (Davis, Gendelman, Tischler, & Gendelman, 1982). The component of the startle response that we assess is the eyeblink; we measure the integrated electromyographic (EMG) activity of the muscle that causes the eyeblink (orbicularis oculi), by attaching two electrodes to the skin surface below the eye. This startle response is exquisitely sensitive to small changes in the parameters of the eliciting stimulus (Blumenthal & Berg, 1986a, 1986b), which makes it a good candidate for development into a sensory assessment technique. As the stimulus is changed, mea-

surable changes in response amplitude, latency, and probability of the eyeblink EMG can be quantified, using the programs described herein. In addition, the startle response to a given stimulus can be modified by the presentation of another stimulus (called a prepulse) shortly before the reflex-eliciting stimulus. The prepulse intensities range from the psychophysical threshold up to intensities sufficient to elicit the startle reflex itself. The prepulse is also effective in any modality, so that cross-modal modification of the startle reflex can be illustrated (Blumenthal & Gescheider, 1987). The advantages of using startle to assess sensory abilities in auditory, visual, or tactile modalities include the fact that no learning, conditioning, or motivation on the part of the subject is required, the stimulus presentation and response measurement are relatively noninvasive, animal and developmental models are well documented, and the response system is graded to the extent that very small changes in the stimuli are reflected in reliable differences in responding.

In our laboratory, the eyeblink EMG signal is differentially amplified, filtered, rectified, and integrated (contour following) before being sampled by the analog-to-digital (A/D) converter. The auditory stimuli are presented at a range of intensities and waveforms, controlled by stimulus generators, electronic switches, and audio am-

plifiers. The stimuli are presented to the subjects via loudspeakers or headphones. The timing of stimulus production is controlled by the programs described below through the MacPacq interface. We are currently in the process of modifying our facility to accommodate children and infants as subjects, and to present vibrotactile as well as acoustic stimuli. Such extensions can easily be accommodated by the programs, with almost no changes made to the programs themselves.

Because the programs were originally developed to facilitate research in the area of startle reflex elicitation and modification, some of the terms may suggest a certain jargon. The main data collection program, after all, is called BLINK. Likewise, terms such as *prepulse* and *startle stimulus* will be found, because they were used in the initial stages of program development. But the programs are much more versatile than these terms may imply. The BLINK program can be used to control a wide variety of peripheral devices, allowing for the precise timing of their onset and offset. BLINK can also record data from a variety of input transducers not necessarily limited to psychophysiological applications. Similarly, the SCORE program can be used to quantify a wide variety of data, with a range of waveforms.

General Considerations

The programs were designed to be general enough for use in various psychophysiological paradigms. BLINK can control the precise timing of the onset and offset of up to eight peripheral devices, as well as store up to eight channels of input from various transducers. SCORE can quantify response waveforms, either analog or digital. BLINK and SCORE permit the user to change stimulus values and response criteria from one experiment to the next; these user-defined functions have been placed in two utility programs, STIMVALUES and CODEVALUES. The specifics of stimulus presentation, data collection, and response criteria can be changed easily, without any modification of the main programs.

BLINK presents stimuli by controlling the opening and closing of electronic switches through which the particular stimuli are passed. It allows for the activation of up to three different switches per trial, with the user specifying the duration of each activation, as well as the intervals between activations. BLINK also controls the input, storage, and display of response measures, and these data can be either digital or analog. The stored data can then be quantified off-line with SCORE, which specifies, according to user-defined response criteria, response onset and latency, response peak and latency, and response amplitude for each trial, and averages these together by trial code to yield average onset and peak latencies, average response amplitude, and response probability for each stimulus condition. The scored data summaries can be stored for later inspection.

Stimulus Production and Data Collection

BLINK requires a pulse file in order to run, which the user must create with the utility program STIMVALUES. When the user has created a STIMVALUES file, BLINK accesses the file on-line. The pulse file supplies BLINK with the necessary information regarding the timing of events, and STIMVALUES allows the user to specify these timing functions exactly. A maximum of 14 different pulse codes can be identified before the beginning of an experimental session (see Figure 1); they are then

StimValues

Code	Pause	PreP1	Out	Inter	PreP2	Out	Inter	Stim	Out	Delay
1	0	0	0	0	0	0	0	50	1	0
2	0	0	0	0	0	0	50	50	1	0
3	0	0	0	0	0	0	100	50	1	0
4	0	0	0	0	0	0	150	50	1	0
5	0	20	2	0	0	0	130	50	1	0
6	0	50	2	0	0	0	100	50	1	0
7	0	100	2	0	0	0	50	50	1	0
8	0	20	2	30	20	3	80	50	1	0
9	0	20	2	30	20	4	80	50	1	0
10	0	20	2	30	20	5	80	50	1	0
11	0	10	2	20	10	3	110	50	1	0
12	0	10	2	20	10	4	110	50	1	0
13	0	10	2	20	10	5	110	50	1	0
14	0	0	0	0	0	0	0	50	6	0

Edit, Add, Delete, Print, Hear, Quit - (E,A,D,P,H,Q)

Figure 1. Specifying stimulus timing and output line selection in the STIMVALUES program.

stored in a file for later access by the BLINK program. Each code contains information to activate an output line, pause, activate an output line (the same as the first or different), pause, and activate an output line (again, the same as either of the others, or different). The sum of all stimulus durations and intervals cannot be greater than 1,500 msec, but this limitation can be overcome with a slight modification. The three pulses within a pulse code can activate the same device or different devices on any of eight output ports. This means that the user can activate one output line on some trials and more than one line on other trials; many combinations of the eight output lines can be activated in an experimental session. Timing may be controlled to a sensitivity of one millisecond, and this can be increased up to the limit of the MacPacq interface. Sampling of the response line can begin before, at, or after the onset of any of the three stimuli specified in a pulse code from the STIMVALUES file.

BLINK begins with an interactive list of questions, which allow the user to specify the number, age, and sex of subjects, the number of samples to be collected (from 250 to 1,000, at a sampling rate of 1 KHz), the number of trials to be presented (up to 100, but the ranges for the number of samples and the number of trials can easily be extended by a slight modification of the program), the intertrial interval (from 0 to infinity), and the STIM-VALUES file to be used to control the timing of stimulus presentation (see Figure 2). The experimenter can thus have several different STIMVALUES files, with each one used for a single session or for a group of subjects. Utilizing the STIMVALUES pulse codes, BLINK presents the different codes in an order that is either random within trial blocks (a trial block consisting of one presentation

of each pulse code) or defined by the user, while simultaneously recording data from the A/D converter in the MacPacq interface (or from any other device, whether analog or digital). Intertrial interval can be determined by the program so that it ranges between lower and upper values or remains constant, or stimulus presentation can be directly controlled by the user, who then activates each trial with a keypress.

For each trial, BLINK will activate the output lines specified in the STIMVALUES file for the times specified in that file. BLINK samples the response input line (from the A/D converter in the MacPacq interface) for the time specified by the user, and displays the A/D converted data on the screen, along with several pieces of subject and trial information.[1] The display can be amplified, reduced, and moved up or down on the screen. During an experimental session, the user can repeat a trial, halt the session (with the computer waiting until the user resumes the session), or terminate the session at any time. Data are automatically stored on the computer's hard disk, in a file that is accessible to the data scoring program described below. At the end of the session, a Log File is created, which includes the subject number, age and sex of subjects, the date and time of the session, the number of trials, the starting code, the amplifier gain, and up to two lines of user-supplied comments. This Log File can be updated at the end of each session.

Several variations on BLINK exist. In one (BLINK-ITI), the user can specify various intertrial intervals, rather than one value or random values within a range. In another (BLINK-HABITUATION), the user can specify one condition code from a STIMVALUES file to be used for a specific number of trials, then a second condition code


```
≡≡≡≡≡≡≡≡≡≡≡≡≡≡≡≡≡≡≡≡≡≡≡  Blink  ≡≡≡≡≡≡≡≡≡≡≡≡≡≡≡≡≡≡≡≡≡≡≡

  Subject Number 99                    Pulse File Number 70
                                       Starting Code  1 - 8 4
  Sampling Rate (Num/Sec) 1000

  Number Of Samples 500

  Number Of Trials 64

  Minimum Interval (Secs) 25
  Maximum Interval (Secs) 35


  Sex m    Age   19.3

  Social Security Number 2345

  Colbourn Gain 5


             ALL CORRECT ? (Y/N/A)
```

Figure 2. Information entered at the beginning of a session, using the BLINK program.

for a specific number of trials, and so on, for a total of 10 different condition codes. In a third (BLINK-BUTTON), the program collects data relevant to a buttonpress in a directed attention paradigm, recording the signal detection accuracy, reaction time, and eyeblink EMG data for each trial. These minor modifications of the general BLINK program illustrate the fact that it can be applied to a number of different experimental problems.

The programs can also be used to calibrate equipment. If we wish to calibrate the timing of some of the peripheral devices, for example, we can treat the output of these devices like response input lines, measuring their output with the BLINK program while activating them with that same BLINK program.

Quantification of Responses

SCORE quantifies the data collected by BLINK. These data consist of a series of digital values (stored as ASCII strings) that reflect the analog EMG activity before and after the presentation of the stimuli (see Figure 3). This EMG activity is relatively stable during a baseline period before stimulus presentation, and the point at which the slope of the EMG tracing changes, due to an increase in muscle activity below the eye, is identified as the onset of the response. The time between the onset of the eliciting stimulus and the onset of the response is identified as response latency. The point at which the EMG activity ceases to increase and the tracing begins to return to baseline is identified as the peak of the response (the maximum voltage of the response). The difference between the voltages at onset and at peak is identified as the amplitude of the response. A response is not elicited on all trials, with a failure to respond to a stimulus indicated by no change from baseline. The number of trials on which a response occurred, divided by the number of trials on which a response could have been measured had one occurred, is identified as response probability.

SCORE requires a code file to run, which the user creates with the utility program CODEVALUES. The code file supplies SCORE with the response criteria for each stimulus condition, and CODEVALUES allows the user to specify these response criteria exactly for each separate trial code, such as the window within which a response onset will be accepted following any of the stimuli presented, the peak window, and how much the slope of the EMG tracing must change (as a change of so many y-units [vertical scale of voltage] within so many x-units [milliseconds], before the computer will accept a response onset; see Figure 4). These response onset and peak windows can be targeted to any of the three stimuli presented in a pulse code (specified by STIMVALUES). The user can specify response criteria for each different pulse code (as identified in STIMVALUES), or the same criteria can be used for all stimulus conditions (the "all trials" option).

SCORE, utilizing the data from CODEVALUES, allows the user to locate and record the onset and peak of the blink response, with the program displaying the x- and y-coordinates (in milliseconds and arbitrary units, respectively) for each point. Providing maximum flexibility, SCORE will find the response onset and prompt the user for confirmation or adjustment; this is true for the response peak as well. The trial can be scored as a bad trial (one on which a response cannot be measured, as,
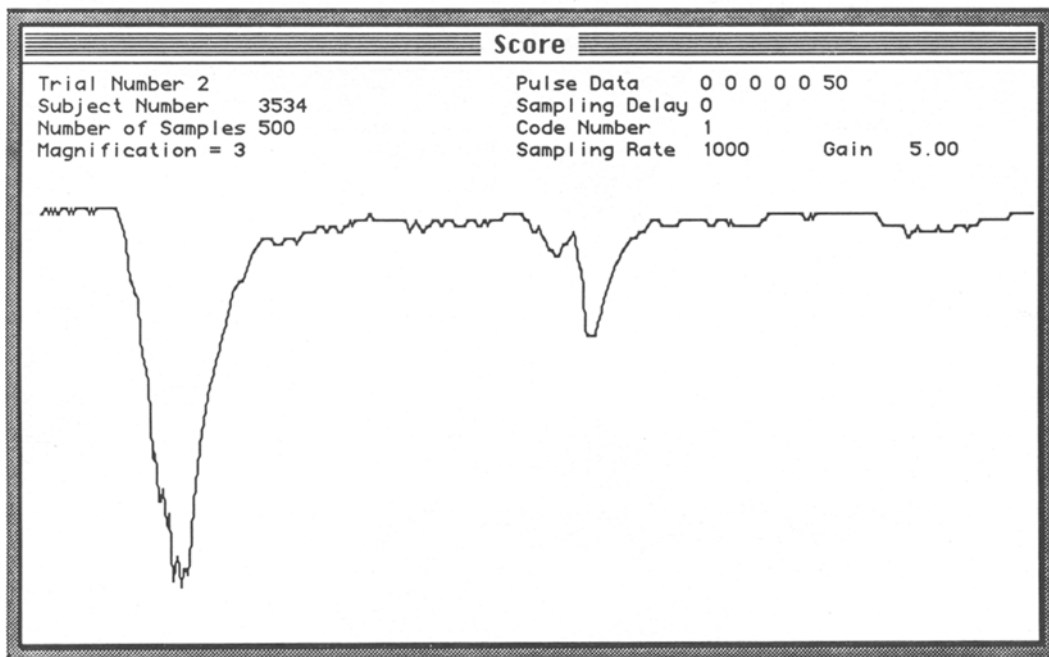

Figure 3. A display of the digitized integrated EMG activity of a reflex response (large) and a later spontaneous response (small), using the SCORE program.

```
╔══════════════════════════════════════════════════════════╗
║                        CodeValues                         ║
╠══════════════════════════════════════════════════════════╣
```

Code	OnStim	OnStrt	OnDura	ChgY	ChgX	PkStim	PkStrt	PkDura
1	1	20	80	2	5	1	20	120
2	1	40	80	2	5	1	40	120
3	1	60	80	2	5	1	60	120
4	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0

All Trial

15	1	20	80	2	5	1	20	120

Edit, Print, Quit - (E,P,Q)

Figure 4. Specifying response criteria with the CODEVALUES program.

for example, in the case of movement artifact) or a zero trial (one on which there is a failure to respond). Once the data have been scored, they are averaged according to trial code and presented to the user. The averaged data and the data for each trial can be printed and/or saved to disk. As with BLINK, the data plot can be magnified and moved on the screen. Other options include a movable cursor to indicate position on the response plot, the ability to go to any trial upon request, and the ability to change scoring parameters at any time.

Once the CODEVALUES file has been created, the user enters the SCORE program to quantify the data from a single session. The user enters the subject number and a standard amplifier gain for the experiment (to accommodate for intersubject differences in response amplitude, the response line must occasionally be amplified more for one subject than for another; the standard amplifier gain option is used for the correction of these gain changes, in order to allow comparisons across subjects and across experiments). SCORE then displays the EMG tracing from one trial on the screen, along with subject and trial information (some of which can, with a single keyboard command, be hidden from view, to eliminate the possibility of biased data scoring). The user has a variety of interactive options during a scoring session, such as amplifying or reducing the size of the display, moving the display up or down, correcting for response amplifier gain changes within a session, repeating a trial, going to any trial, or terminating the scoring session. To score a trial, the user presses a specified key, and the computer, using the response criteria described in the CODEVALUES file, finds what it reads as the onset of the response. The user can agree by means of a keypress, and the program will

then find the peak of the response. If the user agrees, by means of another keypress, the program will then store the information from that trial and move on to the next trial, finding what it reads as the onset of the response. If no onset is found, the user can indicate the failure to respond ("zero response trial"). If the trial is contaminated by movement artifact, the user can specify this as well ("bad trial"). This scoring procedure may seem to be overly interactive, but it is necessary because the data are not perfectly clean in EMG response measurement. The response criteria specified in the CODEVALUES program is used most of the time, but SCORE will occasionally select an incorrect point for the onset or peak of the response. This is due not at all to any shortcoming of the program, but rather to the fact that EMG data are not silent in the absence of stimuli; spontaneous noise is always a slight problem.

After all trials in a session have been scored, or after the user has decided to terminate the session before all trials have been scored, SCORE displays the trial-by-trial values for response latency and amplitude (along with several other pieces of information), followed by the average response latency, amplitude, and probability for each stimulus condition (as specified in STIMVALUES). These averages and trial-by-trial values can be printed and saved in a text file for later use.

Several variations on SCORE exist too. In one, the data from BLINK-BUTTON are analyzed, with the average reaction time and accuracy of the buttonpress in response to the target stimuli identified, and the eyeblink response averages are separated for each attention condition, as specified at the beginning of the BLINK-BUTTON session. In another, called AVERAGE, the user can specify

trials from a session to be averaged together—either all trials or some subset identified by trial numbers. These averaged responses can then be scored in the same way as single trials.

Hardware and Software Requirements

BLINK requires a MacPacq interface, which controls devices used for peripheral stimulus production, logic control, and data acquisition.[2] The SCORE program can be used to quantify data with or without the MacPacq. These programs were developed on a Macintosh SE, in Turbo Pascal, but they do not use the Macintosh pull-down menus, nor do they use several other features of the Macintosh. Therefore, the programs can be easily employed by all users, whether they are familiar or unfamiliar with the Macintosh. The programs will run on any Macintosh Plus, SE, SE 30, or II computer. Due to slight differences in the processor chips in each machine, it is advisable to recompile the programs on the specific computer to be used.

For non-Macintosh environments, the ease of porting depends on the type of A/D converter used to replace the MacPacq (which is available only for the Macintosh). For BLINK, which interacts with the MacPacq directly, an experienced programmer could replace the MacPacq commands with the commands relevant to another A/D converter. For SCORE, which does not actively interact with the MacPacq, only commands incompatible with the particular computer would require changing. These modifications are facilitated by the fact that the programs are written in Turbo Pascal, with very few Macintosh-specific commands. Also, the data created by BLINK (and reduced by SCORE) are stored as an ASCII string and can be ported for use in the current form, if the user knows the order of the data points in the string. The first 15 elements in the string contain information about the sampling rate, pulse code data, and so forth. Therefore, if this information is added to the beginning of a data string collected with a program other than BLINK (or with a different I/O board, or even copied to the Macintosh from a different machine), these data could be quantified with the SCORE program. Alternatively, the SCORE program could handle these other data formats after slight modifications have been made to the program itself.

The pulse file (created with STIMVALUES) must be kept in the same Macintosh folder as the BLINK program, and the code values file (created with CODEVALUES) must be in the same folder as the SCORE program. When the BLINK program collects data, it creates a data file within the same folder. Therefore, we simply move a copy of each of the four programs into a separate folder for each experiment, so that everything that we need is in the same folder.

We are confident that these programs can be useful in many different research settings. Most laboratories involved in startle research are operated with IBM microcomputers, and the programs described in this paper will allow for the expansion of Macintosh-based research options. We use the Macintosh because it is so easy for students to become familiar with, which reduces training time.

Availability

A user's guide is available for each program, as are examples of the programs and all subroutines. To obtain copies of the software, source codes, and documentation, send two 3.5-in. 800K Macintosh-formatted diskettes to Terry D. Blumenthal, Department of Psychology, Wake Forest University, Box 7778 Reynolda Station, Winston-Salem, NC 27109. Full permission for the use of these programs will be provided for any nonprofit purpose; we ask only that we receive credit (citation) for the programs' initial development. We do not grant permission to use these programs for profit in any way.

REFERENCES

BLUMENTHAL, T. D., & BERG, W. K. (1986a). The startle response as an indicator of temporal summation. *Perception & Psychophysics*, **40**, 62-68.

BLUMENTHAL, T. D., & BERG, W. K. (1986b). Stimulus rise time, intensity, and bandwidth effects on acoustic startle amplitude and probability. *Psychophysiology*, **23**, 635-641.

BLUMENTHAL, T. D., & GESCHEIDER, G. A. (1987). Modification of the acoustic startle response by a tactile prepulse: Effects of stimulus onset asynchrony and prepulse intensity. *Psychophysiology*, **24**, 320-327.

DAVIS, M., GENDELMAN, D. S., TISCHLER, M. D., & GENDELMAN, P. M. (1982). A primary acoustic startle circuit: Lesion and stimulation studies. *Journal of Neuroscience*, **2**, 791-805.

HOFFMAN, H. S., & ISON, J. R. (1980). Reflex modification in the domain of startle: 1. Some empirical findings and their implications for how the nervous system processes sensory input. *Psychological Review*, **87**, 175-189.

NOTES

1. The A/D converter on the MacPacq interface currently has a sensitivity range of 8 bits, which is lower than the 10- or 12-bit range normally used in this area of research. However, the 8-bit converter range is sufficiently sensitive for the measurement of these responses. Intersubject differences in startle responsivity result in a wide range of response amplitudes between subjects, but we accommodate for this wide dynamic range by changing the gain on the Coulbourn bioamplifier when necessary, to maintain the responses within the range of the A/D converter. The dynamic range within a single subject is seldom this wide, so the problem is generally reduced within a single testing session. This is not the perfect solution, since it requires correction of the gain changes, but BLINK and SCORE have commands that allow the user to make the corrections. The manufacturers of the MacPacq interface plan to market a 16-bit upgrade of the interface in 1990, which will circumvent the limitation of 8-bit conversion.

2. The MacPacq interface is available from Biopac Systems, 5960 Mandarin Drive, Suite D5, Goleta, CA 93117.