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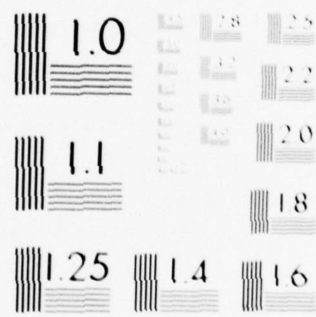

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MEMPHIS STATE UNIVERSITY

DEPARTMENT OF ELECTRICAL ENGINEERING
MEMPHIS, TENNESSEE

LEVEL II

INVESTIGATION OF EVOKED POTENTIALS
RELATED TO
SIMULATOR ONSET CUES

FINAL REPORT

APRIL, 1979

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Memphis State University
Department of Electrical Engineering
The Herff College of Engineering

INVESTIGATION OF EVOKED POTENTIALS RELATED TO SIMULATOR ONSET CUES

FINAL REPORT
APRIL, 1979

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

In the initial phase of this work, facilities were developed for controlling evoked potential experiments in which the input stimuli are related to certain onset cues produced in flight-training simulators. Experiments were developed and vertex measurements were taken, processed and stored under control of a hybrid computer.

One stimulus consisted of the observation of a sudden vertical displacement of a slowly moving visual image. A second stimulus consisted of a sudden deflation of a pneumatic cushion. Each of these stimuli appears to produce a different, but reasonably

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(20) well-defined evoked potential. The most conspicuous attribute of the deflatable seat response appears to be a sharply defined N200 wave.

The preliminary exploratory experiments and certain variations of these experiments suggest more formal experiments that may be performed to help determine if evoked potential measurements may be useful for contributing to ground-based simulator design criteria. These experiments are outlined in the ensuing report

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Chapter 1

INTRODUCTION

1.1 Background:

The work described in this report initially was conceived during participation in a USAF-ASEE Summer Faculty Research Program in the summer of 1977 at the Human Resources Laboratory at Wright-Patterson Air Force Base. The work pursued was an exploratory study related to the following general questions: (1) Can evoked potential technology be utilized as a practical tool to assist in decision making related to design and evaluation of pilot-training simulators? (2) Can evoked potentials be utilized to assist in identifying either high-priority cues or redundant and unnecessary cues? Do they have potential use in the evaluation of an individual's training performance? It is of interest to investigate whether the electrical potential measured at scalp nodes can be utilized as an objective measurement related to sensing various stimuli, or interpreting the information content of a particular stimulus. For efficient design of ground based flight training simulators, it is important to know, for any specific mission, not only which cues are important, but also which cues may detract from the performance of a trainee or his transfer of training if these cues are not properly synchronized with all other cues. It is postulated that measurement of evoked responses will be of use in obtaining this information. The work described in this report is preliminary work aimed at addressing these questions.

1.2 Research Objectives:

It has been suggested that responses from a much wider range of stimulus parameters be studied, and that a body of normative data for various stimuli be established. In order to assess the potential usefulness of evoked potential techniques to contribute to simulator design criteria and assist in training evaluation, it was proposed that a set of more application-oriented EP experiments be performed.

Most EP experiments that have been performed involve application of a well-defined, sensory stimulus in a laboratory environment. In order to test a simple hypothesis, it is important to avoid interraction of a number of different variables. However, in real world flight-training situations, there are generally a number of interrelated variables involved. For instance, the action of a G-seat may stimulate motion, tactile, and proprioceptive receptors. Simultaneously, meaningful visual and auditory inputs may be present. The onset time of the G-seat stimulation may be difficult to define, and the various modes of stimulation may not occur simultaneously. It seems apparent that the response to such multimodal stimuli should be investigated utilizing a research-oriented simulator such as the Advanced Simulator for Undergraduate Pilot Training. The gap between conventional laboratory experiments and simulator-based EP experiments is wide. Therefore, it was proposed that prior to designing simulator-based EP experiments, laboratory experiments involving multimodal inputs related to pilot training be performed. It was anticipated that experience and results obtained from these experiments would be useful in designing simulator-based experiments that will more directly address the questions that are being posed.

It was proposed to design three types of exploratory experiments. One experiment involved a stimulus consisting of the observation of visual motion. A second experiment utilized an onset stimulus related to a G-seat onset stimulus. A third experiment involved a combination of a visual and G-seat type stimulus. Since the proposed work was exploratory in nature, precise hypotheses were not tested. It was proposed that some of the following questions be addressed:

1. Can a lambda wave associated with observation of visual motion readily be detected?

2. Are the latencies of the evoked responses relatively constant

   a. for different tests on the same subject?
   b. among different subjects?

3. Is control of physiological artifacts or elimination of artifact contaminated responses necessary?

4. Can a specified evoked response be detected from a single sample?

5. Is the response detected in the parietal region more discernible than that detected in other regions of the scalp?

6. Does the response with a task differ significantly from the response without an associated task?

7. Can a computer algorithm be formulated for nearly real time operation that reliably identifies visual motion onset solely from the measured scalp response of the subject?

It was anticipated that not all aspects of the three exploratory experiments would be thoroughly investigated. It was further anticipated that information related to several of the specific questions being addressed would be obtained.

1.3 Research Activities:

Experiments related to observation of visual motion, a seat deflation stimulus and a combination of the two stimuli were developed and tested. Questions 5 and 7 in the preceding section were not addressed. However, at least some information related to the other five questions was obtained. The experiments described in the original proposal were all slightly modified. The modifications made were consistent with the overall objectives. The experiments performed and results obtained are described in Chapters 3 and 4.

The research potentialities resulting from the development of our evoked potential facilities significantly exceed our original expectations. Capabilities we now possess as the result of this development of facilities are described in Chapter 2.

Chapter 2

FACILITIES DEVELOPED

2.1 Hardware Development:

A flexible system, capable of controlling a wide variety of stimuli has been developed. The system is controlled by a small, general purpose hybrid computer. The experiments are controlled by software operating on a PDP-8/I minicomputer. Interfaced to the computer and used in conjunction with the computer are two analog computers, a parallel patchable logic console, two magnetic tape drives, two analog tape consoles and two analog display devices. Both visual and pneumatically induced motion cues are controlled by the hybrid computer, and all sampled responses are stored on magnetic tape files. A block diagram of the system facilities is given in Figure 1.

The Hewlett-Packard Bioelectric System is used for amplifying the evoked response. The entire electrical activity at four nodes can be monitored and recorded during the conduct of an experiment. A high-level output is sent to the hybrid computer for additional amplification, sampling and analog-to-digital conversion.

The digital logic console is utilized for timing, analog computer control and for certain logic operations. The patching of the clock used to control sampling rate is illustrated in Figure 2. Three 4-bit counters are utilized such that the carry-out of one counter is connected to the carry-in of the next counter. The counters are driven by a one megacycle clock. With leads A and B connected as shown, flag F2 comes up 2.048 milliseconds after the clock is started. This flag is sensed by the digital computer to control uniform sampling rate of the evoked

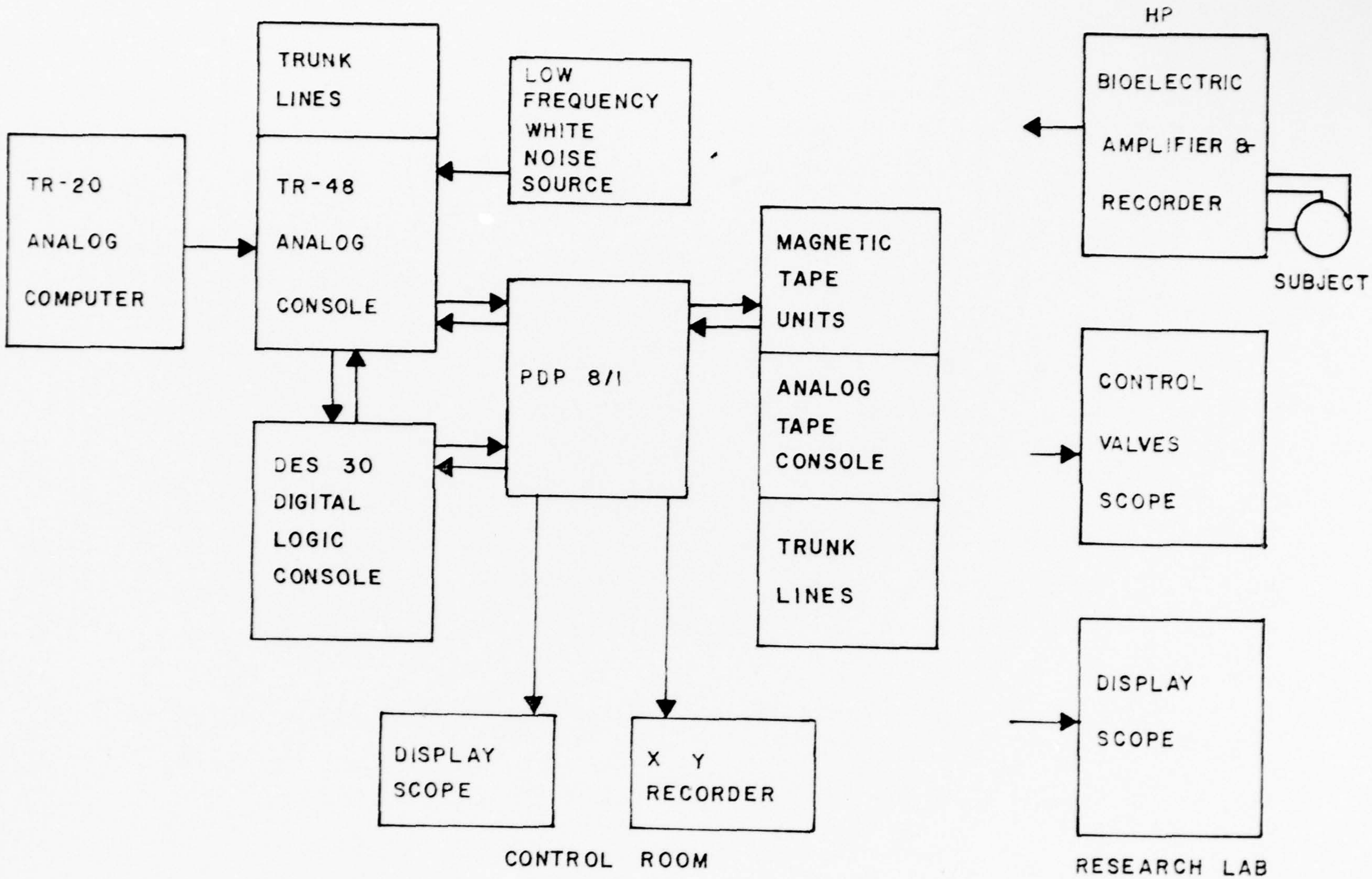


FIGURE I. BLOCK DIAGRAM OF SYSTEM FACILITIES

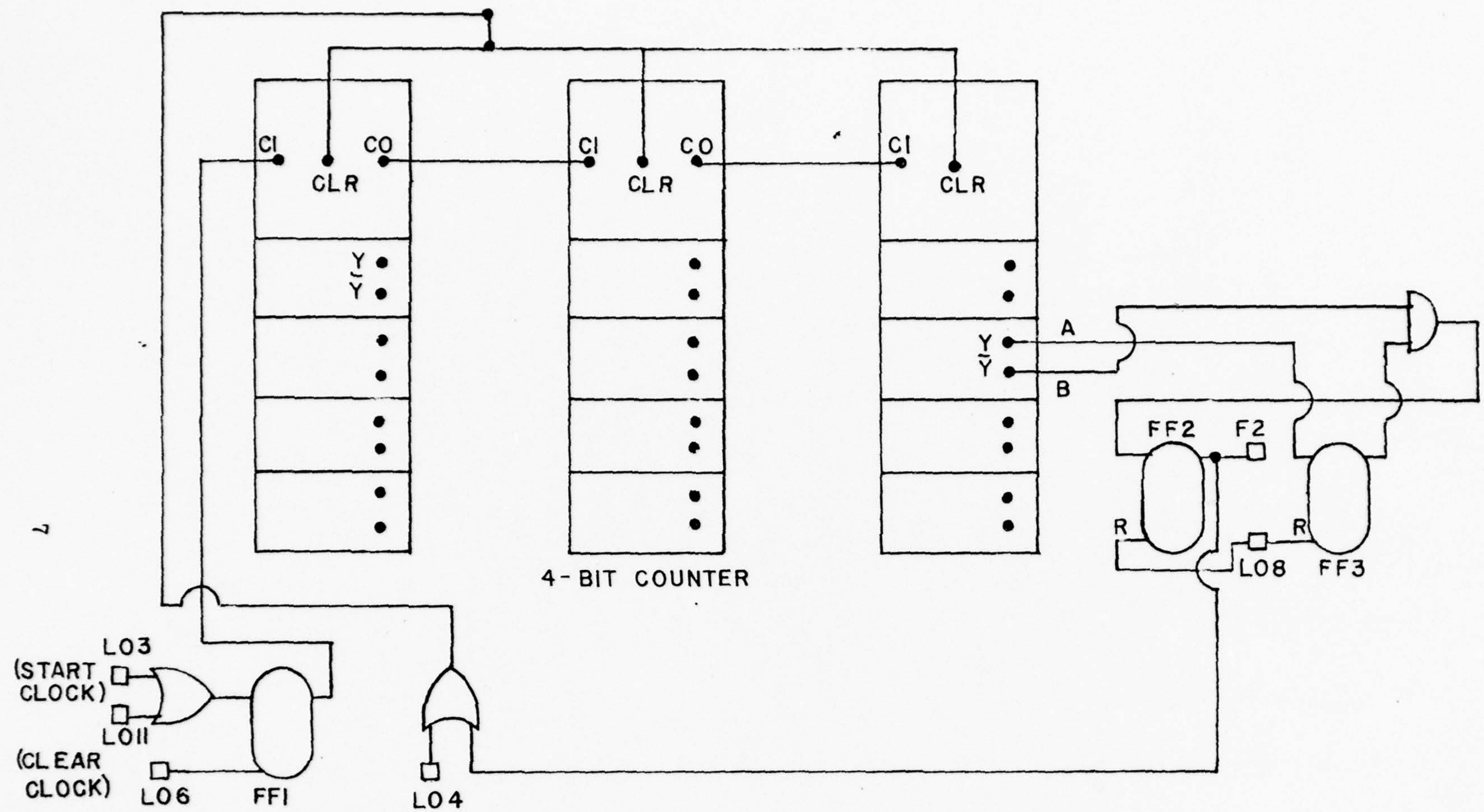


FIGURE 2. DIGITAL LOGIC IMPLEMENTATION OF GENERAL PURPOSE CLOCK.

response. To increase the sampling rate, leads A and B can be moved up or to the left. To decrease the sampling rate, the leads are moved down. If the researcher wishes to focus on either a narrower or wider evoked response during the conduct of an experiment, he can do so by changing these leads during an inter-stimulus interval. This can be done without halting the experiment, and all information is retained and can be processed and displayed using a post-processing software package.

The analog computers are used to control the size and shape of the visual display, to control the horizontal and vertical motion of the visual display, to randomly vary the inter-stimulus interval and to drive the voltage controlled pneumatic valves. An analog patching diagram for image generation and horizontal motion is shown in Figure 3. An analog computer diagram for stimulus control and inter-stimulus interval variation is shown in Figure 4.

Refer to Figure 3. The polar coordinates for a circle are the outputs of integrators 13 and 15. The size of the ball can be varied by adjusting potentiometer P13. Nonlinearities in the visual display device can be compensated for by varying P19 or P20. Horizontal harmonic motion of the display is produced by integrator 21. The width of the horizontal excursion is controlled by P10.

It should be noted that even though most experiments we performed involved non-visual stimuli, the moving visual images were still used in the control room for system checkout and for real-time monitoring of the current state of the experiment.

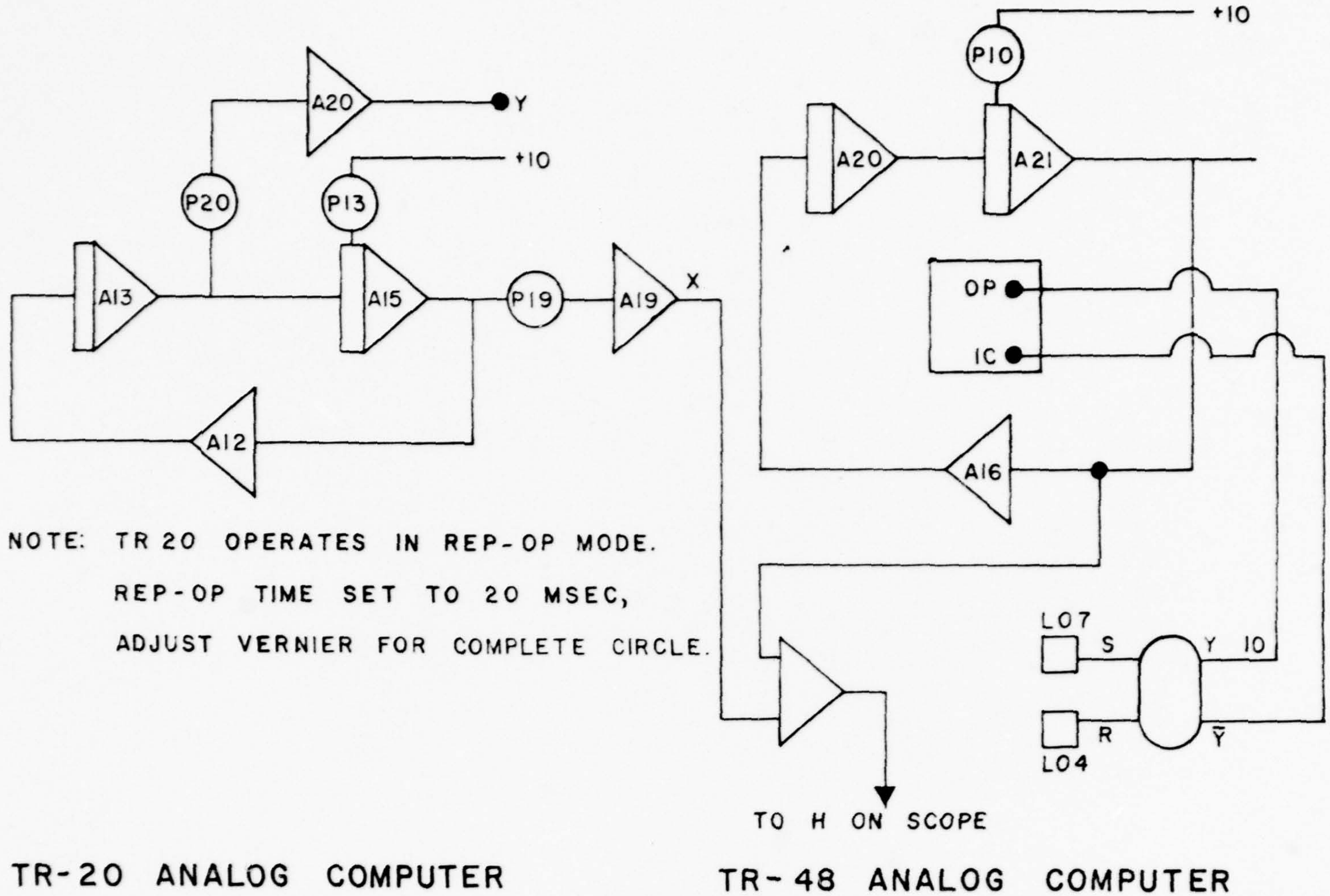


FIGURE 3. ANALOG COMPUTER PATCHING DIAGRAM FOR IMAGE GENERATION & HORIZONTAL MOTION.

Refer to Figure 4. The output of integrator A14 is a one-dimensional random walk. When boundaries specified by inputs to comparators C11 or C27 are crossed, flag F9 comes up, and the random walk is terminated. If one of two randomly selected stimuli is to be applied, such as an up displacement versus a down displacement or a left seat deflation versus a right seat deflation, then flag F4 is sensed, and the appropriate stimulus is applied. This is done by setting either logic output 3 or logic output 11. Setting LO3 produces a sudden downward vertical displacement of the image, whereas setting LO4 produces a sudden upward displacement of the visual image. The use of normally-opened switches 3, 4, 5 and 6 enables the same patching diagram to control seat partition deflations. This is described in more detail later in this chapter.

Vertical displacement velocities can be varied by varying P21 and P22. Inter-stimulus intervals are controlled by P2. In order to enhance the chances of selecting a particular stimulus, the settings of P11 and P14 can be changed. Furthermore, all these adjustments can be made during the real-time conduct of an experiment. The capability to vary inter-stimulus interval and to bias the selection of a particular stimulus during the conduct of an experiment proved to be particularly useful

Use of a general-purpose hybrid computer for the control of evoked potential experiments is somewhat novel. The benefits accrued from this approach are the following:

1. Complexity and storage requirements for system software are reduced

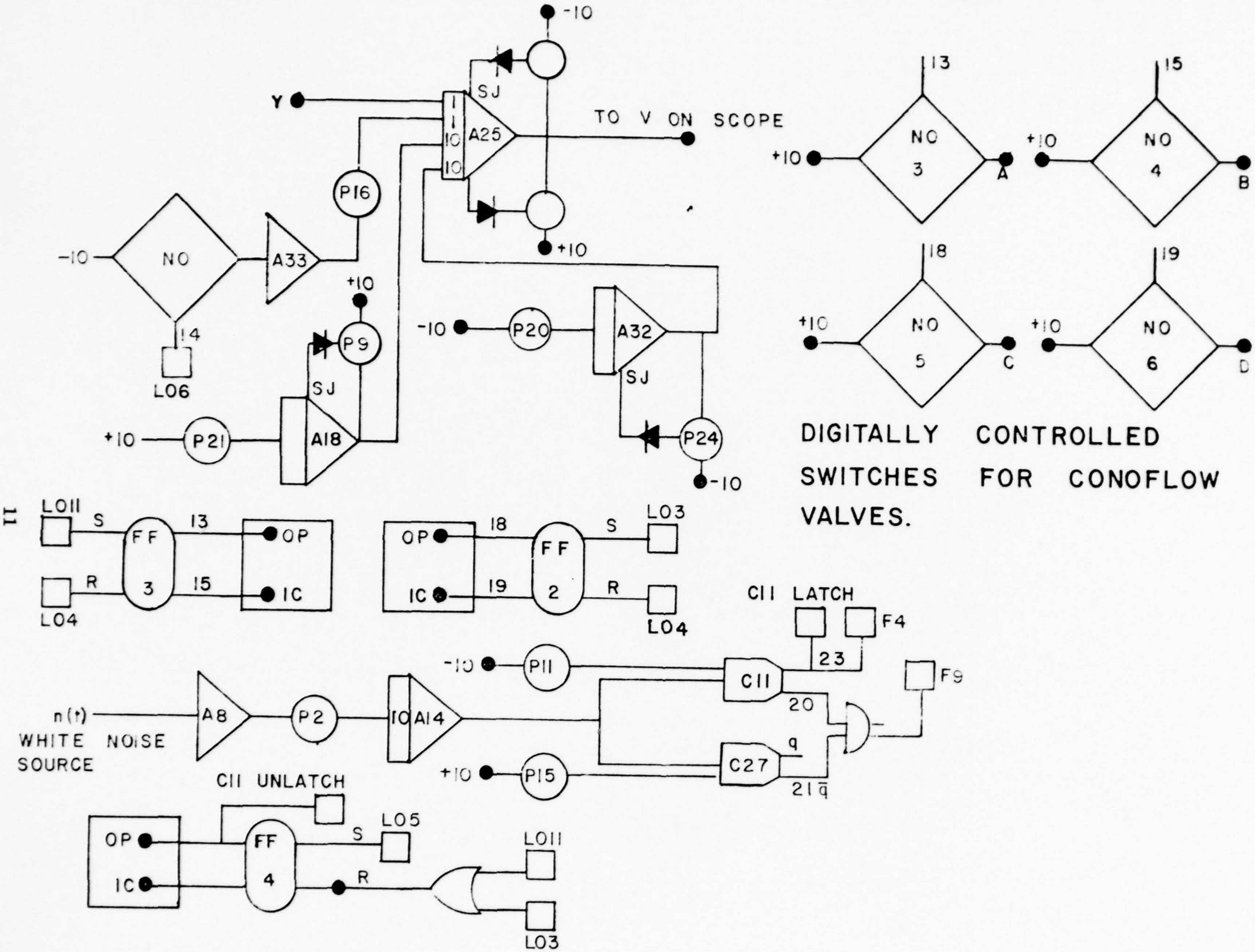


FIGURE 4. ANALOG COMPUTER PATCHING DIAGRAM FOR STIMULUS CONTROL.

2. Real time parameter adjustments can be made during the course of an experiment

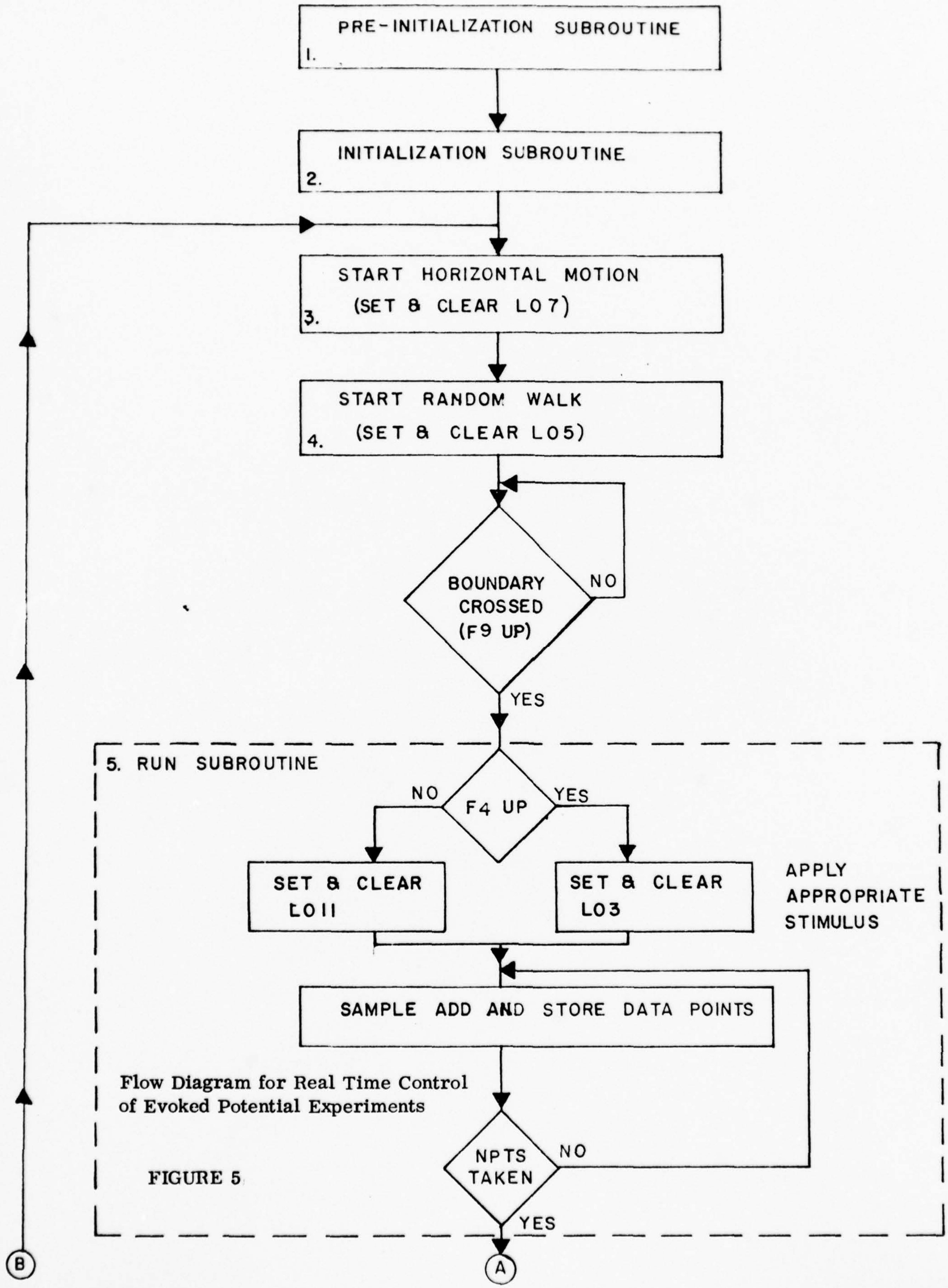
3. A variety of experiments can be performed without changing system software.

4. Requirements for special-purpose hardware appear to be significantly reduced.

2.2 Software Development:

Very general system software has been developed. This software and the use of analog computer components enable experiments to be modified or even changed significantly with very little additional effort. The existing software is utilized both for experiments involving visual stimuli and those involving seat or backrest stimuli. A flow diagram for the real-time control of the evoked potential experiments is given in Figure 5.

Refer to Figure 5. The pre-initialization routine zeroes all counters and flip-flops, accepts an ID number and spaces the magnetic tape forward past all previous stored data. The initialization routine clears all summing registers, and accepts input data specifying the number of evoked responses, the number of points per response and how frequently the running averages are to be displayed. Block 4 produces the random interstimulus interval resulting from the random walk. Block 5 controls sampling, computation of running averages and accumulation of data for a single evoked response. Subsequent to this, data points for a single evoked response are DMA transferred to magnetic tape. Block 8 controls incrementation of the number of samples, selection of the display interval and display of the running average of the evoked response. If one of two possible input stimuli has been selected, such as seat deflation or backrest deflation, then the running averages



Flow Diagram for Real Time Control of Evoked Potential Experiments

FIGURE 5

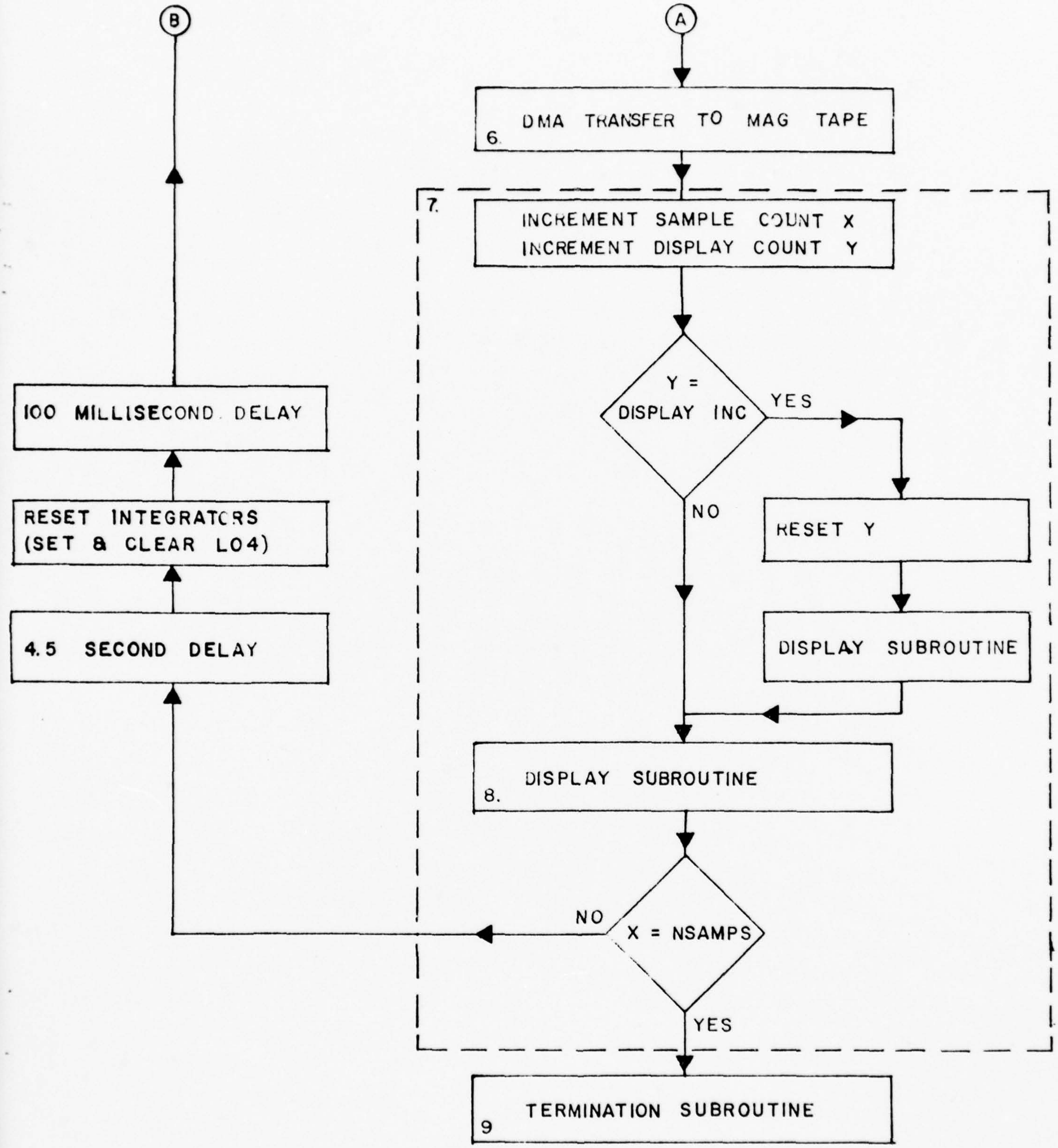


FIGURE 5 - Continued
Figure 5a

from just one of these stimuli can be displayed in real time. In block 9, a fixed interstimulus delay is provided, and certain integrators and the clock are reset. The termination subroutine provides housekeeping operations such as removing the visual image from the CRT screen, terminating data storage with an end-of-file mark and rewinding the tape.

In addition to the software utilized for real-time operation, a post processing system has been developed. A detailed flow diagram for this system is given in Figure 6. This system enables any response from any subject to be recalled and displayed, scaled, identified and filtered. Although theoretically any digital filter can be inserted into this software package, it is anticipated that only finite impulse response (FIR) filters will be utilized. The filter currently in use is a general Nth - order smoothing filter, in which N can be selected by the user. As an example, use of a 15th order filter in conjunction with a 1.025 millisecond sampling rate essentially removes 60-Hz artifacts with very little low-frequency distortion of the measured response. The transfer function for such a filter is

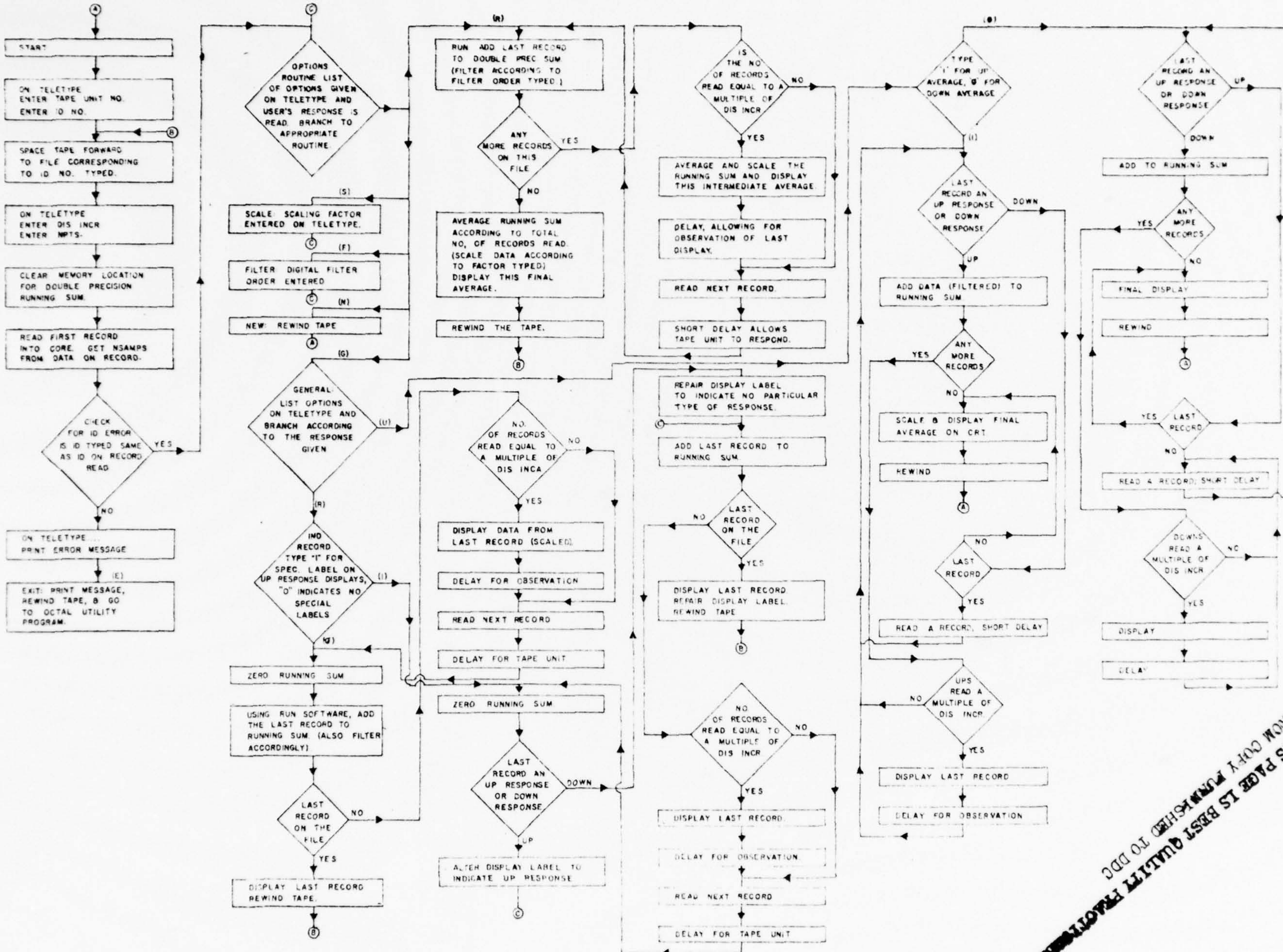
$$T(f) = \left(\frac{1}{16} \sum_{k=0}^{15} z^{-k} \right)_{z=e^{j2\pi f(1.024\times10^{-3})}}$$

The magnitude response for this filter is shown in Figure 7.

For subjects with certain hair textures, it was difficult to rapidly affix scalp probes such that 60Hz artifacts would be minimal. Since it was deemed undesirable to clip any hair, use was made of this smoothing filter. Figure 8a illustrates a single response from such a subject when the filter was not utilized. Figure 8b illustrates the filtered response.

The post processing package was developed so that new options can

FIGURE 6. FLOW CHART FOR POST PROCESSING SOFTWARE



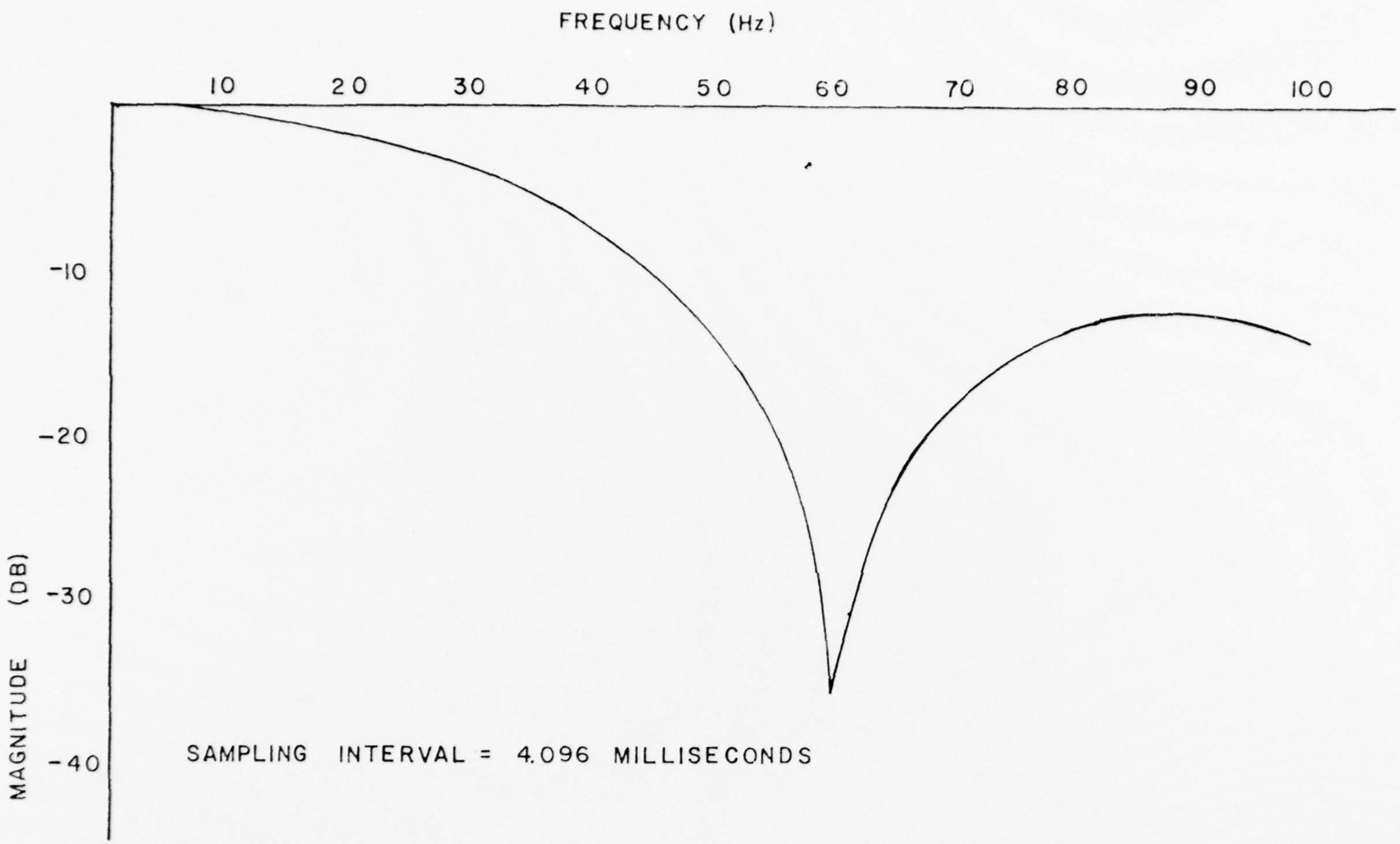


FIGURE 7. MAGNITUDE RESPONSE FOR 15th ORDER SMOOTHING FILTER.

SCALE:

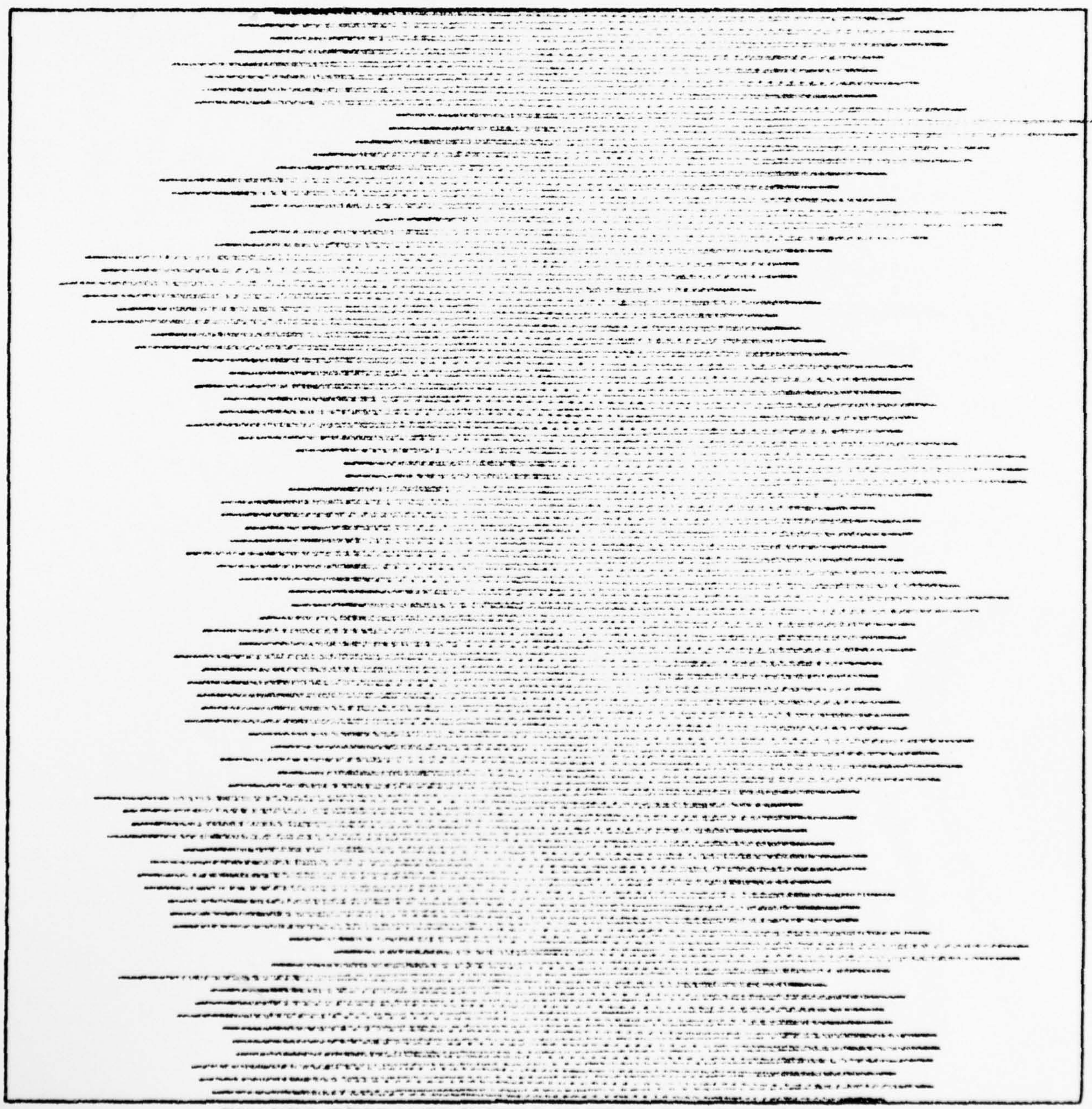
Horizontal: 196 msec/in.

Vertical: 24.7 MV/in.

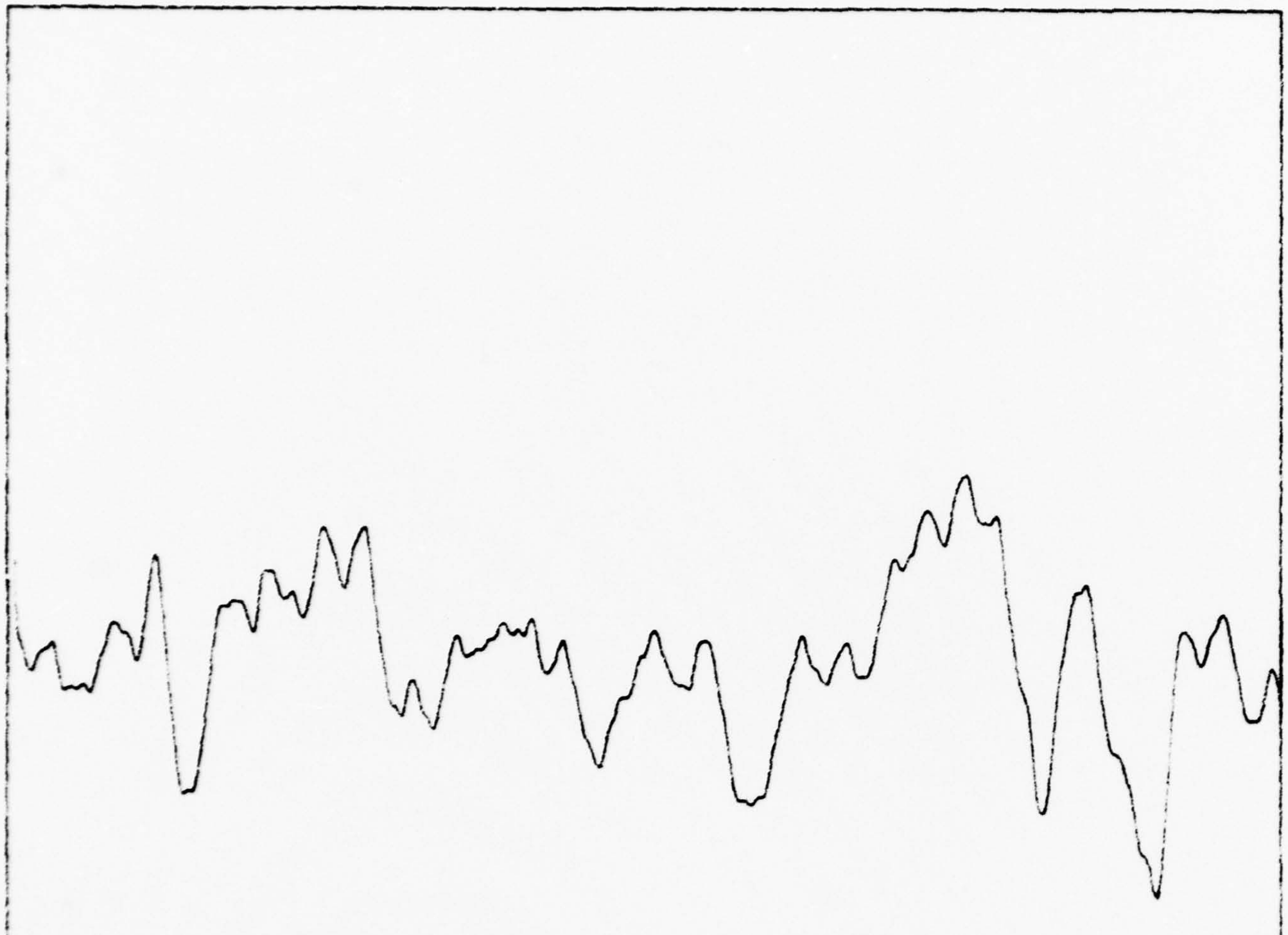
Sampling Interval:
2.05 milliseconds

SUBJECT L

20-year-old female.
First response to combination of visual-observation-of-motion and seat-deflation stimulus.



EVOKED RESPONSE WITH LARGE 60-H_Z ARTIFACT
Figure 8



DIGITALLY FILTERED EVOKED RESPONSE WITH 60Hz ARTIFACT

Figure 8a

SCALE:

Horizontal: 196 msec/in.

Vertical: 24.7 μV/in.

Sampling Interval:
2.05 milliseconds

SUBJECT L

20 year-old female.
First response to combination of visual-observation-of motion and seat deflation stimulus.

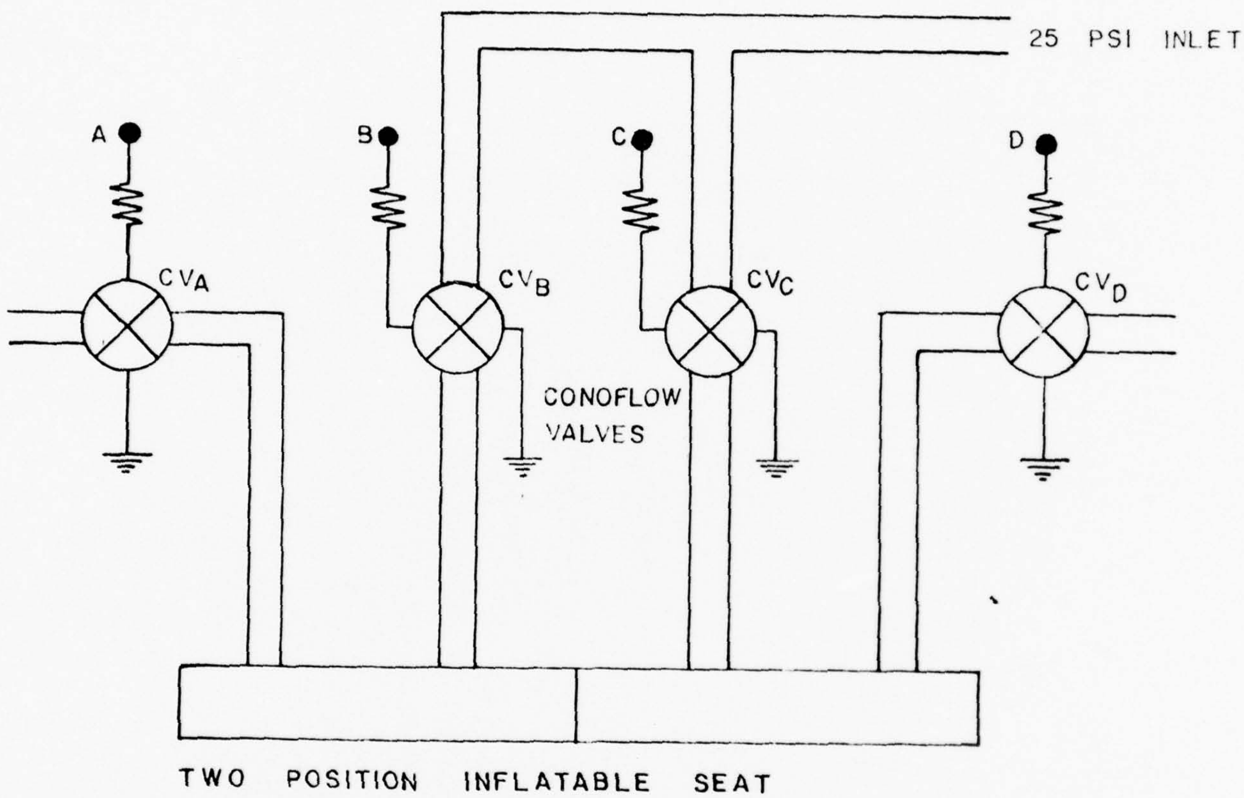
easily be added. One option that is planned is the capability to mark or delete certain responses from the running averages. Examples of responses to be deleted are responses obtained when a subject was interrupted, or any responses that resulted during saturation of an amplifier.

2.3 System Operation:

When experiments are being conducted, the subject is located in a research laboratory. All experiments were performed with the subject seated in a dimly lighted room. A research assistant stays in the research laboratory with the subject. The assistant is not visible to the subject, but observes the stimulus that is being applied. The electrical activity at the vertex node as displayed on the bioelectric recorder, and the running averages of the evoked responses can be monitored by the research assistant. The research assistant also records any distractions or significant subject activities that may tend to bias results.

The research assistant has telephone communications with the principal investigator in the control room. Once initialized, the experiment is under control of the computer. However, during the conduct of an experiment, the principal investigator may vary certain parameters, as noted earlier in this chapter.

All equipment except the stimulus producing equipment and the bioelectric recorder is located in the control room. Consider the experiment in which the stimulus consists of either a left-partition seat deflation or a right-partition seat deflation. The control hardware for this stimulus is shown in Figure 9. Refer also to Figure 4. If the right boundary of the random walk is crossed flag F4 comes up, and the stimulus is applied by setting digital output LO11. Setting LO11



NOTE: A, B, C, & D ARE OUTPUTS FROM DIGITALLY CONTROLLED SWITCHES SHOWN IN FIGURE 4.

FIGURE 9. SEAT DEFLATION CONTROL SETUP.

sets flip-flop 3 which puts a 1 on line 13 and a 0 on line 15. Thus, ten volts is applied to point A in Figure 9, and 0 volts is applied to point B. This closes the input conoflow valve to the left partition and opens the exhaust valve CV_A, producing a left seat deflation stimulus. By observing Figures 4, 5 and 9, it is seen that after the evoked response has been measured, the seat is returned to its initial inflated position, and a delay is implemented in order to allow the subject to return to an unstimulated state.

Chapter 3

EXPLORATORY EXPERIMENTS

The experiments that were developed were selected solely for the purpose of addressing the general questions posed as part of our research objectives. Whereas classical research techniques involve fixing all parameters such that a response can be associated with a single well-defined input, onset cues produced on flight-training simulators are complex and occur when the subject is already performing multiple tasks. Since there is no reason to expect linearity in the response to multiple inputs, classical type experiments were not performed.

A systems approach was utilized. The input to the system was considered to be the particular stimulus. The output was the electrical potential measured at the vertex mode. Measurements were with respect to the mastoids and utilized a common-mode configuration.

For the visual stimulus, if the purpose of the experiments had been to measure the evoked cortical potentials associated solely with motion abstracting mechanisms, then it would be desirable to instrument the eyes and to compensate for eye-movement artifacts. An alternate approach that has been implemented is to use the electrical potential associated with rapid eye movement to trigger the measurement of an evoked response. Even for our non-visual stimuli, the seat deflation stimuli, it is possible that a portion of the measured responses could be produced by rapid eye movements. If so, this could probably be eliminated by instructing the subject to keep his eyes closed during the experiment.

However, it would be difficult to associate such an experiment with the arrival of an onset cue when a trainee is operating a simulator or an aircraft.

The following hybrid-computer controlled experiments were designed and performed:

Experiment A:

The subject was seated 6 feet from a 3-5/8 x 4-5/8 inch Tektronix oscilloscope screen. An image of a 3/4 inch diameter ball of medium light intensity was displayed on the screen. The subject was instructed to observe the ball as it moved laterally across the screen with simple harmonic motion at a frequency of 1 radian/second. The stimulus consisted of a randomly occurring downward impulse acceleration of the ball at a speed of 64 cm/second.

The subject was seated in a dimly-lighted unshielded room and was instructed to count the number of stimuli observed. The response was amplified by a Hewlett-Packard bioelectric amplifier with a lower cutoff frequency of 0.15 H_z and an upper cutoff frequency of 30 H_z. The signal was sampled approximately every 1.03 milliseconds for a selected time period, usually 0.6 seconds. A 10-bit A/D converter was used to sample the signal.

Experiment A-M1:

The same visual image described in Experiment A is utilized as a stimulus. In addition a 19" TV screen was placed with its center approximately 2 feet to the right and one foot below the center of the Tektronix oscilloscope, clearly within the frontal vision of the subject.

Experiment A-M2:

In this experiment, the same visual image described above is moving laterally across the screen with simple harmonic motion. The stimulus consists of either an upward or downward rapid vertical displacement of the circular image. The velocity of the vertical displacement has a magnitude of 64 cm/second. Responses to the UP stimulus and the DOWN stimulus are averaged separately. Observations of the measurements may suggest formulation of a hypothesis that the response to an UP visual motion is different from that of a DOWN visual motion. If so, a formal experiment can be designed to test this hypothesis.

Experiment B:

The stimulus for this experiment is a motion and proprioceptive stimulus. It consists of the deflation of an inflatable bladder upon which the subject is seated. When inflated to a pressure of 3 pounds/square inch, the dimensions of the bladder are approximately 20" x 14" x 3/4". The bladder is placed on a wooden seat that is parallel to the ground. The back portion of the wooden chair forms an angle with the vertical of approximately 10°. Electro-pneumatic valves are located at the input and output lines of the cushion. During the inflated state, the input valve is set to maintain a pressure of approximately 3 pounds/square inch, and the output valve is closed. To apply the stimulus, a driving signal under control of the digital computer opens the output valve and closes the input valve. With a medium-weight adult seated on the cushion, total deflation requires about two seconds. It is desired to measure the response to the stimulus onset.

Experiment B-M1:

Experiment B is performed. The subject wears headphones to exclude the sound associated with the seat deflation.

Experiment B-M2:

Experiment B is performed. The subject wears stereo headphones, and soft music is piped into the headphones to mask the sound associated with seat deflation.

Experiment B-M3:

Experiment B is performed except that the subject does not sit on the deflatable seat, but adjacent to it. The subject hears the same sound when the stimulus is applied, and perhaps senses differential pressures as the seat is deflated. It is of interest to ascertain if the evoked response measured in Experiment B is produced by the motion, tactile and proprioceptive onset cues produced when sitting on the seat, or merely by the associated residuals.

Experiment B-M4:

The stimulus consists of either the deflation of the left partition of the seat or the right partition of the seat. Responses to the LEFT and RIGHT stimuli are averaged separately. Observation of the measurements may suggest formulation of a hypothesis that response to a LEFT stimulus is is different from that of a RIGHT seat stimulus. If so a formal experiment can be designed to test this hypothesis.

Experiment B-M5:

Experiment B is repeated except that a backrest rather than a seat is deflated. Observation of the measurements may suggest formulating an experiment that is designed to determine if a backrest stimulus can be differentiated from a seat stimulus from the observation of the corresponding evoked responses.

Experiement C:

Experiments A-M2 and B-M4 were conducted simultaneously. This was an initial exploratory effort intended to suggest a well-defined experiment in which both visual cues and corresponsing motion cues occur, but not necessarily in synchronism.

All evoked responses were measured at the vertex with respect to the mastoids. Three 6-mm Neher tin electrode disc probes were utilized. The probes were affixed to the scalp using collodion, and a standard electrode paste was utilized.

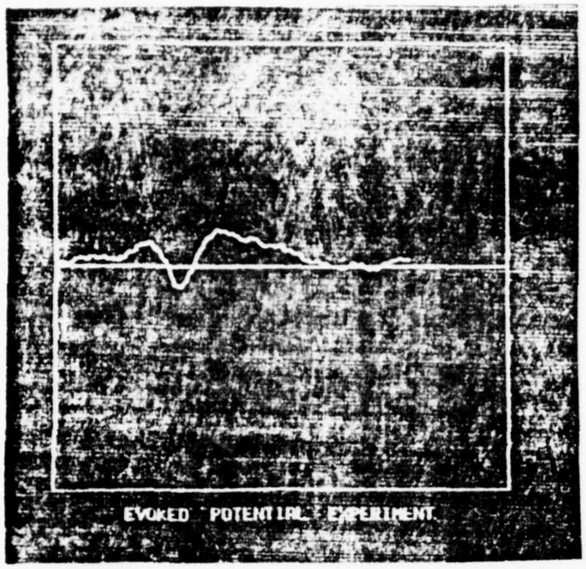
Chapter 4
RESULTS

Both visual and g-seat type stimuli produced evoked responses that appear to be well-defined for particular individuals, and generally appear to possess attributes that are common for different individuals. In obtaining these responses, only averaging techniques and simple smoothing techniques were utilized. The predominant artifact encountered was 60 - Hz pickup. This was easily removed from individual responses without significant distortion of the predominant peaks. It appears that the predominant peaks and latencies can frequently be observed from just a single response if the 60-Hz artifacts are removed. The only task assigned to subjects during these experiments was to count the number of stimuli received. Although other investigators have measured effects of specific tasks on evoked response, the effect of this task on the evoked response was not evident from visual inspection of the measurements.

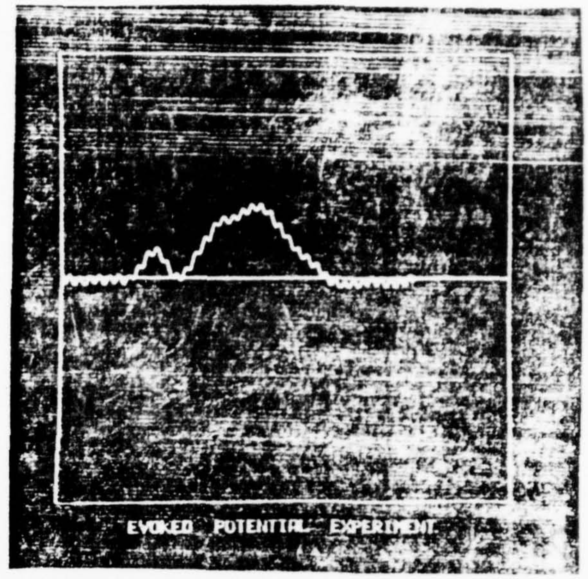
4.1 Visual Motion Responses:

Average evoked responses to the visual observation of an impusle acceleration were measured. Typical attributes apparent from visual inspection of the results include a small positive peak that occurs approximately 150 milliseconds after the stimulus onset. A well-defined negative peak is present approximately 200 milliseconds after the stimulus onset. This is followed by a sharp transition to a P300 wave. The latter excursion represents the most significant magnitude variation. Average evoked responses for four different subjects are shown in Fiugre 10.

Since there is variability within each subject, the average response has attributes that are different from th se of individual responses. In particular, if responses are summed, any variability in latencies tends to cause peak attenuation



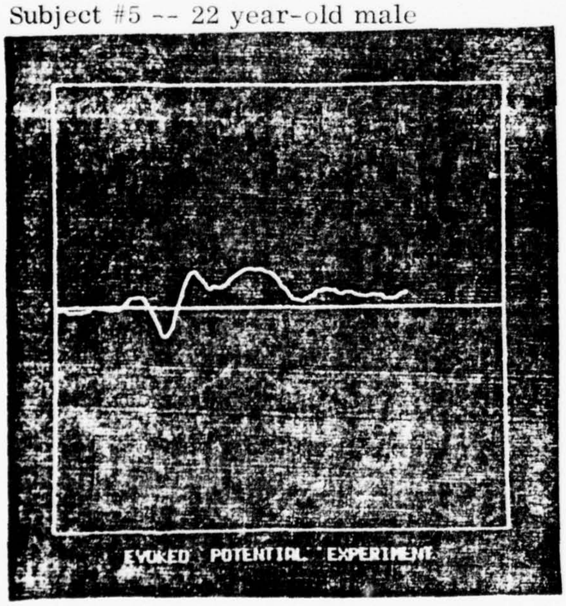
Subject #3 -- 26 year-old male



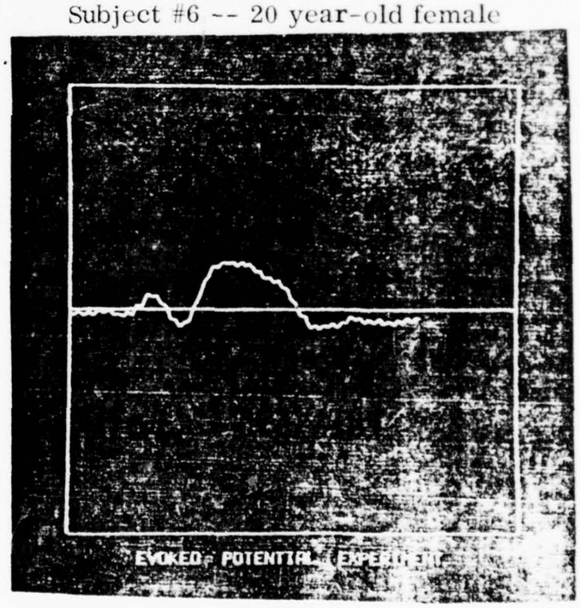
Subject #4 -- 20 year-old male

Each picture is the average 32 responses

Subject #5 -- 22 year-old male



Subject #6 -- 20 year-old female



SCALE: Horizontal: 300 msec/in. Vertical: 93.7 μV/in.

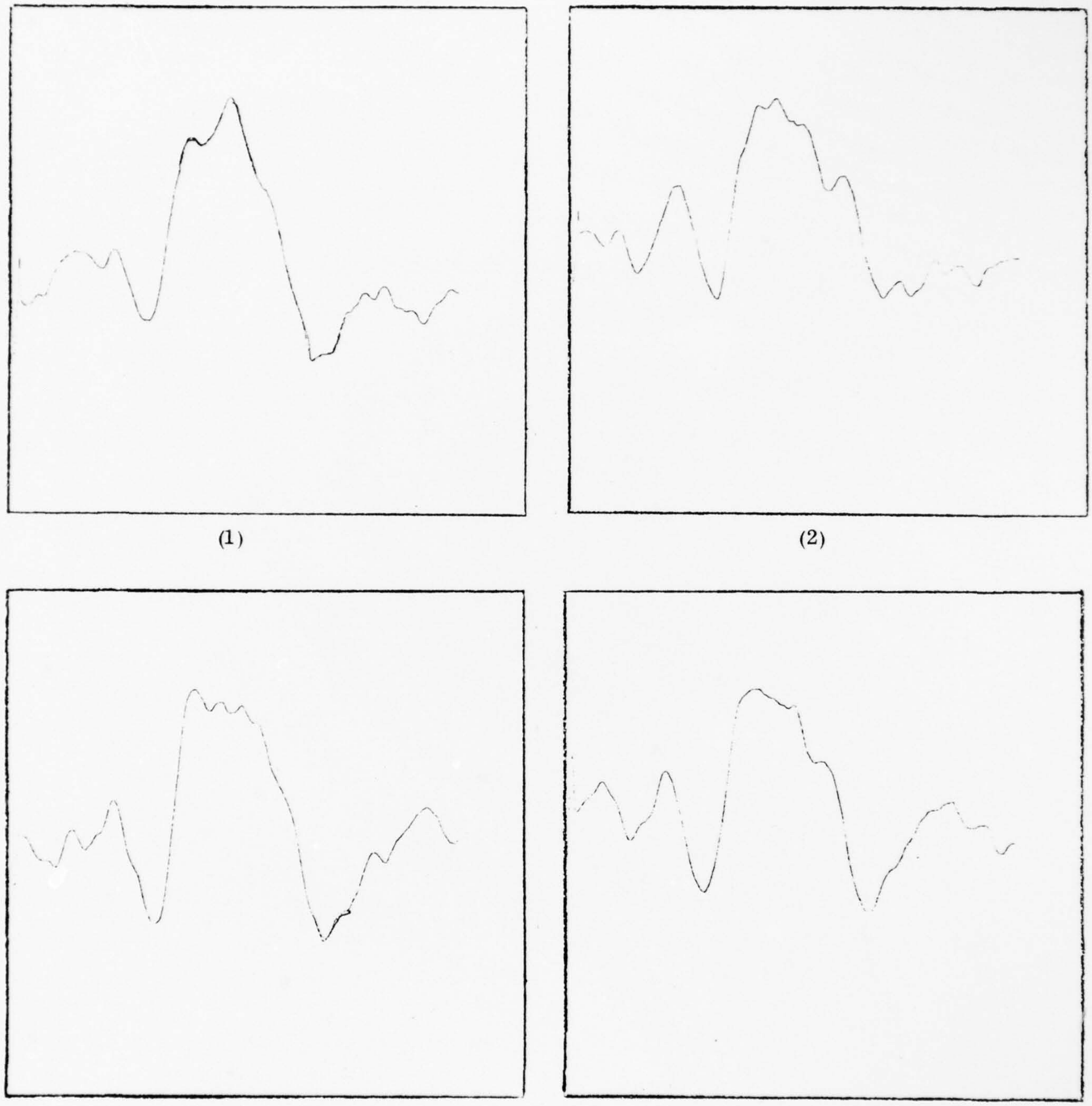
AVERAGE EVOKED RESPONSE FROM FOUR DIFFERENT SUBJECTS
PRODUCED BY VISUAL MOTION STIMULUS
FIGURE 10

in the averaged responses. Filtering algorithms have been developed to compensate for random latency shifts. However, such algorithms result in tradeoffs which may be either undesirable or intolerable.

Refer again to Figure 10 d. Figure 11 shows the first four responses measured by this subject. Observe that the P_1, N_1, P_2, N_2 and P300 waves frequently associated with visual stimuli appear to be present, even though there is no suggestion of the presence of P_1 and N_1 in the average response. This is caused by latency variability in the P_1 and N_1 peaks. Refer to Figure 12. This is the average response of the first ten evoked responses measured from the same subject. Note that P_1 and N_1, although attenuated, are still clearly visible.

Although other investigators have observed variability in certain latencies within subjects, it cannot be inferred from this experiment that the latency variations for peaks P_1 and N_1 are intra-subject variations. Prior to each stimulus onset, the visual image moved laterally across the screen with a slow harmonic motion. The stimulus onset was random. It is possible that the latencies of these peaks can be associated with the horizontal position and/or velocity at which each vertical onset stimulus occurs. This can be investigated by performing a similar experiment in which the horizontal voltage wave at the point of each stimulus onset is sampled and stored. With our present system, it would be quite easy to implement this revision.

Experiment A was modified in that a TV set was placed in the view of the subject, as described in the previous chapter. During the course of the experiment, an extraordinary amount of action occurred on the TV screen. In addition,



(1) (2) (3) (4)

SCALE: Vertical: 93.7 MC/in Horizontal: 196 msec/in.

FIRST FOUR RESPONSES BY SUBJECT #6 TO VISUAL MOTION STIMULUS

Figure 11

SUBJECT #6: 20 year-old female

SCALE: Horizontal: 94 milliseconds/inch
Vertical: 24.7 microvolts/inch
15th Order Smoothing Filter Applied to Data

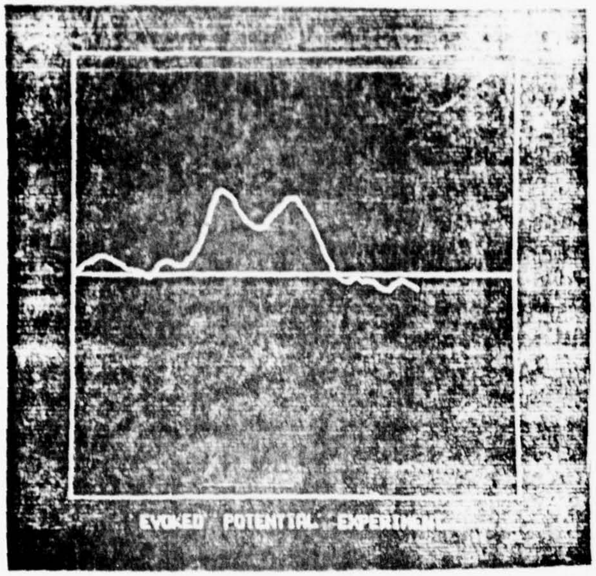
AVERAGE RESPONSE FROM 10 OBSERVATION OF VISUAL MOTION STIMULI

Note: There is still evidence of P_1 and N_1 peaks. They occur 60 milliseconds and 96 milliseconds after the stimulus onset.

Figure 12

vertical roll problems occurred during the latter part of the experiment. However, as can be observed from the results given in Figure 13, the P300 portion of the response due to the onset stimulus still appears to be present. If this experiment is performed again, a recorded TV presentation will be utilized in order that the rather extreme visual distractions that occurred during this experiment may be avoided.

In another modification to Experiment A, visual onset stimuli in which the image was displaced upward were randomly interspersed with stimuli in which the image was displaced downward. The responses were averaged separately. The average of 13 DOWN responses for one subject is given in Figure 14a and the average response from 12 UP stimuli is given in Figure 14b. From the results presented, it is not clear whether the responses caused by the two stimuli are different. Although there has not been sufficient analysis to support a conclusion, we tentatively suspect that the responses are different. This is suggested since we were able to view individual responses (as opposed to average responses) and estimate with a fair degree of accuracy if the response was caused by an UP or a DOWN stimulus. In order to test the hypothesis that the responses are different, it will be necessary to use a statistically discriminatory technique, such as the method of stepwise discriminate analysis. It is interesting to note that the P300 portions of the two waves appear to be quite similar. This can be observed by averaging together responses from both the UP stimuli and the DOWN stimuli. This is illustrated in Figure 15.

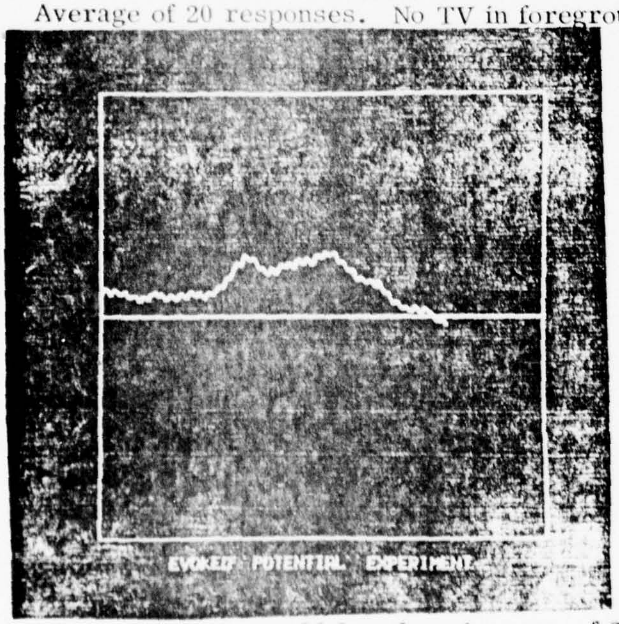


SCALE:

Horizontal: 300 milliseconds/inch

Vertical: 93.7 microvolts/inch

Subject #9: 9 year-old female
Average of 20 responses. No TV in foreground



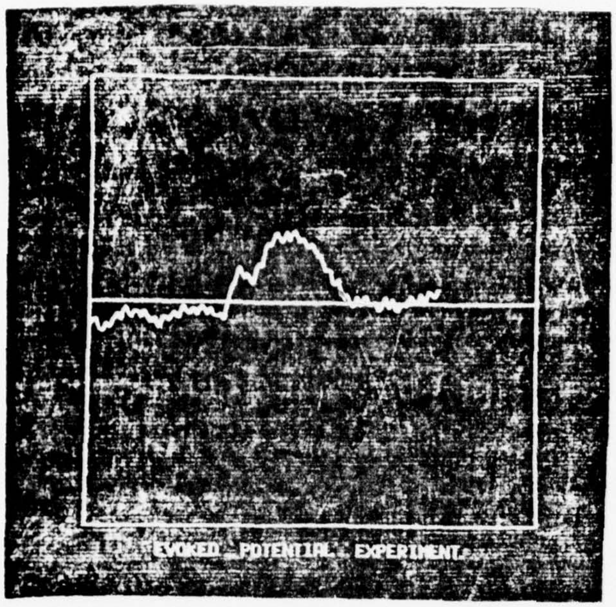
SCALE:

Horizontal: 300 milliseconds/inch

Vertical: 93.7 microvolts/inch

Subject #9: 9 year-old female. Average of 26 responses
TV is operating in foreground.

RESPONSE OF SUBJECT #9 TO VISUAL MOTION STIMULUS
WHEN TV IS IN FOREGROUND AS COMPARED TO RESPONSE WITHOUT TV
Figure 13

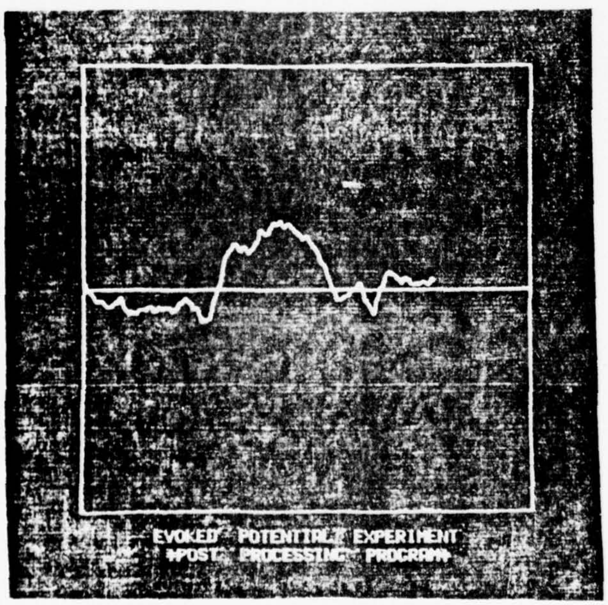


SCALE:

Horizontal: 300 milliseconds/inch

Vertical: 93.4 microvolts/inch

a) SUBJECT 7: 21 year-old male
Average of 12 Responses to UP Stimulus



SCALE:

Horizontal: 300 milliseconds/inch

Vertical: 70 microvolts/inch

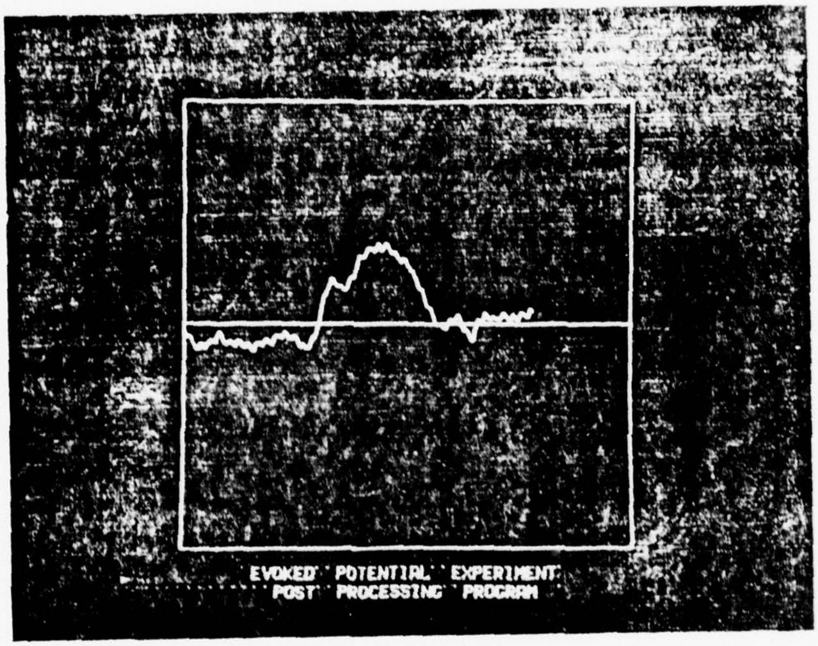
b) SUBJECT 7: 21 year-old male
Average of 13 Responses to DOWN stimulus

RESPONSES OF SUBJECT TO VISUAL OBSERVATION
OF UPWARD MOTION AND TO VISUAL OBSERVATION OF DOWNWARD MOTION

Figure 14

Scale:

Horizontal: 300 milliseconds/inch
Vertical: 70 microvolts/inch



Subject #7 . 21 year-old male.

Average of 12 UP Responses and 13 DOWN Responses

RESPONSES IN FIGURE 14 AVERAGED TOGETHER

Figure 15

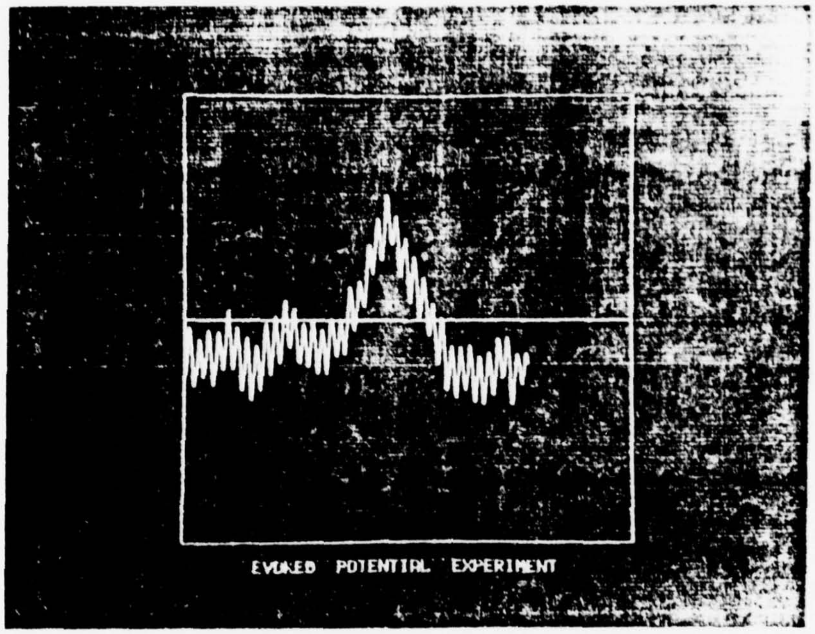
Certain researchers have reported observing lambda waves in response to observation of visual motion. These waves have the appearance of a large inverted V. In some of our individual responses, it appears that a lambda wave is present. Due to small latency variations, these waves tend to partially "wash out" in averaged responses. The large lambda-type waves that we observed occurred in the P300 region. Figure 16 illustrates a single response in which a λ wave appears to be present.

Smaller lambda-type waves were observed occurring in earlier portions of certain evoked responses. If certain onset cues relating to observation of visual motion regularly produce these waves, it is suggested that real-time detection of these signals could be useful for possible augmentation of pilot performance in the operation of a high performance aircraft.

4.2 *Responses to G-Seat Stimuli*

Results of our literature search did not reveal any previous evoked potential studies utilizing a G-seat type stimulus such as described in Chapter 3. The responses from these stimuli measured at the vertex node appear to be large and reasonably well-defined. The first clearly discernible peak is a very sharp negative peak in the N200 region. This peak appears to have a nearly constant latency. This is followed by a sharp transition into the P300 region. The responses appear to be quite similar for different subjects and different from the responses obtained from our visual stimuli. Average responses for two subjects are shown in Figures 17 and 18.

By use of sophisticated statistical techniques, it is now possible to classify



Subject #4: 20 year-old male. Response to first stimulus.

Horizontal Scale: 300 milliseconds/inch
Vertical Scale: 93.7 microvolts/inch

SINGLE UNFILTERED RESPONSE TO VISUAL MOTION STIMULUS WITH LAMBDA WAVE IN P300 REGION

Figure 16

Scale:
Horizontal: 209.9 milliseconds/inch
Vertical: 24.7 microvolts/inch
Sampling Interval: 2.049 milliseconds

Deflatable Seat Stimulus. 22-year old female

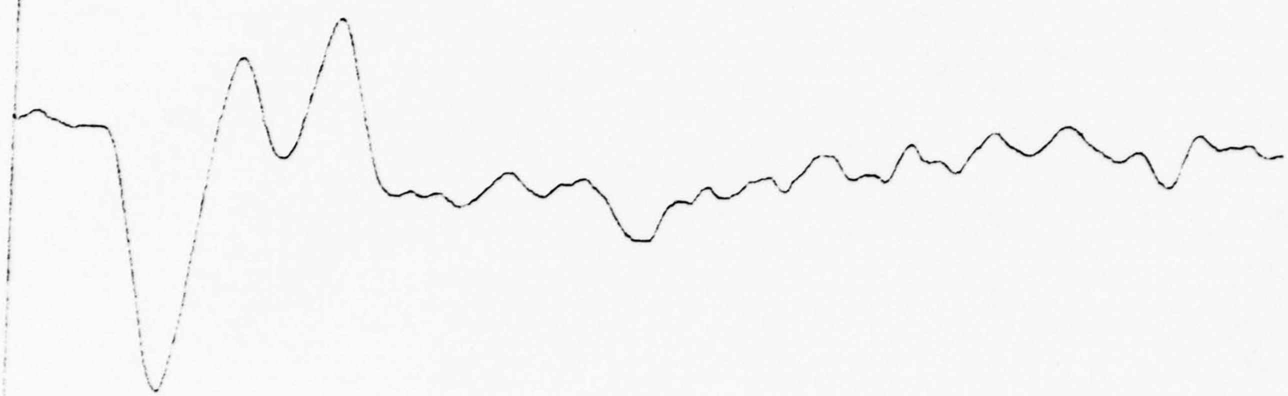
Average of 22 Responses. 7th order Smoothing Filter Applied to Data

AVERAGE RESPONSE TO DEFLATABLE SEAT STIMULUS FOR SUBJECT M

Figure 17

Scale:

Horizontal:	209.9 milliseconds/inch
Vertical:	24.7 microvolts/inch
Sampling Interval:	2.049 milliseconds



Deflatable Seat Stimulus. 21 year-old male

Average of 32 Responses. 7th order Smoothing Filter Applied to Data

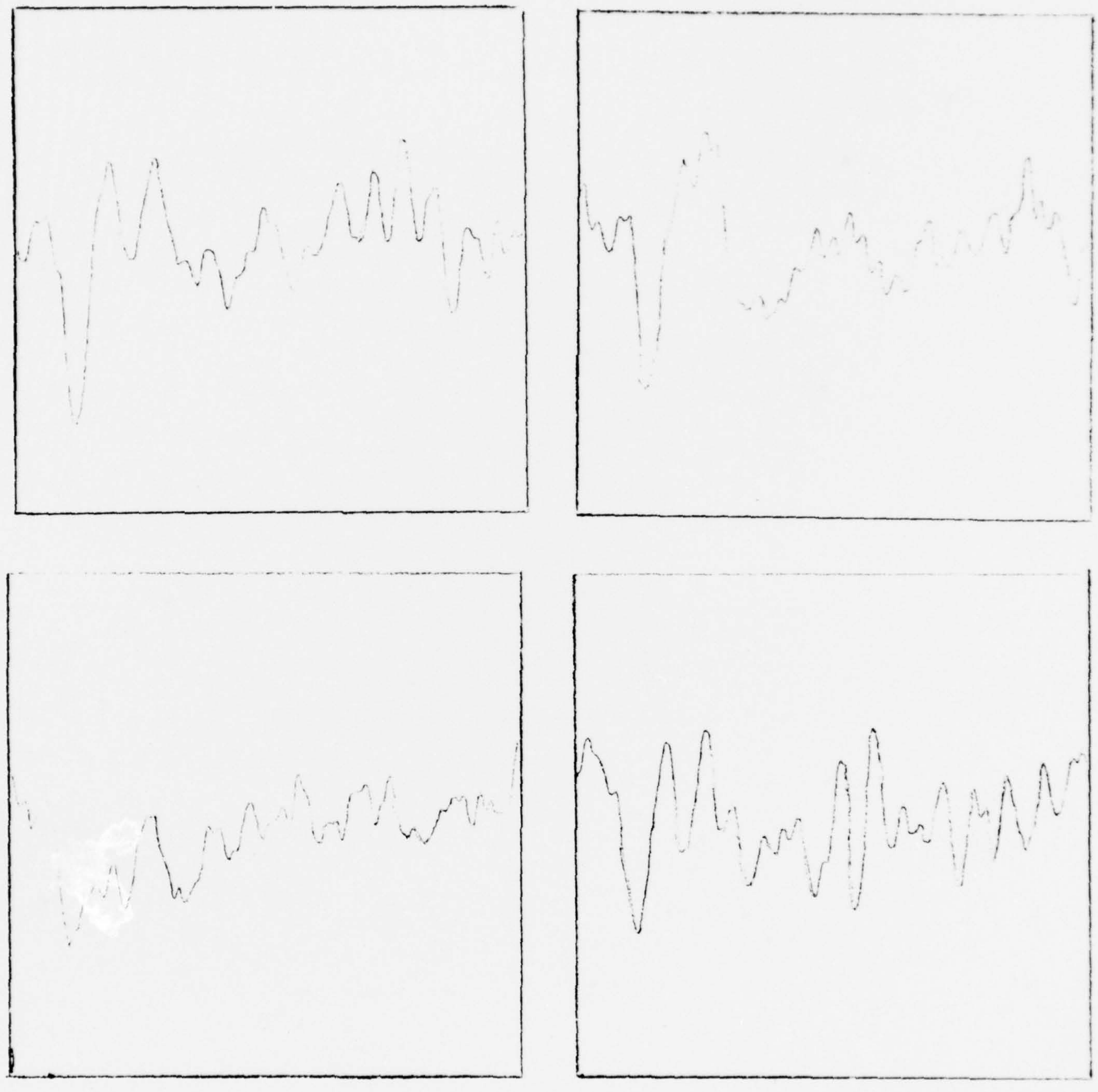
AVERAGE RESPONSE TO DEFLATABLE SEAT STIMULUS FOR SUBJECT H

Figure 18

certain evoked responses from measurement of a single response. For the results of our seat deflation experiment, it appears that certain attributes of the response can frequently be observed by visual inspection without any statistical processing. Refer to Figure 19. Four consecutive responses to the seat deflation stimuli are presented. For these responses, it appears that both the N200 peak and the P300 wave are discernible by simple visual inspection of just a single measurement.

Modifications were made to the seat deflation experiment in order to ascertain if the measured response was due to the combination of the tactile, proprioceptive and motion onset associated with the seat deflation, or whether perhaps the response was produced by the mechanics associated with implementing the seat deflation. For example, deflation of the seat was accompanied by sounds associated with conoflow valve operation, and the pneumatics associated with air flow out of the seat. In order to mask the sound, headphones were placed on a subject, and the deflation experiment was performed. A significant response was still measured. In another modification of the experiment, soft music was piped into a set of stereo headphones in order to mask the sound. A response to the stimulus was still observed.

In another modification to the experiment, the subject was seated next to the deflatable seat instead of on it. The response was measured to the deflation stimulus. An evoked response was measured in the subject. However the response measured appears different and of lesser magnitude than that obtained from the subject when he was sitting on the seat. Figure 20 is the average of the first five responses from Subject G when he was on the seat. Figure 21 is the average of the first five responses when the subject is seated next to the controlled pneumatic seat. There appears to be



Subject H: 21 year-old male

SCALE: Horizontal: 4.25 milliseconds/in Vertical: 49.4 microvolts/in

FOUR SINGLE RESPONSES TO DEFLATABLE SEAT STIMULUS

Figure 19

SCALE:

Horizontal: 208 milliseconds/inch
Vertical: 24.7 microvolts/inch

7th Order Smoothing Filter Applied to Data

AVERAGE RESPONSE TO 5 DEFLATABLE SEAT STIMULI FOR SUBJECT G
Figure 20

SCALE:

Horizontal: 200 milliseconds/in
Vertical: 24.7 microvolts/in.

7th order smoothing filter applied to data

AVERAGE RESPONSE TO 5 STIMULI FOR SUBJECT G

Note: The stimulus consists of deflation of the pneumatic cushion. However the subject is not seated in the cushion, but is seated adjacent to it.

Figure 21

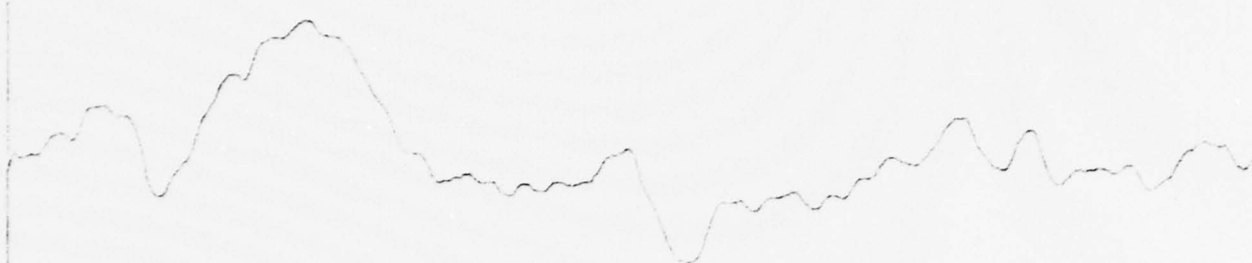
little similarity in the responses. It should be mentioned that in later responses, there is more similarity. Perhaps the subject is learning to associate the sounds with the G-seat excursions.

It should be observed that the responses to our G-seat type stimuli are measured for nearly 1.5 seconds after the onset signal is applied. The significant measured responses all were observed early in the response waveform. After the seat has been almost completely deflated, which is in the order of magnitude of 1 second, the subject feels a well defined sensation as the ischial bones come in contact with the wooden seat underneath the pneumatic cushion. It was desired to determine if this secondary stimulus produced a well-defined response. No such response was observed. This does not necessarily imply that such a response was not present, since we believe there was considerable variability in the time that it took for the ischial bones to come in contact with the hard surface.

In another modification to Experiment B, the subject was placed on a 2-compartment seat. The onset stimuli consisted of left-compartment deflations randomly interspersed with right compartment deflations. Differences in the responses were generally not obvious from visual inspection. However, for one subject, the pre-deflation pressure in the right compartment was approximately 0.5 PSI higher than the pre-deflation pressure in the left compartment. This produced sensations which the subject described as significantly different. It also resulted in average responses that appear significantly different. The sharp or large magnitude response is associated with the larger pressure differential. Average responses for these cases are shown in Figures 22 and 23. The results appear analogous to results obtained from measurement of responses evoked by visual stimuli. Larger responses are generally generated by

Subject F: 21 year-old male. Average of 9 responses.
SCALE: Horizontal: 214 milliseconds/inch
Vertical: 24.7 microvolts/inch

7th Order Smoothing Filter Applied to Data



RESPONSE OF SUBJECT F TO RIGHT-COMPARTMENT SEAT DEFLATION
Static presure in right compartment $\simeq$ 3.2 PSI

Figure 22

Subject F: 21 year-old male. Average of 11 responses.
SCALE: Horizontal: 214 milliseconds/inch
Vertical: 24.7 microvolts/inch

7th Order Smoothing Filter Applied to Data

RESPONSE OF SUBJECT F TO LEFT-COMPARTMENT SEAT DEFLATION
Static pressure in left compartment ≃ 2.7 PSI

Figure 23

higher light intensities or sharper edge patterns.

One more modification of Experiment B was incorporated by having the subject sit on a pneumatic seat with his back leaning against a pneumatic backrest. The stimuli consisted of seat deflations randomly interspersed with backrest deflations. The responses to the two deflations were averaged separately. The results are shown in Figures 24 and 25. For this subject, it is observed that the leading lobe of the P300 wave is greater than the trailing lobe for the backrest deflation, but less than the trailing lobe for the seat deflation. This suggests conducting a formal experiment and using statistical techniques to test the hypothesis that the responses produced by the two stimuli are different.

In taking various measurements, it was observed that the fastest sharp peak in an average response occurred for our youngest subject (9 years old). The longest latency to a P300 wave was for our oldest subject (43 years old). It may be of interest to pursue an investigation concerning possible relationships between age groups and latencies.

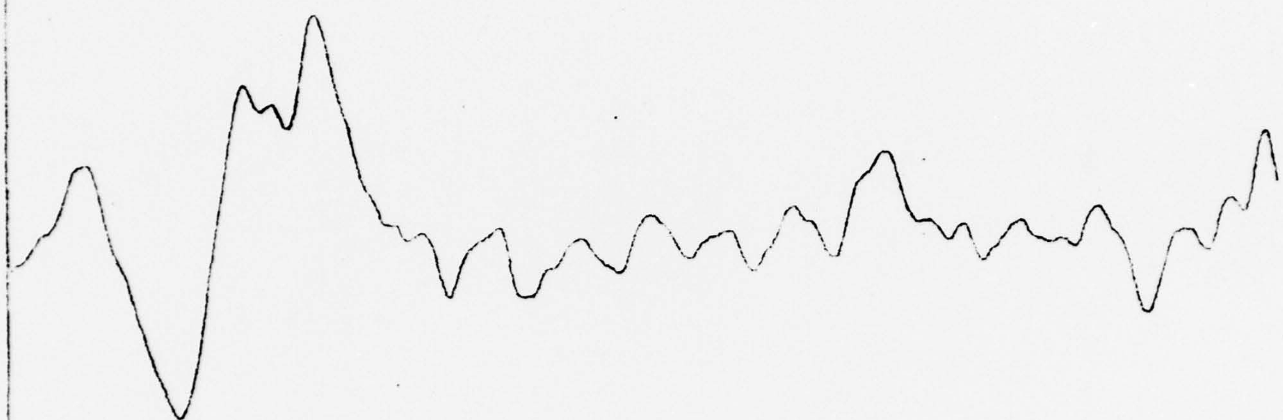
4.3 Combined Visual and G-Seat Stimulus:

The visual stimulus and the G-seat stimulus were presented to a subject simultaneously. That is the same driving signal was used to activate both stimuli. Clearly the inertia in the pneumatic system results in some delay. An average response for this combined stimulus is shown in Figure 26. Visual inspection of this response suggests that it is different than the response from just a visual stimulus or just a G-seat stimulus.

Rather than pursue this effort, it was decided to design an experiment in which the visual stimulus can be more closely related to the G-seat stimulus. Such an experiment is described in Chapter 5.

Subject G: 23 year-old Male. Average of 15 responses.
SCALE: Horizontal: 208 milliseconds/inch
Vertical: 24.7 microvolts/inch

7th Order Smoothing Filter Applied to Data



AVERAGE RESPONSE TO SEAT DEFLATION FOR SUBJECT G

Figure 24

Subject G: 23 year-old male. Average of 15 responses.
SCALE: Horizontal: 205 milliseconds/inch
Vertical: 24.7 microvolts/inch

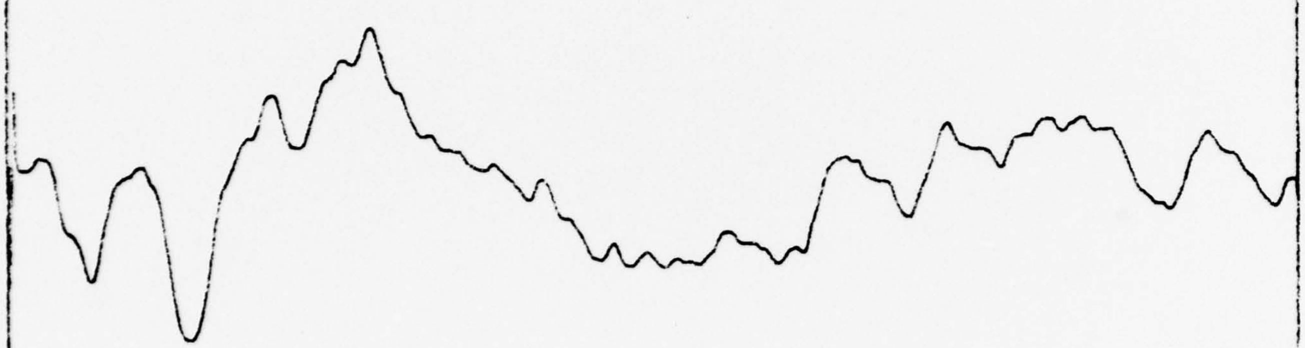
7th Order Smoothing Filter Applied to Data

AVERAGE RESPONSE TO BACKREST DEFLATION FOR SUBJECT G

Figure 25

Subject L: 20 year-old female. Average of 6 responses
SCALE: Horizontal: 196 milliseconds/inch
Vertical: 24.7 microvolts/inch

7th Order Smoothing Filter Applied to Data



AVERAGE RESPONSE OF SUBJECT L TO A COMBINED VISUAL & G-SEAT STIMULUS

Figure 26

Chapter 5

CONTINUING EFFORTS

The work that has been done has been largely exploratory in nature. The work that is currently being planned consists of some more formalized experiments as well as certain additional exploratory efforts. All continuing efforts are still addressed to the general obejctives that are specified in Chapter 1. The following efforts are currently being planned:

1. It is planned to investigate if certain onset stimuli can be identified from observation of evoked scalp potentials. From our current data, it appears that observation of an average response is sufficient to identify the stimulus producing it, at least for a small class of possible input stimuli. Two approaches will be considered. First, we will analyze an average evoked response that is known to result from one of two possible stimuli. The method of discriminant analysis will be utilized. A second approach will be to formulate an algorithm based on observed mean attributes measured for various stimuli. The algorithm will be scored based on the number of successes and failures in classifying the response. If either of these techniques proves fruitful the identification problem will be pursued. It will be attempted both to identify the responses from a larger class of possible stimuli, and to identify the response from a smaller number of averaged responses, perhaps even from a single response.

   In general, it would be desirable to identify meaningful onset cues from observation of a continuous record of the scalp potentials of the subject. Although we are not ready to address this general problem, it may be possible at this time to pursue certain restricted cases.

2. Measurements have been made identifying various time delays encountered in subsystems of the advanced Simulator for Undergraduate Pilot Training. Measured system delays were small for visual systems, larger for motion systems, and largest for G-seat systems. Other studies have suggested that if there exists a time delay between a visual cue and a corresponding motion cue, and if the time delay exceeds a certain threshold, then the motion cue has no positive value in assisting an operator in performance of a related task.

It is planned to investigate the evoked response caused by a stimulus that visually produces a sensation of motion accompanied by a corresponding non-visual onset cue. It is further planned to investigate the effect of transport lag in the measured evoked responses.

We plan to develop a visual display that will tend to induce a feeling of a tilt, or roll onset. We will also attempt to precisely define a roll onset or tilt produced by inflation of one compartment of a pneumatic seat simultaneous with deflation of the other compartment. An attempt will be made to identify at least one mean attribute of the response caused by the combined stimulus that does not result from just the visual stimulus. If such an indentification is made, time delay will be introduced to the combined stimulus, and we will attempt to observe if the attribute produced by the joint stimulus is "washed out" as time lag is increased. If so, a mean time to washout will be estimated.

The first task required for performance of this experiment is generation of a static tilt onset using visual techniques. We will consider a static roll onset to be a sudden tilt and a dynamic roll onset to be a sudden change in direction or velocity of roll motion. In order to generate a roll sensation visually, we will use two peripheral displays, similar to those used on the Roll Axis Tracking Simulator at the Aerospace Medical Research Laboratory. Either horizontal lines or bars will appear on the displays, and the controlled visual roll sensation will be generated by rolling the displays in opposite directions. Seat roll will be produced by varying the pressure of the two compartments in the inflatable seat. An attempt will be made to adjust the magnitude of the visual roll velocity so that subjectively it appears to relate to the magnitude of the roll motion of the seat. To enhance this relationship, subjects will be pre-conditioned by riding the seat accompanied by correlated peripheral visual roll motion. The visual motion will be generated by the output of pressure transducers connected to each of the two compartments, and thus will be synchronized with the varying seat-compartment pressures.

For this series of experiments, just static onset stimuli will be given. Tentatively, it is planned to use time delays within the range between -40 and +200 milliseconds, and to vary the delays in increments of 20 milliseconds. Since previous experience suggests subject fatigue if an excessive number of stimuli are taken, each subject will have to return several times, and certain overlapping data will have to be taken and tested to determine whether or not the mean attribute measured for the zero time lag is still present at a different date.

3. It is planned to continuously record scalp potentials from a subject who is performing a task on a Roll Axis Tracking Simulator. From this data, we will attempt to identify electrical responses that are evoked by

identifiable onset cues.

If evoked potential technology is to be utilized to assist in determining which sensory mechanism is processed under various flight conditions, then it appears worthwhile to attempt to measure an evoked response to a recurring stimulus that appears during a normal training mission. Classical evoked potential experiments involve use of well-defined stimuli in a well-controlled passive environment. Such experiments can be designed so that the results of statistical inference are reasonably valid. However, the results of these experiments may shed little information related to the the general objectives that are being addressed. Furthermore, at the present time, it doubtful that significant training devices should be instrumented solely for the purpose of obtaining evoked potentials.

The purpose of this task is to determine if non-invasive evoked potential measurements can be taken from a subject during an instrumented training mission. The data will be taken during a tracking mission conducted on the Roll Axis Tracking Simulator. Vertex node voltages will be amplified by a bioelectric amplifier and recorded on one channel of a 16-channel FM Sanborn Recorder. Digital logic will automatically reset the amplifier to its baseline if saturation is sensed. During a reset mode, a mark will be placed on a second channel of the recorder. Signals proportional to the relative position of the subject and to the angular displacement of a frontal image, corresponding to the difference between controlled plant roll angle and target roll angle, will be recorded on separate channels. No processing of the scalp node voltage will be done during the experiment.

Utilizing the recorded data and appropriate display software, dynamic onset cues will be identified and marked. A dynamic onset cue will be defined as a reversal in the direction of roll within specified angular limits. It is recognized that none of the cues will be identical. However, each will include this well-defined change in direction component.

Responses to this defined stimulus will be averaged. The responses averaged will consist of the potential measured from each subsequently defined onset for a period of approximately 600 milliseconds after the onset. We will observe whether or not certain peaks or latencies are preserved after a large number of responses are averaged. If so it will be postulated that these attributes were produced by the reversal-in-roll-direction component of the stimulus.

The purpose of this particular task is merely to investigate the feasibility of taking parasitic evoked potential measurements. If the results of this investigation appear to be positive, then it appears plausible to design experiments that can test whether EP responses to a dynamic visual stimulus are as fast as those produced by a dynamic motion stimulus. Likewise, positive results would enhance the possibility of performing evoked response experiments in which responses obtained in aircraft can be compared with responses obtained in a simulator.

The continuation of the efforts referred to above are contingent on the prospects of obtaining additional support.

RELATED LITERATURE

Cooley, W.W. and Lohnes, P.R., Multivariate Data Analysis, New York, John Wiley, 1971.

Cooper, R., et al, "Cortical Potentials Associated with the Detection of Visual Events," Science, 196, 1 April 1977, pp. 74-77.

Donchin, E., "Brain Electrical Correlates of Pattern Recognition in Bio-Medical Engineering," in Signal Analysis and Pattern Recognition in Bio-Medical Engineering, (Insbar, G., Ed.) John Wiley, 1975, pp. 199-218.

Donchin, E., "Discriminant Analysis in Average Evoked Response Studies: The Study of Single Trial Data," Electroencephalography and Clinical Neurophysiology, 39, 1970, 429-440.

Donchin, E., "A Multivariate Approach to the Analysis of Average Evoked Potentials,"IEEE Trans. On Bio-Medical Engineering, 13, 3 July 1966, pp. 131-139.

Donchin, E., and Herning, R.I., " A Simulation Study of the Efficacy of Stepwise Discriminant Analysis in the Detection and Comparison of Event Related Potentials," Electroencephalography and Clinical Neurophysiology, 38, 1977, pp. 51-68.

Donchin, E., "Use of Electrocortical Activity to Monitor Human Decision Making," DARPA Report DAHC 15 73 C 0318, June, 1975.

Donchin , E. "The Vocabulary of Brain Potentials: Inferring Cognitive Events from Brain Potentials in Operational Settings," DARPA Report N-000-14-76-C-0002, July, 1976.

Glaser, E.M. and Runchin, Principles of Neurobiological Signal Analysis, Academic Press, New York, 1976.

Hartwell, J.W., and Erwin, C.W., "Evoked Potential Analysis: One-line Signal Optimization Using a Mini-Computer," Electroencephalography and Clinical Neurophysiology, 41, 1975, pp. 416-421.

Gum, D.R. and Albery, W.B., "Time-Delay Problems Encountered in Integrating the Advanced Simulator for Undergraduate Pilot Training," Journal of Aircraft, 14, 4 April 1977, pp 327-332.

Jermann, W. H., "Investigation of Evoked Potentials Related to Simulator Onset Cues," Proceedings of the USAF-ASEE Summer Faculty Research Program, The Ohio State University, 1977.

Jermann, W.H., Preliminary Progress Report for AFOSR-78-3626, "Investigation of Evoked Potentials Related to Simulator Onset Cues," Memphis State University, July 7, 1978.

Jermann W.H., Progress Report #2 for AFOSR-78-3626, "Investigation of Evoked Potentials Related to Simulator Onset Cues," Memphis State University, August 7, 1978.

Junker, A. and C. Replogle, June 1975. Motion Effects on the Human Operator in a Roll Axis Tracking Task, Aviation, Space and Environmental Medicine, 46: 819-822.

Klecka, W.R., "Discriminant Analysis," in Statistical Package for the Social Sciences, Nie, N.H. et al (Eds.), New York, McGraw-Hill, 1975, pp. 434-467.

Kohn, M., and Lifshitz, K., " A Nonparametric Statistical Evaluation of Changes in Evoked Potential to Different Stimuli," Psychophysiology, 13, 5, September, 1976, pp. 392-398.

McGuiliem, C.D. and Aumon, J.I., "Measurements of Signal Components in Single Visually Evoked Brain Potentials," IEEE Trans. on Bio-Medical Engineering, BME-24, 3, May 1977, pp. 232-241.

Regan, D., Evoked Potentials In Psychology, Sensory Physiology, and Clinical Medicine, London, Chapman and Hall, Ltd., 1972.

Seal, H. L., Multivariate Statistical Analysis for Biologists," Methuen & Co., London, 1964.

Stark, L.H. et al, "Cortical Potentials Associated with the Detection of Visual Events," Science, 195, 1 April 1977, pp. 74-77.

Van Rotterdam, A., "Limitations and Difficulties in Signal Processing by Means of the Principle-Components Analysis," IEEE Trans. on Bio-Medical Engineering, BME-17, 1970, pp. 268-269.

Woody, C.J., "Characterization of an Adaptive Filter for the Analysis of Variable Latency Neuroelectric Signals," Med. Biol. Engrg., 5, 1967, pp. 539-553.