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BIOCYBERNETICS: AN INTERACTIVE MAN-  
MACHINE INTERFACE

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California University

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## Project Summary

The research reported here and supported by the Advanced Research Projects Agency of the Department of Defense involves the detection of human bioelectrical phenomena that have been made analogs of ongoing cognitive processes and the utilization of these phenomena to control and/or communicate with external devices. The technique is applicable to situations requiring rapid human intervention in the control of complex systems operation. The major advantage of the procedure is the virtually automatic control of systems by the trained subject.

We are training human subjects to respond to alpha-numeric symbols such that a discriminable response is obtained for each symbol. The symbols are an abbreviated list of the English alphabet. The bioelectric response is the electromyogram (EMG) recorded from the surface of the skin overlying muscle. The actual training was accomplished initially on an off-line logic device and later by an interactive computer programmed to present stimuli and deliver reinforcements of various kinds to the subjects given the appropriate response code. This year's final report covers the preliminary training procedures and the instrumentation and software developed in support of the project. To provide a perspective for this year's accomplishments, a brief resume of subsequent project goals are presented below.

As the project proceeds the subjects will be required to correctly codify increasingly complex stimulus patterns, such as simple words or phrases. We will also train subjects to interpret machine generated codes presented through EMG recording electrodes, thus incorporating the provision for machine-to-man as well as man-to-machine communications.

Concurrent with these efforts we also plan to record EMG potentials from the vicinity of the oral cavity (larynx, tongue) to investigate the feasibility of performing pattern recognition analysis on these responses which have been implicated in subliminal vocalization. We also will record and analyze brain potentials from the surface of the scalp in an attempt to obtain an even more "central" measure of cognitive functioning than the EMG measures described above.

The immediate applications of this research are in 1) the development of computer systems to decode and analyze human communication - in this respect we view this program as an alternative or adjunct to current efforts involving the development of a machine capable of decoding human voice; 2) monitoring the reactions and decision making processes occurring in stressful, complex, or persuasive situations; 3) situations requiring rapid and continuous feedback of systems operations to the human controller; 4) situations wherein interactive communication between man and machine are desirable but not currently practical because of time restraints or environmental restraints.

### System and Procedural Overview

→ The long range objective of this project is the development of an efficient and accurate man-machine interactive method, involving use of biofeedback control. As such, it is our goal to utilize clearly structured bioelectrical aspects of human response generation and decision making. The major advantage of this goal is virtually automatic interactive systems control by trained subjects.

We are currently training subjects to respond to alpha-numeric symbols such that a discriminable response will be obtained to each symbol. The symbols are a truncated set of the English alphabet. The response is the electromyogram (EMG) recorded from the surface of the skin overlying muscle. The EMG is most directly an index of motor nerve activity rather than of muscle activity level since the magnitude of the electrical response is a direct function of the amount of neural activity imposed upon the individual motor units of skeletal muscle. The EMG is always present upon sufficient neural activity to elicit muscle movement and is also detectable given neural activity insufficient to generate movement. Interestingly, when a subject is instructed to "think about" flexing a specific muscle, a recording of the EMG accompanying this cognitive process is possible. In short, the EMG has the unusual property of being activated by the mere thought of activating the response system, e.g., the muscle (Leuba & Dunlap, 1951). This property of the EMG has been known for years (Hefferline & Perera, 1958) and has been utilized in several applied bioengineering

situations, most notably the control of prosthetic devices. In this case the subject, with sufficient training, becomes quite adept at controlling his prosthetic device and reaches the point where he need not actively conceptualize a muscle movement to produce the EMG signals necessary to control the limb and reach his goal, but merely "thinks" of the desired movement to be performed. The thought of the movement is sufficient to produce the necessary EMG's. Later in his training he need not even think of the movements necessary to reach the goal, but merely thinks of the goal with the same lack of direct, conscious commands as does an intact human. It follows, of course, that the muscles used to control the limb cannot be occupied with other tasks that would produce error commands.

3 -> The project reported herein deals with the capability of training a human subject to control and/or interact with complex electronic or mechanical systems. Basically the project involves the detection of bioelectrical phenomena that are analogs of ongoing cognitive processes and the utilization of these phenomena to control external events. The project also allows the system being controlled to communicate with the human operator in either a feedback or an interactive manner. In bypassing the subject's manual or verbal response apparatus an appreciable time saving may be achieved. By eliminating the normal feedback/interactive modes of communication currently employed by machines (generally visual signals produced mechanically or electronically) a further potential time saving can be realized.

We have achieved the initially described first year objectives during the past eight months of the project. In essence these were twofold: 1) develop the interactive systems hardware and software, and 2) train subjects to generate and respond correctly to alpha-numeric symbols using EMG responses.

The semi-annual report (January 1 to June 30) described initial development of a partially hard-wired system (the final system required additional computer equipment which was only delivered in September, 1972) and initial subject training.

A central instrument in the conduct of this project is the augmented computer configuration. Since we have completed the transition from off-line logic control to on-line control and analysis, we are now in a position from the computational point of view to be able to acquire up to 24 simultaneous EMG and EEG records as necessary to support the various tasks defined for subsequent years. This acquisition capability in conjunction with the data storage and computational capability in the form of the disc facility and the floating point processor provide a highly flexible tool for use in the accomplishment of the defined task sequences.

The software which was developed before delivery of the add-on equipment was oriented toward the control of the training program. We are currently expanding these software sets to utilize the full capabilities of the system.

Subjects have been trained to generate 16 different muscle patterns on cue. The process of training subjects to generate these precisely

defined motor responses to visual stimuli proceeds from a simple match-to sample task to the codification of a truncated alphabet by use of these defined sets of responses. The responses currently being directly trained are the electromyographic (EMG) records from the skin surface overlying four muscles.

Left and right flexor pollicis brevis (thumbs)

Left and right obductor digiti minimi (little fingers)

Subjects are required to generate these EMG responses without appreciable movements of the muscles or fingers. This aspect of the task--generating the EMGs--has proved easy for subjects and surprisingly "enjoyable" for them. They report that it is "fun" to do it with the attendant computer biofeedback. We have emphasized use of immediate visual feedback in training to date. It is in fact remarkable how rapidly well trained subjects can generate the alpha-numeric and how quickly untrained subjects can learn the task. We were pleasantly surprised that training naive subjects proceeds so fast. We have a strong impression that the manual capabilities of man, utilized in terms of EMG activity rather than substantial movements, far exceed expectations based on current manual task requirements.

This final report for the first year of the project encompasses three areas. These are reports of:

Methods and techniques involved in the overall training procedures.

Permanent subject performance under several paradigms.

Short term subject performance under a multimode feedback situation.

Each of the topics will be considered in a separate section.



### Technique and Methods

The initial task was addressed to the problem of selecting EMG recording sites. The criteria for selecting muscles to be used were as follows: The muscle must be superficial and not lie under an overly thick layer of adipose tissue which would act as an electrical shunt. The muscle had to be reasonably large such that a detectable EMG would be generated given minimal neuromuscular activation. Since our task will eventually require very rapid patterns of responses the muscle had to be capable of responding at high rates of brief contractions. We have limited ourselves to surface recording of the EMG with disc electrodes. This necessitated a recording site which was not affected by the activation of other muscles lying adjacent to our target muscle. Thus, we were seeking a muscle which was relatively anatomically isolated. A prime consideration dealt with the possible confounding effects of using muscles which might be expected to be utilized in normal postural control. For this reason we eliminated most of the large muscles of the limbs (they also are incapable of responding at high frequencies). After trial we eliminated the muscles of the face and head because they were 1) too small and 2) were involved in largely involuntary movements associated with respiration, swallowing, eye blinks, etc. Since we want to utilize a rather subliminal muscular contraction a muscle with as high an innervation ratio as possible would be desirable. Finally, for practical reasons, the muscle had to be readily accessible without embarrassment or discomfort due to electrode placement.

Muscles that were considered and rejected for one or more of the above reasons included: frontal and occipital epicranium, orbicularis oculi, superior auricular, depressor labii inferioris, masseter, trapezius, biceps brachii, brachioradialis and other superficial muscles of the forearm. The muscles deemed most suitable for this project were the flexor pollicis brevis (flexion and adduction of thumb) and the abductor digiti minimi (abducts little finger) both intrinsic muscles of the palmar surface of the hand. To simplify the subject's task we have utilized four muscles giving 16 response combinations. From these 16 combinations (discrete response plus no response) one can construct a communicable alphabet (see Appendix A).

Once chosen the muscles were mapped on the surface of the overlying skin to determine the location yielding the best signal to noise level. Using differential amplification the most satisfactory results were obtained by placing the active electrode over the belly of the muscle and the indifferent over the distal tendon. All recording configurations employ earlobe grounding. Amplifier gain was from 30-150 V/cm. (Grass polygraph--EEG channel) with a bandpass of 1 to 75 Hz. Figure 1 shows a recording from the flexor pollicis brevis (brevis) and abductor digiti minimi (minimi) for both hands. The subject here is performing low amplitude twitches of the muscles at will.

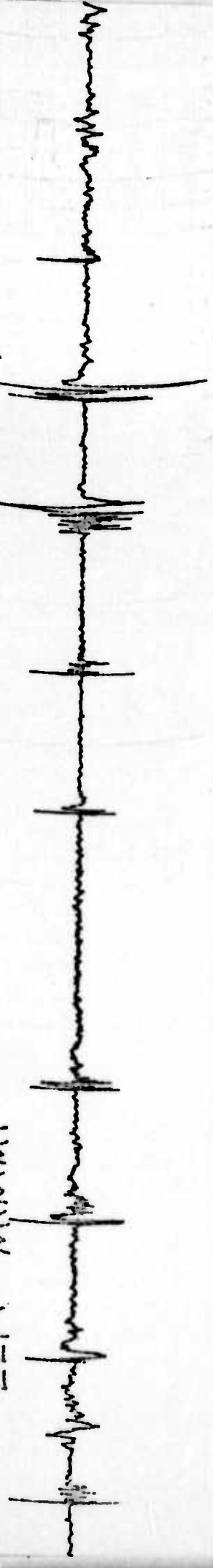
Testing and training took place in a sound-attenuating, ventilated chamber which was dimly lit (see Figure 2). The subjects sat in a comfortable, stuffed chair and were not required to utilize any of

Figure 1 Polygraph recording of EMG's obtained from relatively untrained subject instructed to perform low amplitude twitches of four muscles at will. Minimi refers to the abductor digiti minimi (little finger); brevis refers to flexor pollicis brevis (thumb).

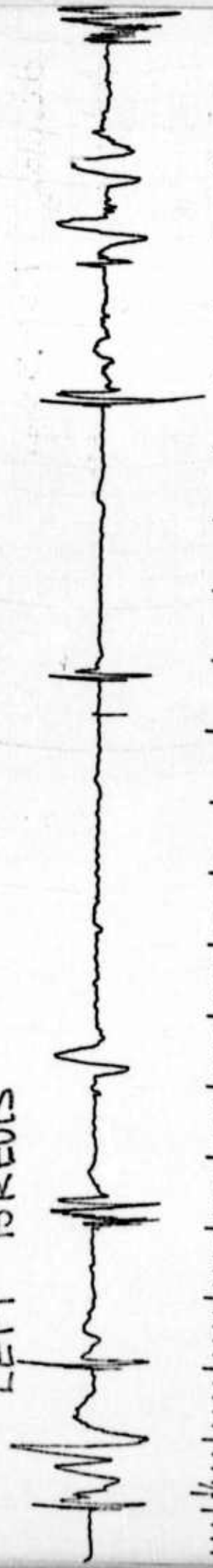
Gain = 75  $\mu$ V/cm; speed = 2.5 mm/sec.

gain 75  $\mu$ V/cm. 2.5 mm/sec.

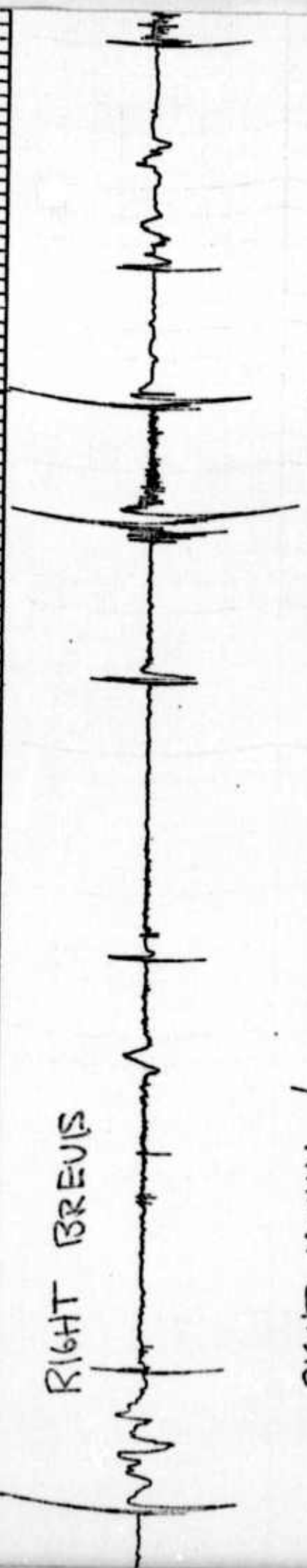
LEFT MINIMI



LEFT BREVIS



RIGHT BREVIS



RIGHT MINIMI

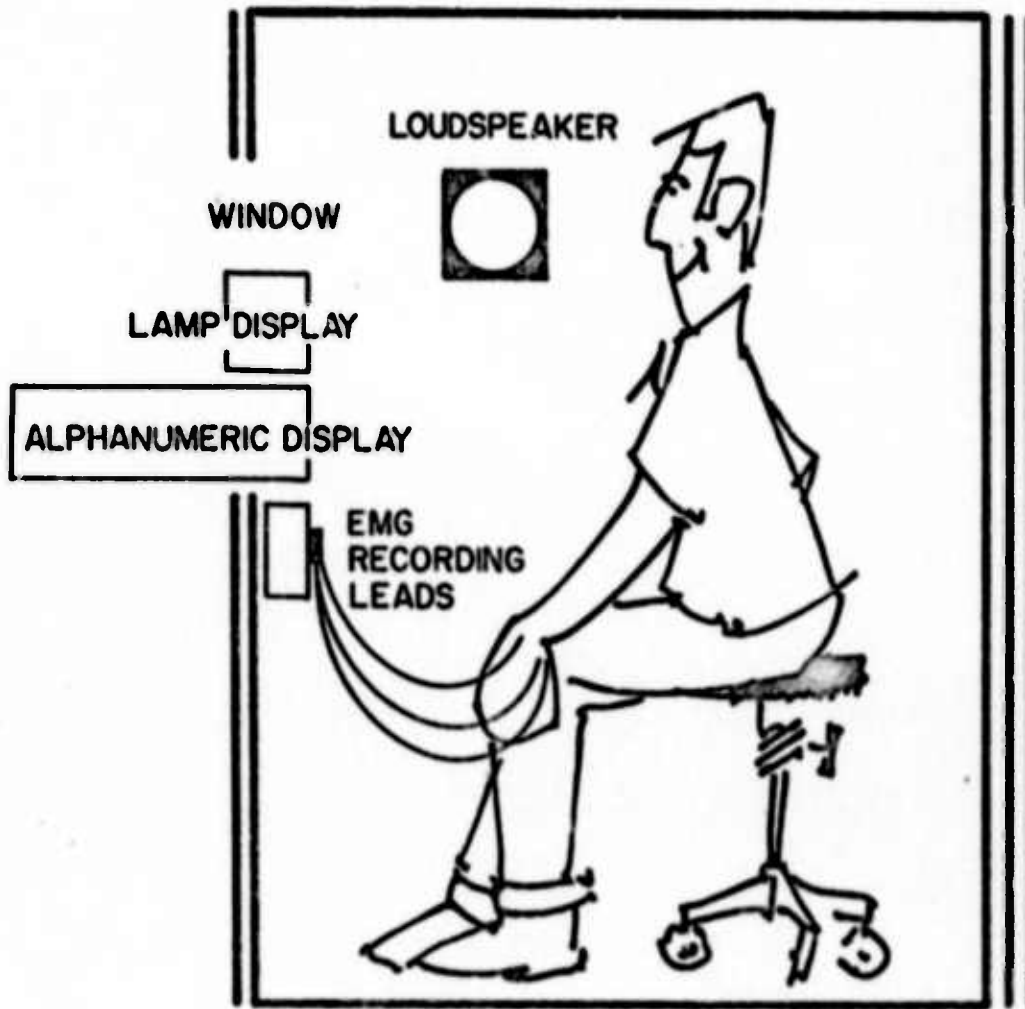


96

10

Figure 2 Physical arrangement of the training facilities.

PHYSICAL ARRANGEMENT



SOUND ATTENUATING ROOM

their musculature to remain in a comfortable position. Subjects faced a window in the room through which they saw the lamp display and alphanumeric display devices (to be described later). A black cloth around these units reduced distracting visual stimuli to a minimum. The EMG was recorded using gold disc electrodes and electrode paste and held on with tape.

#### Patterned Light Training

Each of the truncated list of English alphabet characters has been assigned a particular code (see Appendix A). These codes can be considered as four lamps which can be lit or dark in various combinations. Thus, to train subjects we employed a lamp display panel (see Figure 3). The display consists of two rows of incandescent lamps. Lamps in the top row have orange lenses, the lamps on the bottom are green and the single lamps on the extreme right and left are red.

Rather than initially present the alphanumeric display and the associated code as displayed on the lamp display we first trained the subjects to respond correctly to the lamps alone. It was felt that this was a somewhat simpler task and that the alphanumeric display could be added later. The task consisted of the presentation of a pattern of lit lamps on the upper row. The upper row of lamps for convenience are referred to as the S code (Stimulus Code) lamps. The subject was to turn on the lower row of lamps such the pattern of lit lamps in the two rows coincided. The lower row of lamps will be referred to as the R Code (Response Code) lamps. Thus, the task is a match-to-sample paradigm.

Figure 3 Representation of the interactive display devices. The subject is seated 1 meter in front of the window.

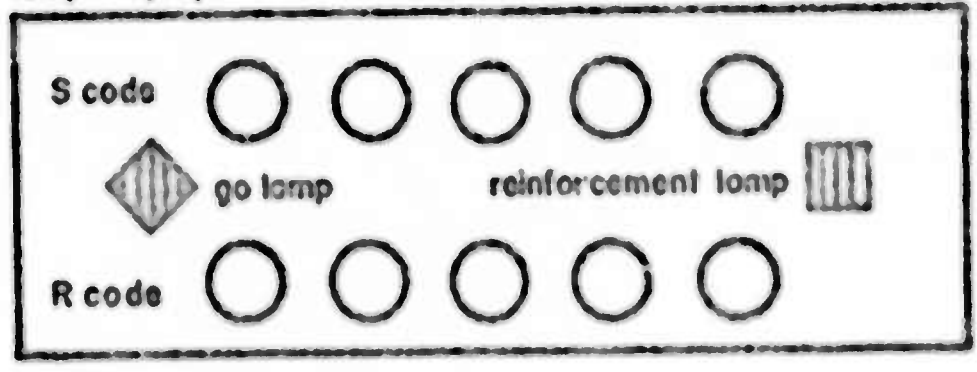


### INTERACTIVE DISPLAY DEVICES

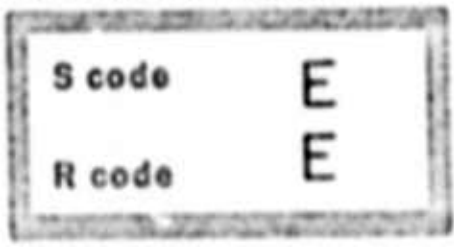
window



lamp display



alphanumeric display



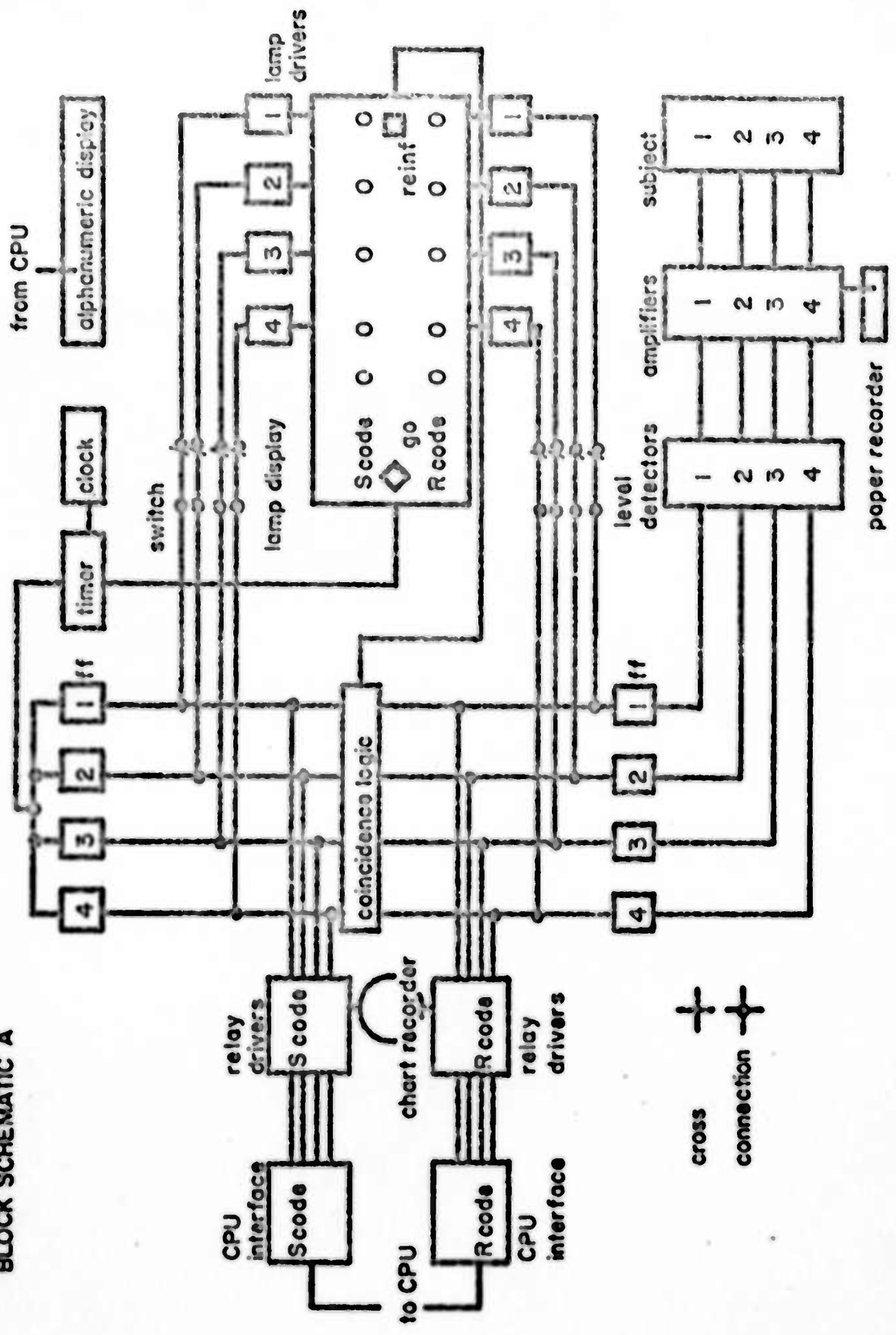
Every 6-10 seconds the S Code was displayed for a variable period of time (from 3 sec down to 1/4 sec as training progresses). At the same time the left hand red lamp is lit signalling the start of a trial (termed the GO lamp). The subject then issues a response. If successful in matching to the sample the right hand red light is lit (reinforcement lamp). At the end of the trial the lamp display panel is turned off.

The initial training was accomplished with logic devices as shown in Figure 4. The four channels of EMG information were amplified and simultaneously written onto a pen-writing polygraph. The amplified and filtered EMG was fed into a series of level detectors which produced standard logic level pulses when the voltage of the EMG exceeded a preset level. The output of the level detectors set R Code flip-flops which in turn activated lamp drivers providing a visual lamp display. The output of the R Code flip-flops in addition activated two interfaces; one to a chart recorder for a printed record of response, the other to the computer external sense lines.

The S Code presented on any trial was randomly determined by a highspeed digital clock that transferred its count to the S Code flip-flops upon command from a timer. The flip-flops in turn activated the lamp drivers and S Code lamps of the display panel. The S Code, too, was routed to a chart recorder and the computer. The reinforcement lamp was lit when the output of the coincidence logic indicated that the R Code equalled the S Code. Twenty-five trials constituted a block and a session contained ten blocks.

**Figure 4 Block Schematic A. Logic devices utilized in initial training.**

BLOCK SCHEMATIC A

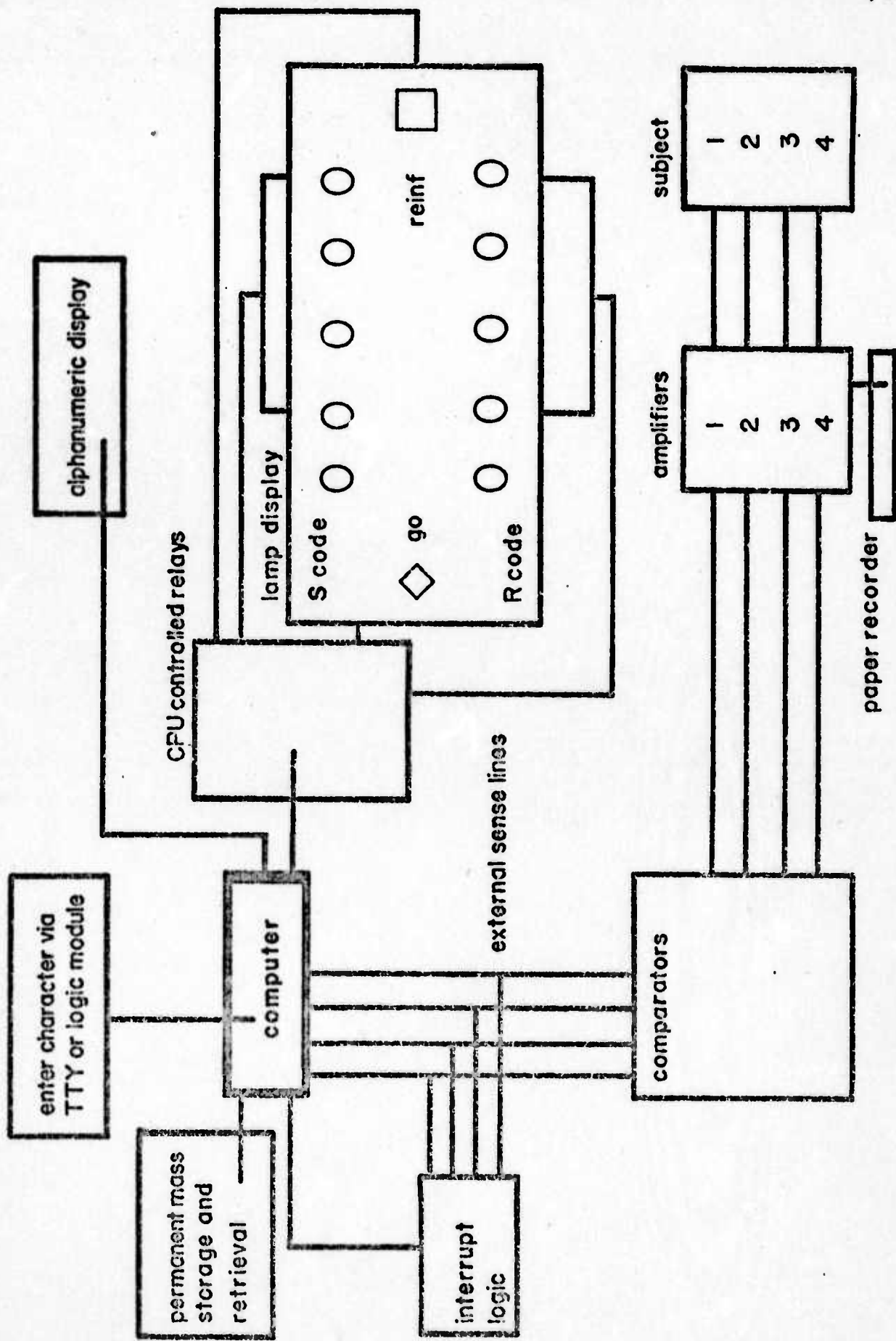


The next phase of training and system development involved the association of the S Code lamps with a particular alphanumeric display. Referring back to Block Schematic A (Figure 4) note that the S Code was relayed to the computer. A program was developed (Appendix B) to decode the S Code and display the appropriate alphabetic character on the remote display unit for the subject to view. The results of this stage are discussed in the section dealing with permanent subject training and performance.

The use of control logic left much to be desired in terms of reliability, flexibility and convenience. Consequently, we redesigned the control and analysis systems to shift system control and monitoring to the computer. Block Schematic B (Figure 5) depicts the current system configuration. A new computer program (Appendix C) was developed to support the new configuration. The EMG "R Code" is captured in the same manner as previously but is now routed to a series of comparators to perform an analog to digital conversion. The computer external sense lines then permit decoding of the R Code under software control. As a function of the detected R Code and at the experimenter's option the computer can 1) activate the R Code lamps for patterned visual feedback; 2) activate audio oscillators which are spatially arranged for auditory feedback; or 3) display the R Code alphabetic character on the alphanumeric display unit as a form of cognitive feedback.

Figure 5 Block Schematic B. Systems configuration to support the experimental control and data analysis of the project.

BLOCK SCHEMATIC B





The S Code is generated either by a random logic device or by manual intervention through the computer's teletype device. The computer presents the S Code and monitors the sense lines for the R Code. While monitoring and matching the R Code to the S Code, the computer constantly updates the feedback options with the current R Code responses. When a match is detected between the S Code and R Code the computer signals a reinforcement.

Under the control logic system we could only determine the total number of correct responses during trials. This program provides a letter by letter analysis for each trial consisting of an indication of the S Code, the subject's response, and the latency for each muscle group in milliseconds.

This provides the substrates for a much finer grained analysis of these behavioral properties. Appendix D contains the computer programs used for the analysis of data acquired this procedure.

We are currently developing a program which provides the capability of multi-character S Code and R Code control and analysis. This program will also provide for incorporation of the analog-to-digital capabilities for EMG and EEG patterns analysis scheduled for year #2.



### Permanent Subject Training and Performance

Using the procedures described previously we have two permanent subjects in different stages of training. The first subject was initially trained with the logic control system and her training has continued after the transition to computer control. The second subject began training after the implementation of the computer control system. Consequently, the training for the two subjects has differed slightly.

#### Preliminary Training Both Subjects

We noticed that although the two muscles on each hand are well separated that the contraction of one was accompanied by the activation of the other to a noticeable degree. Our first step was to eliminate this interaction. To this end we placed a 4-trace oscilloscope in front of the subjects. The subjects saw each EMG channel and received immediate visual feedback that served two functions. One, it effectively eliminated the muscle interactions by allowing the subjects to observe and suppress the "wrong" response. Secondly, it gave the subjects a "feel" for what kinds of bioelectric signals she could produce.

During this phase of training, the subjects were instructed to twitch their muscles at will and simply observe the oscilloscopic display. The subjects were asked to attempt to twitch each muscle independently and in various combinations. They were also asked to

make smaller and smaller twitches. The subjects found these tasks relatively easy. In fact at the end of this phase of training the subjects were able to issue quite respectable potentials (about 50-100  $\mu$ V) without any apparent movement.

## PERMANENT SUBJECT ONE

Alphabetic Training

The initial alphabetic training for this subject was with the logic control system. The subject attained 90 to 95% correct match-to-sample responses at 1 sec display time after 1000-1500 trials. Figure 6 presents a polygraph record of the subjects performance at the end of this phase of training. As can be seen the baseline is relatively quiet. Most of these responses occur in the absence of any overt twitch.

Figure 7 presents the results of a session after the subject had mastered the match-to-sample task. In this particular session the subject was exposed to four different display times: 3.0, 2.5, 1.5 and 1 sec. Plotted are the percent correct responses per block for the various display times. As can be seen the longer display times represented a relatively easy task. At one second display times the subjects performance improved from 50% correct (where 6% is the chance level) to 85% correct in three blocks. Interestingly when the subject made an error there was often an increase in intertrial responses. This probably reflects an emotional response on the part of the subject to the cognizance of making an error. At the end of this phase of alphabetic training the subject evidenced a high degree of control over the EMG responses to the S Code lamps.

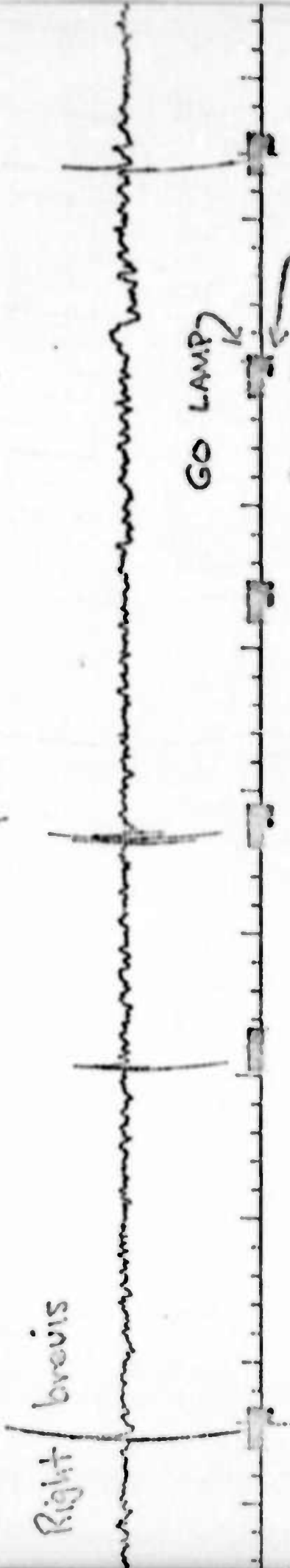
Figure 6 Polygraph recording of ENG's obtained from a subject well trained on the lamp display match-to-sample task.  
Gain = 50  $\mu$ V/cm; speed = 5 mm/sec.

Alphanumeric training

gain 50  $\mu$ V/cm 5 mm/sec



Right brevis



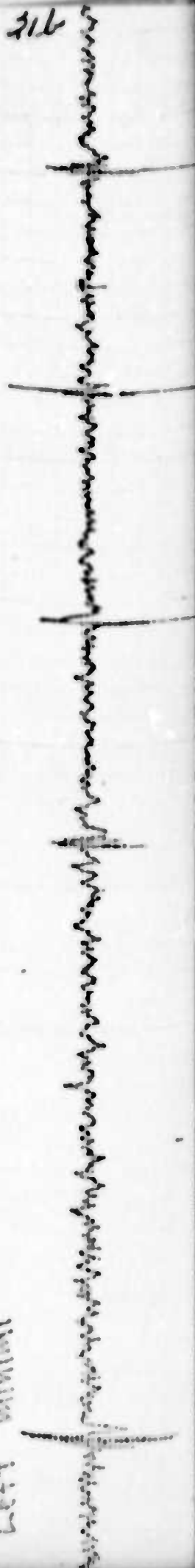
GO LAMP

REINFORCEMENT

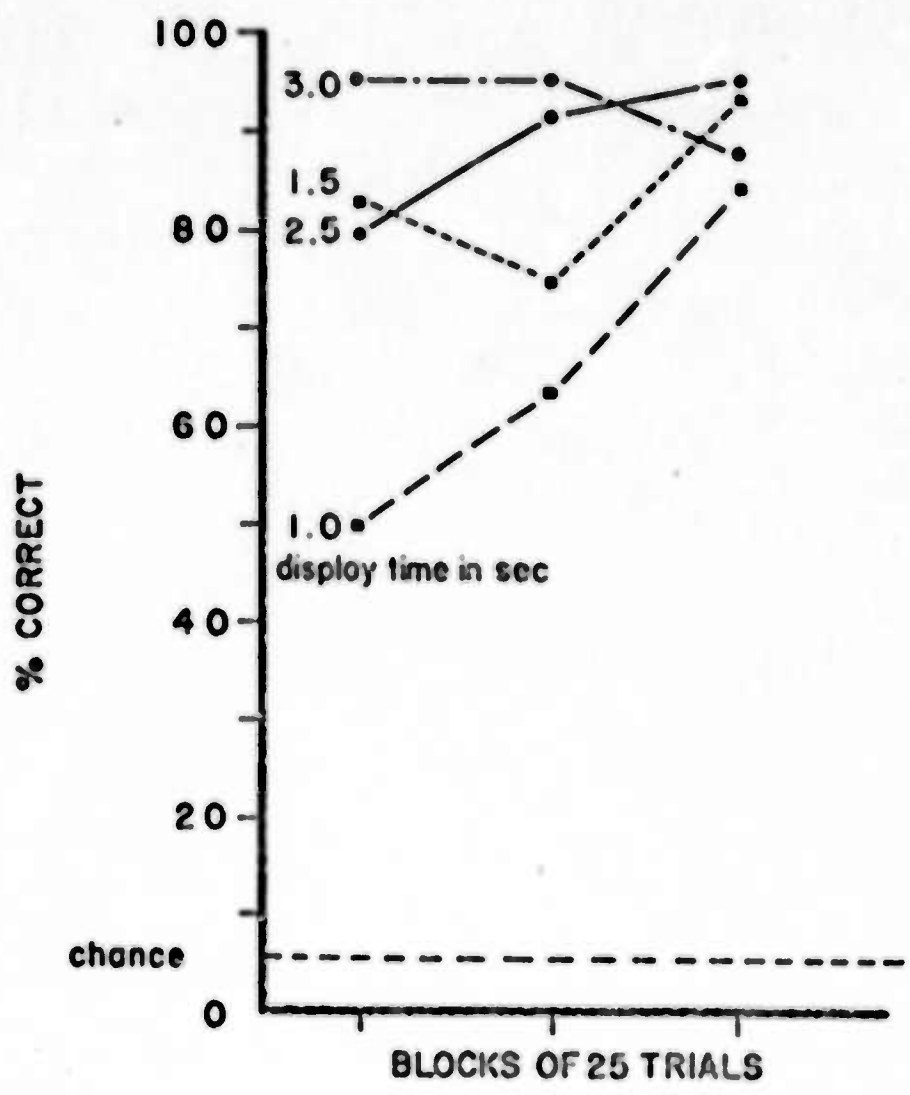
Left brevis



Left wingtip



**Figure 7** Results of a final session of lamp display match-to-sample training. Plotted are the percent correct responses per block of 25 trials as a function of display time.

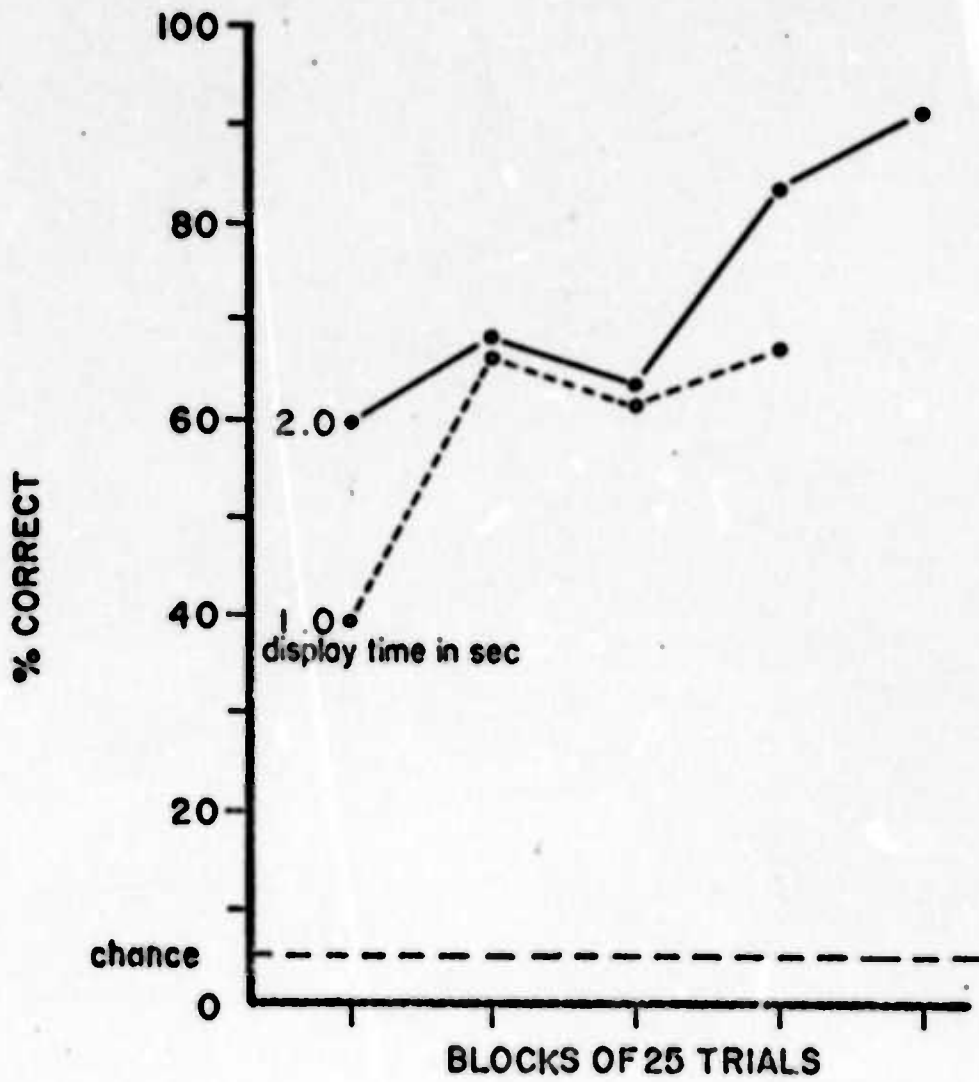


The subject learned the association in several sessions. The S Code lamps were then turned off leaving only the alphabetic character displayed. The R Code lamps, the GO lamp and reinforcement lamp were still present. Figure 8 presents the results of a session of alphabetic display training only. In this session the characters were displayed for either 2.0 sec or 1.0 sec. It is apparent that the longer display is again an easier task. These data were also analyzed for a trials effect across blocks within the session (Figure 9). The 25 trials were collapsed into five blocks of five trials. The data are expressed for the 1.0 sec display time, the 2.0 sec display time, and for both display times pooled together. Across trials one can see that performance improved but that it falls off somewhat at the end of the block. This latter effect may reflect a fatigue phenomena which might be alleviated by either a longer inter-trial-interval or fewer trials in a block.

With implementation of the augmented computer facility we were able to accomplish more detailed performance analyses as noted previously. In this context, we have identified letter by letter performance characteristics for this subject. Figure 10 depicts the percent correct of responses for each letter for this subject with a 2 second display time. The number associated with each letter is the arbitrary octal code assigned per Appendix A. Figure 11 reflects performance with a one second display time, while Figure 12 reflects a 280 millisecond display time.



Figure 8 Results of a session of alphabetic display training. plotted are the percent correct responses per block of 25 trials as a function of display time.



**Figure 9** Results of the alphabetic display training analyzed for a trials effect across blocks within a session. The 25 trials were collapsed into 5 blocks of 5 trials each. Plotted are the percent correct responses per 5 trial block as a function of display time (1.0 sec display, 2.0 sec display, and both display times pooled together).

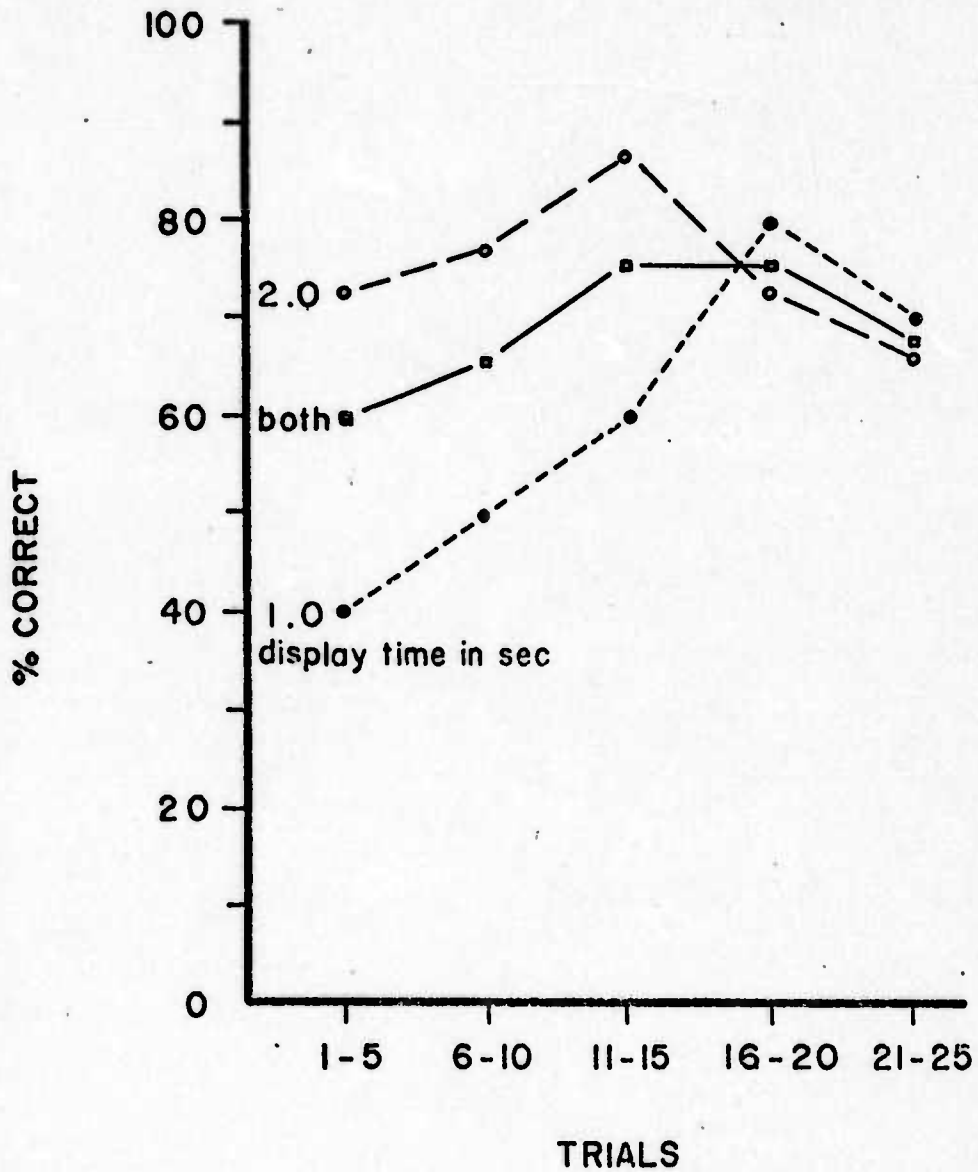


Figure 10 Results for alphabetic training from five daily sessions of 256 trials each. Plotted are the sixteen alphabetic responses and the overall performance in percent correct responses. Display time here is 2 seconds.

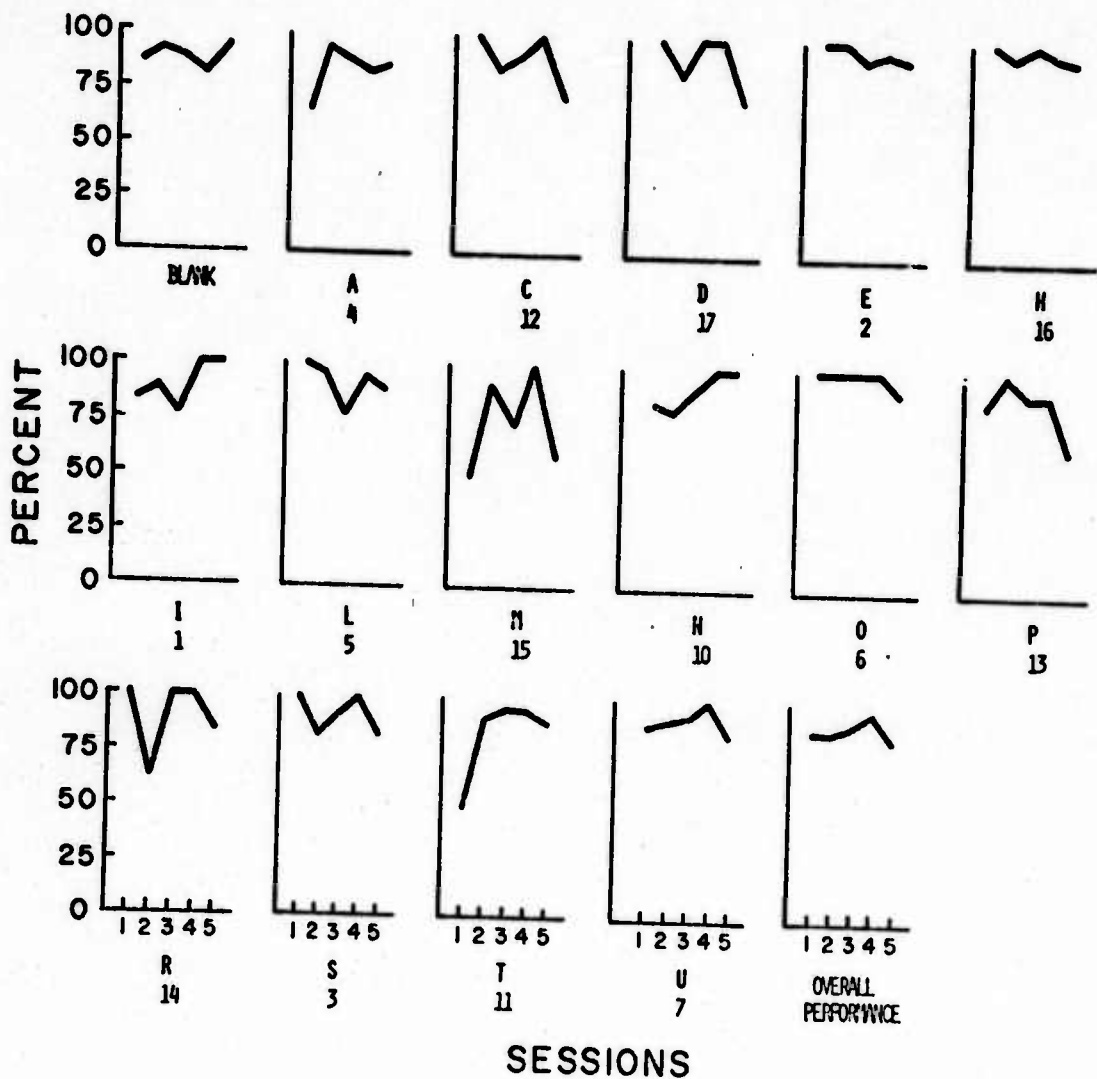
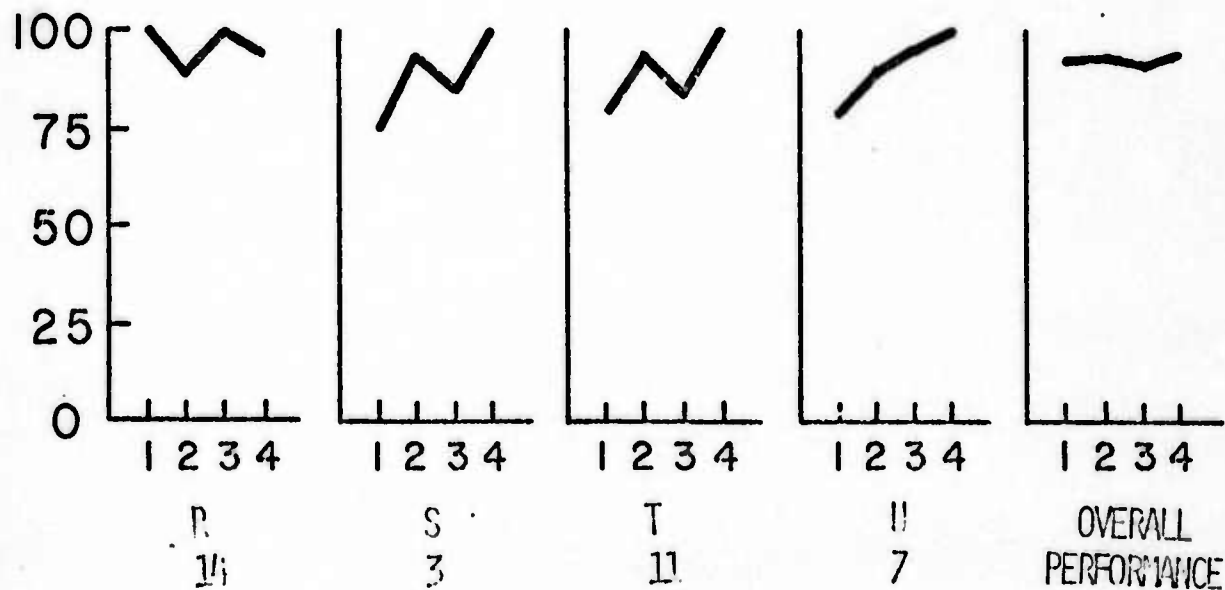
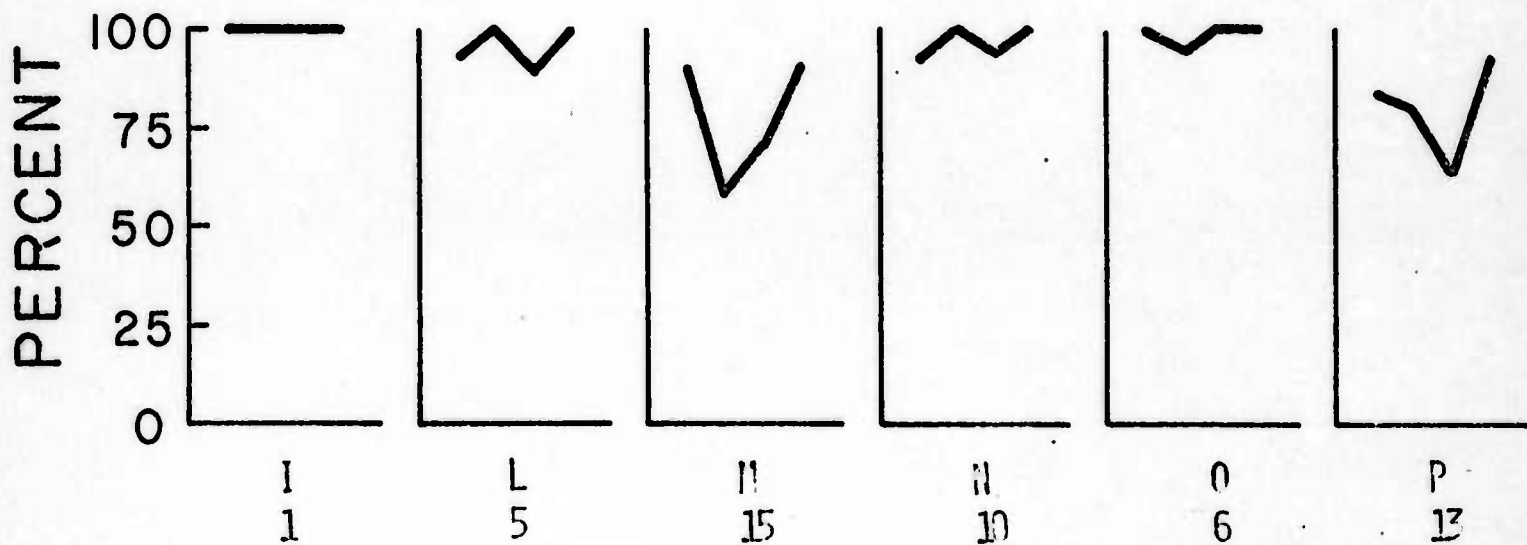
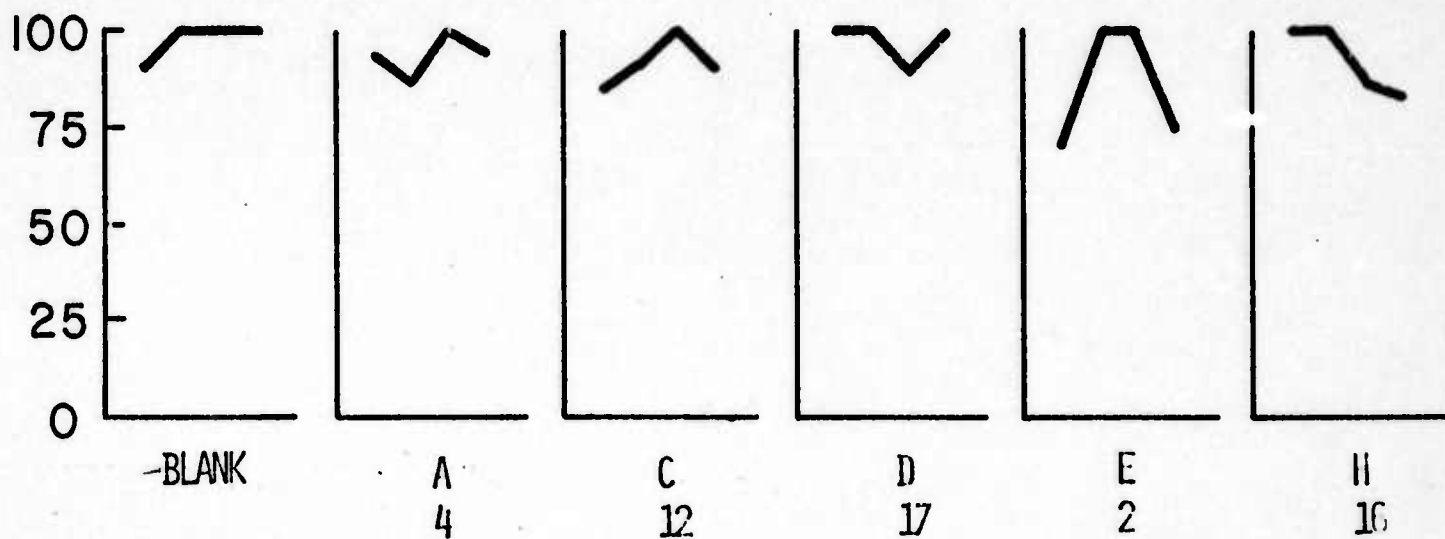


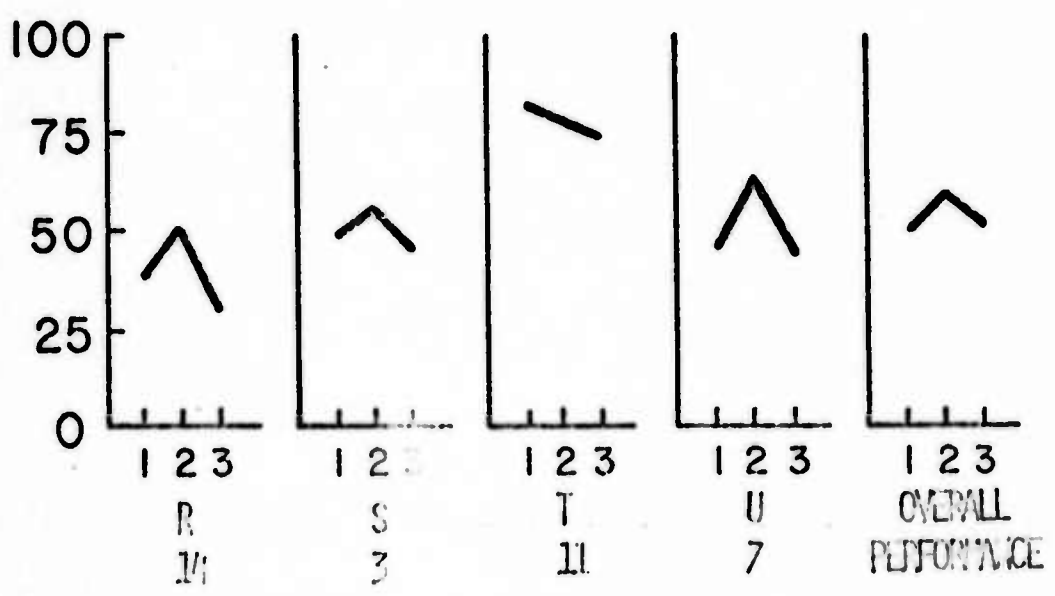
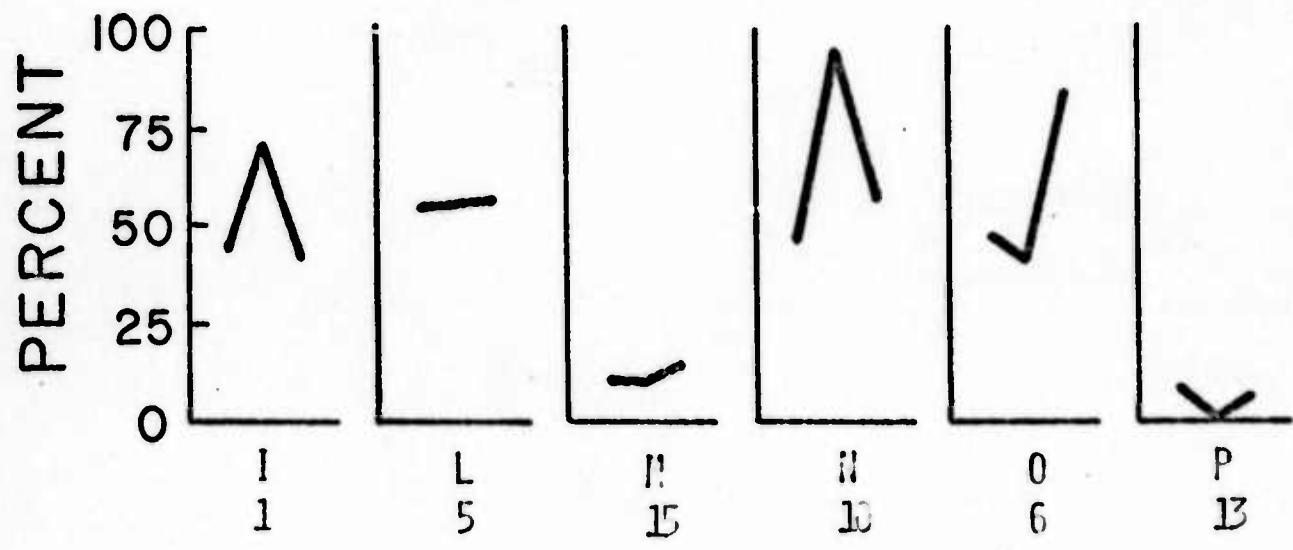
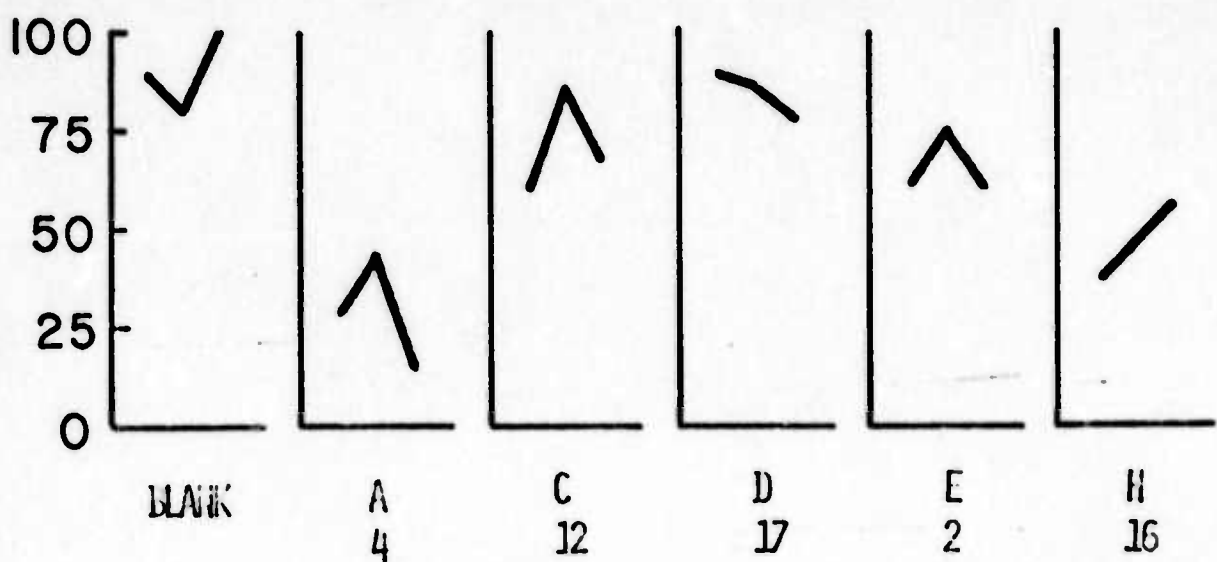
Figure 11 Results for alphabetic training from four daily sessions of 256 trials each. Plotted are the sixteen alphabetic responses and overall performance in percent correct responses. Display time 1 second.



SESSIONS



Figure 12 Results for alphabetic training from three daily sessions of 256 trials each. Plotted are the sixteen alphabetic responses and overall performance in percent correct responses. Display time is 280 milliseconds.

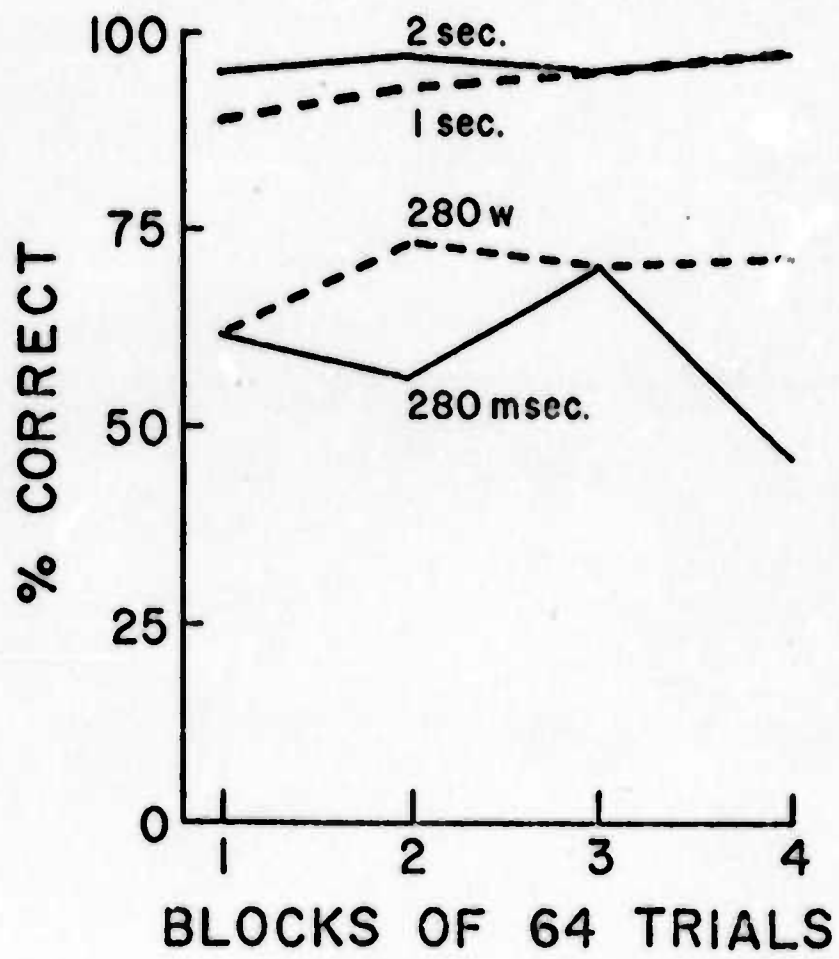


SESSIONS

As can be seen in Figure 11 this subject's overall performance exceeds 90% correct at a 1 second display time. When display times are reduced to 280 milliseconds (Figure 12) overall performance levels drop to about 50%. This is to be expected since this display rate approaches the limit of human performance for a visual motor reaction task with a vigilance component. Only one response pattern falls to chance level (the pattern for the letter "P"), the rest continues to be performed at a level significantly above chance performance.

A crucial point to recall, here, is that during the trial's the subject does not know what the next response requirement will be. Consequently, she must wait until a stimulus is presented and then select and initiate the appropriate response. The subject is required to perform at a rate selected by the system as opposed to performing at her own selected rate. The effect of this is suggested in Figure 13 where performance at 280 msec with warning is better than without warning. The performances reflected in Figures 10 through 12 were also analyzed for a trials effect similar to that of Figure 9 (Figure 13). In this case 256 trials were collapsed into four blocks of 64 trials. The data are expressed for display times of 2 seconds, 1 second, 280 millisecond, and 280 millisecond preceded by a 1 second warning light. Performance is essentially asymptotic with the 2 second and 1 second displays (compare to Figure 9) The performance at a 280 millisecond is as good or better than the 1 second performance earlier (Figure 9), while the 280 millisecond display performance is reminiscent of

Figure 13 Results of alphabetic display training analyzed for a trials effect across blocks within a session. The 756 trials were collapsed into four blocks of 65 trials each. Plotted are the percent correct responses per 64 trial block as a function of display time (2 seconds, 1 second, 280 milliseconds and 280 milliseconds preceded by a warning light).



the late trial diminution of Figure 9. It is quite clear that the subject shows significant performance in that reaction times approach limits of human visual-reaction performance (see below).

One of the goals of this project is the training of "automatic" or nearly reflex responding and encoding in human subjects. To this end we are decreasing the display time for this subject to the lower limits of human visual-motor reaction times.

There are two main goals of this type of training. The first is to train subjects to make all responses for a given code nearly in unison ( $\pm 50$  milliseconds). The second is to minimize the time available for discrimination and response selection thereby forcing near automatic responding. Table 1 shows the response latency by muscle for each letter averaged over three sessions with a 280 msec display time.

TABLE I

POOLED OVERALL LATENCIES  
IN MILLISECONDS

	Left LL Minimi	Left LT Brevis	Right RT Brevis	Right RL Minimi
A		235		
C	220.8		228.9	
D	201.	198.2	197.8	210.4
E			214	
H	220.4	235.7	231.4	
I				213.8
L		205.4		226.8
M	224.5	241.0		258.7
N	224.6			
O		220.2	227.5	
P	207.7		222.6	205.75
R	226.7	212.9		
S			213.5	232
T	198.3			207.2
U		218.3	222.1	225.2

Reaction latencies seem to be shorter for combinations of muscle responses as opposed to single muscle responses. This reflects the physiological control exerted by motor cortex on flexor motor neurons activating the muscles in question.



## PERMANENT SUBJECT TWO

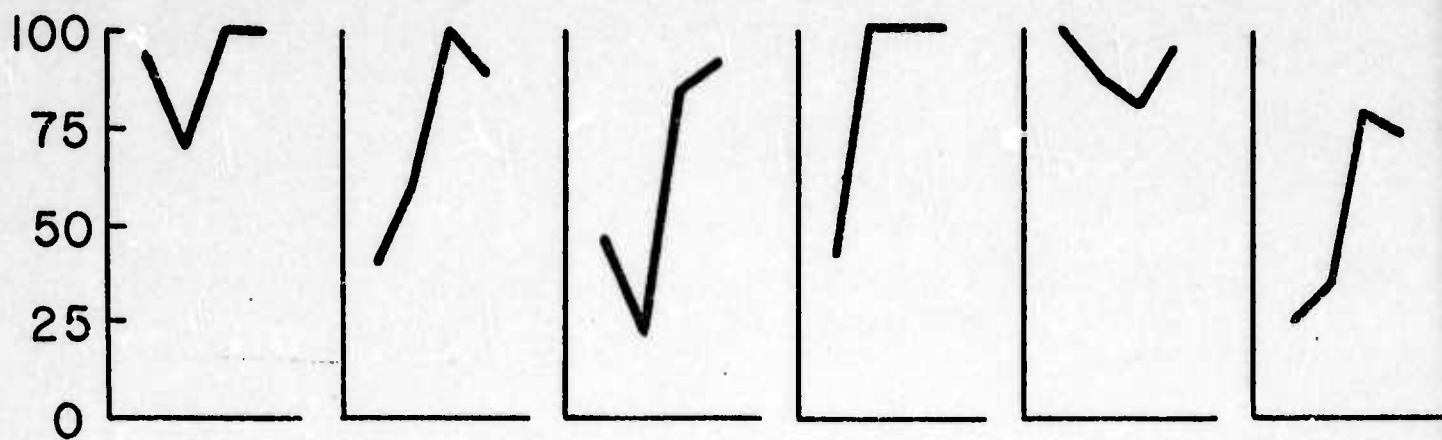
Figures 14, 15 and 16 deal with permanent subject two's performance during three portions of training. Figure 14 reflects patterned light performance for each light pattern (Appendix A) at a 2-second display time for several sessions. There are clear learning curves associated with each pattern and by the third session performance was above 90% controversial. Figure 15 shows performance during the transition from patterned light to alphabetic encoding. There were four sessions during which the subject was presented both patterned light and alphabetic displays. Again, by the third session this subject was performing in excess of 90% correct overall.

The subject was then trained on alphabetic displays only. Figure 16 reflects performance by letter during the first four sessions of letter training at a 2 second display time. Over the sessions, the subject shows consistent improvement and is responding at 90% accuracy by the fourth session. Figure 17 shows a trials effect analysis for two display times for this subject. One curve is for a second display period the other is for a one second period.

These data reflect performance after essentially six days of alphabetic training, four days at 2 seconds and two days at 1 second. At a 2 second display the performance is asymptotic during the session. The more difficult, at this stage of training, one second display response task is indicated by a 60 to 80% performance level. One expects that this performance level will improve also in accord with the other long term subject's performances.



Figure 14 Results of seven daily sessions of lamp display match-to-sample training. Plotted are the sixteen response combinations and overall performance in percent correct. Display time is 2 seconds. The alphabetic characters permit comparison between this and subsequent graphs.



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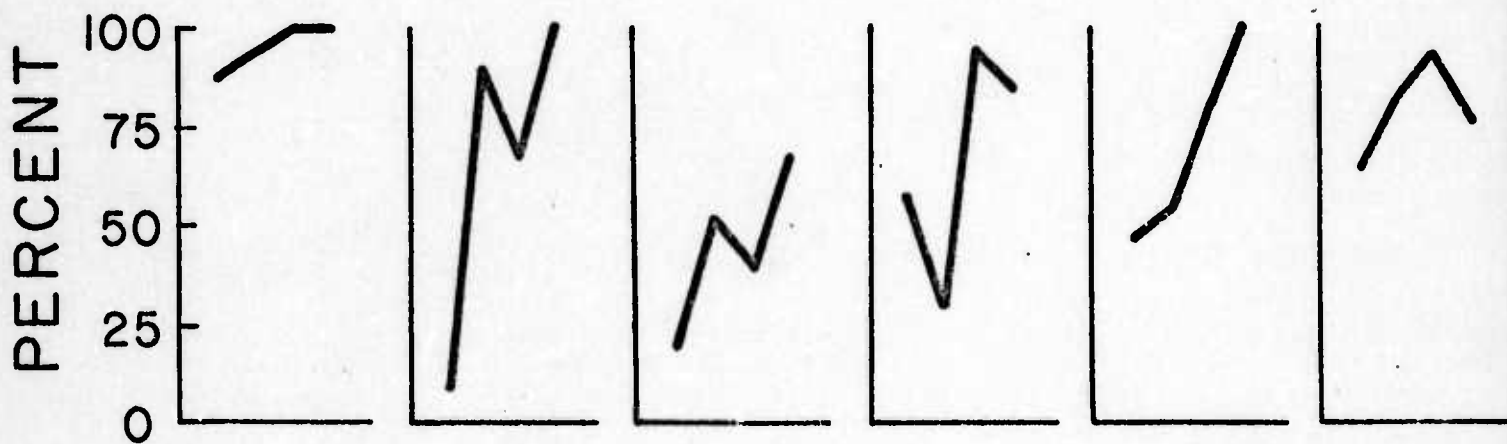
A  
4

C  
12

D  
17

E  
2

H  
10



I  
1

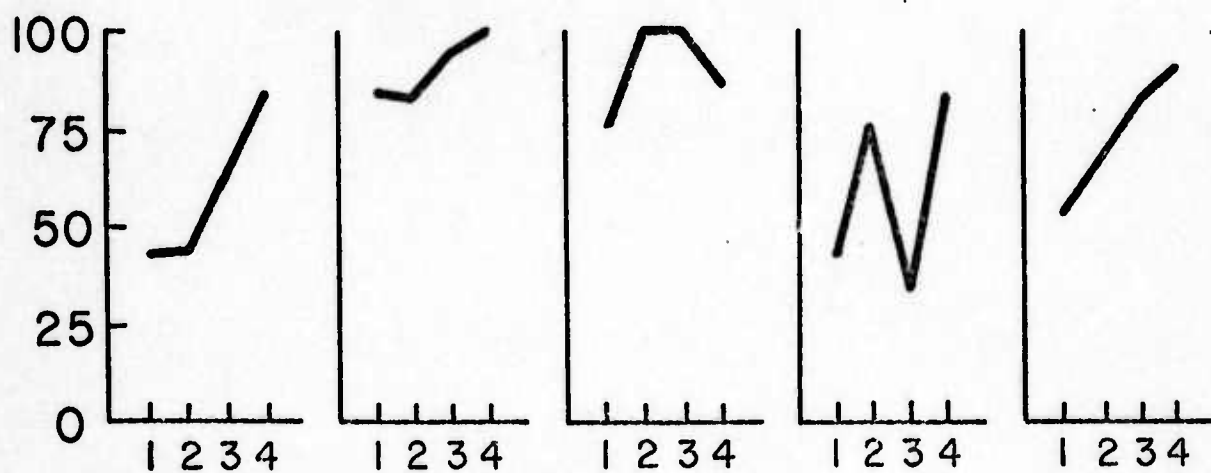
L  
5

M  
15

N  
10

O  
6

P  
13



R  
14

S  
3

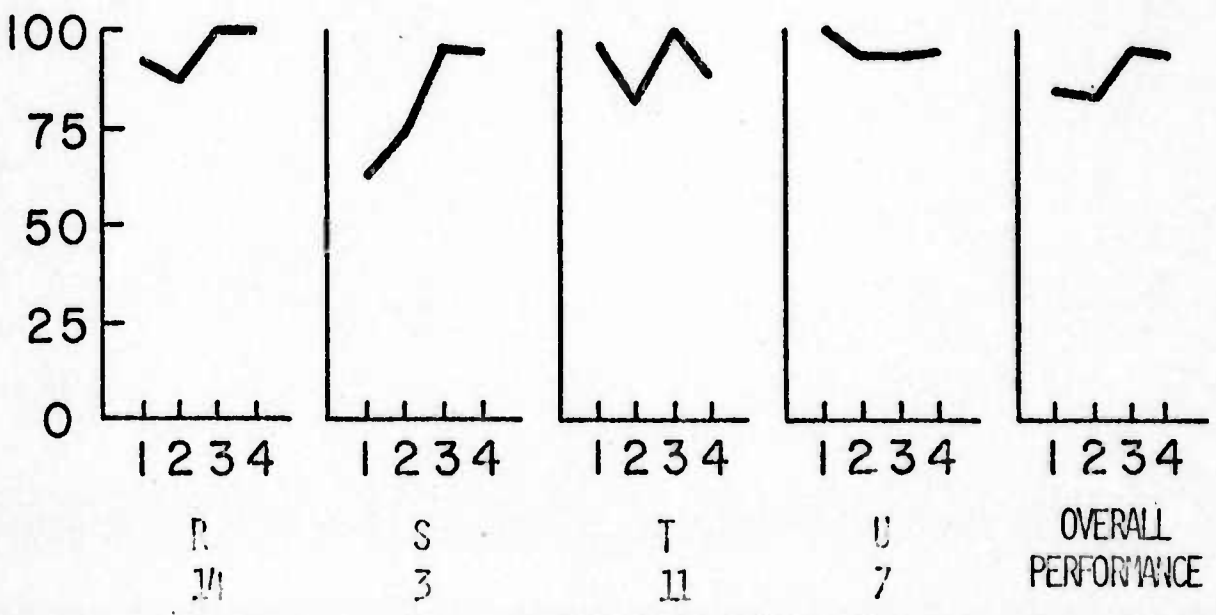
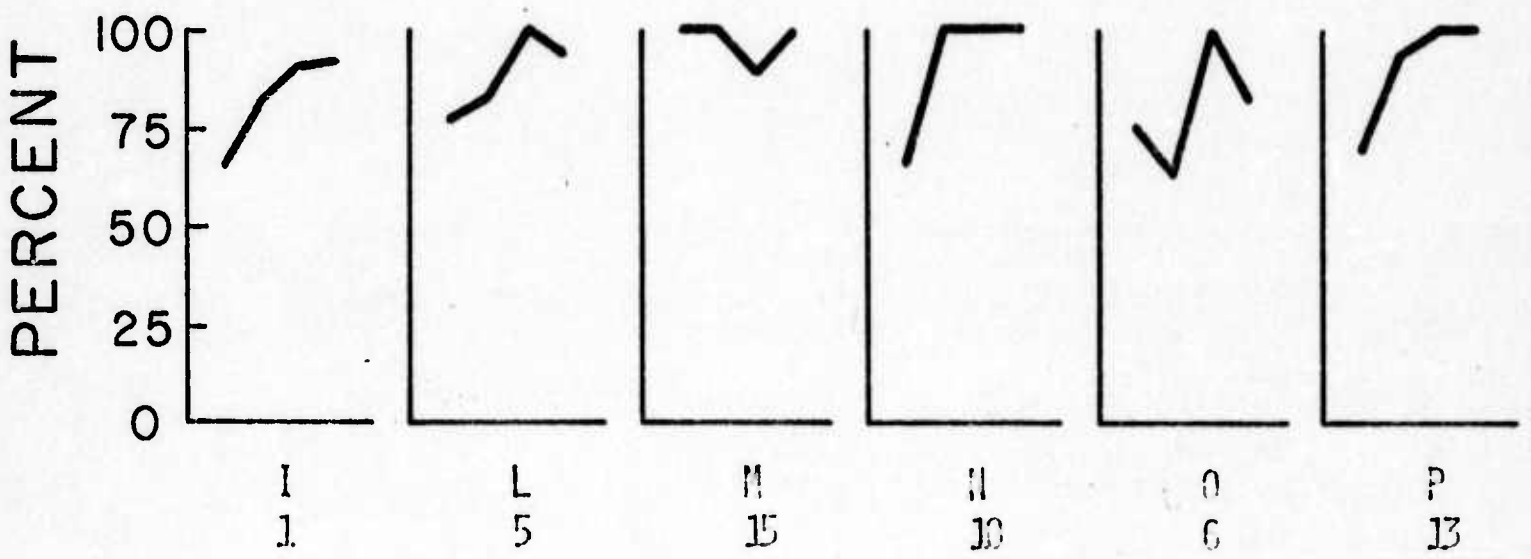
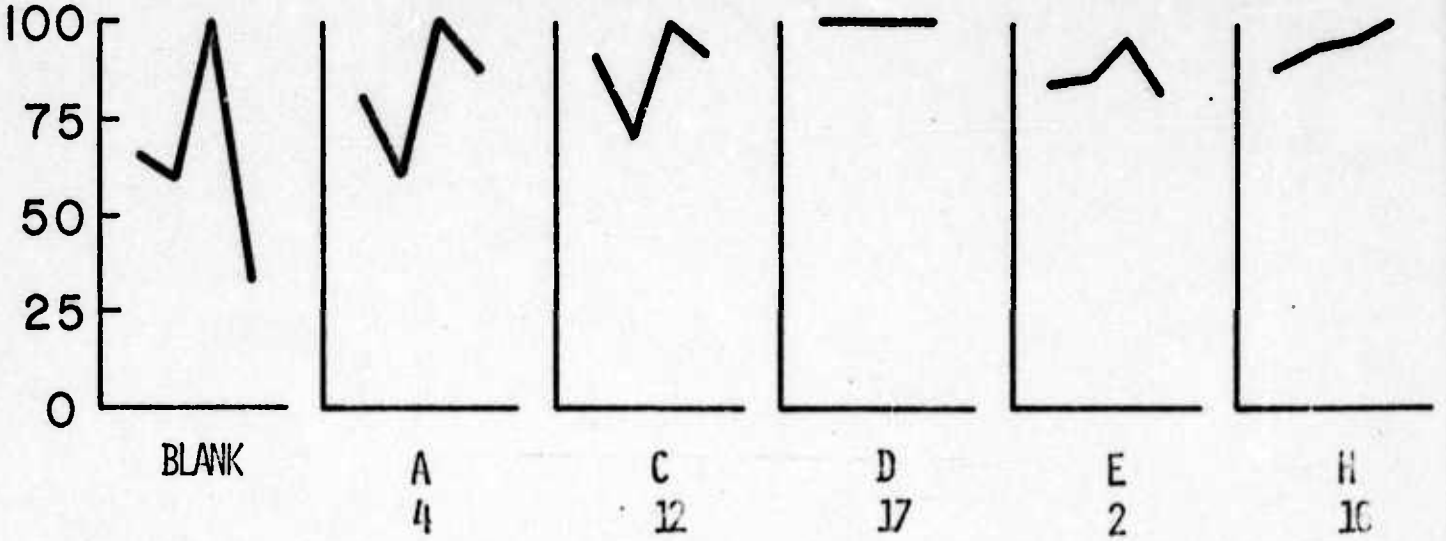
T  
11

U  
7

OVERALL  
PERFORMANCE

SESSIONS

Figure 15 Results of four daily sessions of lamp match-to-sample in conjunction with alphabetic training. Plotted are the sixteen alphabetic responses and overall performance. Display time is 2 seconds.



SESSIONS

Figure 16 Results for alphabetic training from seven daily sessions of 256 trials each. Plotted are the sixteen alphabetic responses and the overall performance in percent correct responses.  
Display time here is 2 seconds.

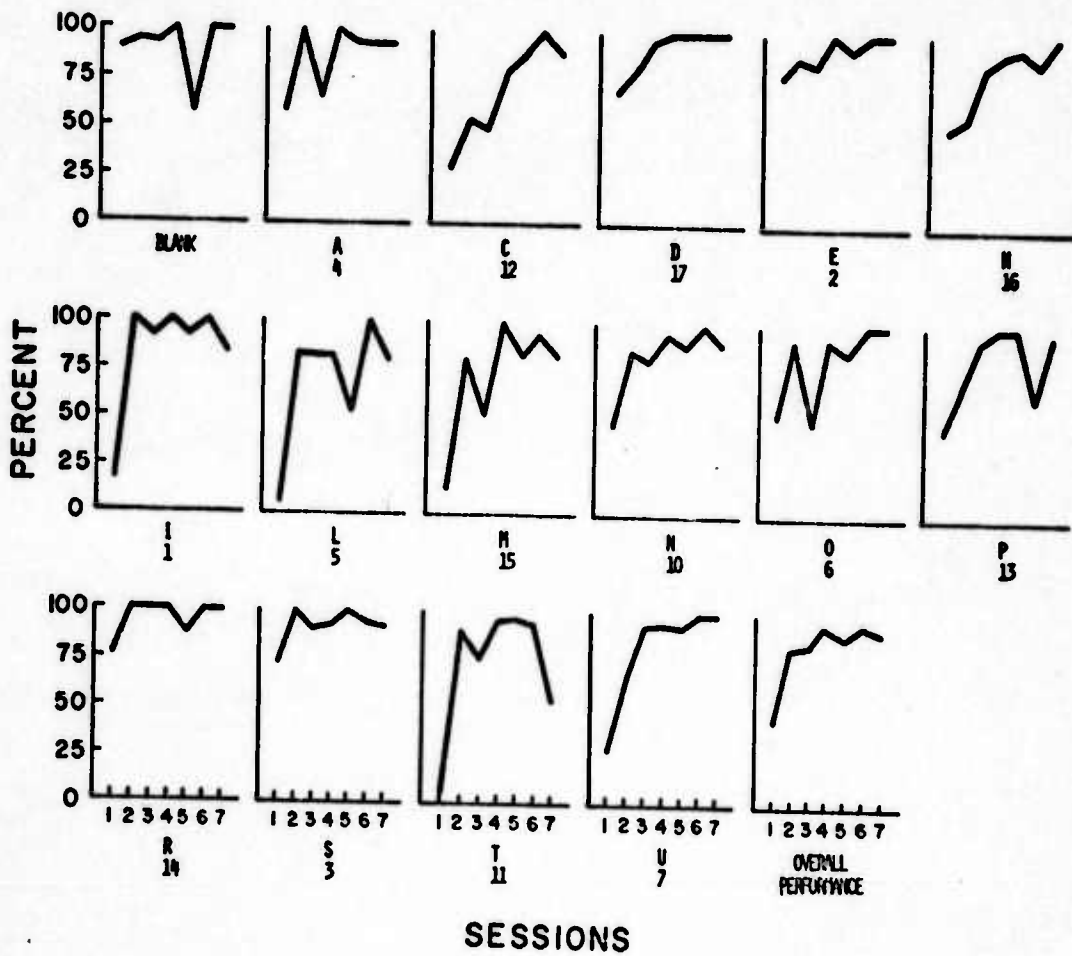
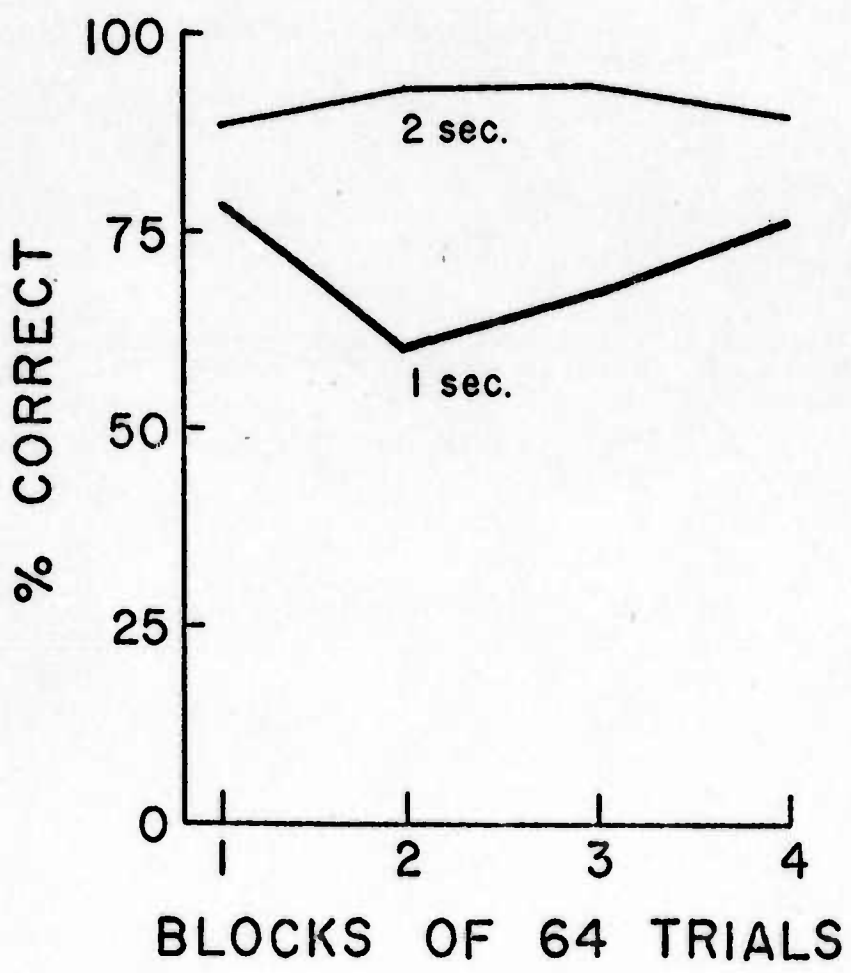


Figure 17 Results of alphabetic display training analyzed for a trials effect across blocks within a session. The 256 trials were collapsed into four blocks of 65 trials each. Plotted are the percent correct responses per 64 trial block as a function of display time (2 seconds, 1 second).







### BIOFEEDBACK STUDY

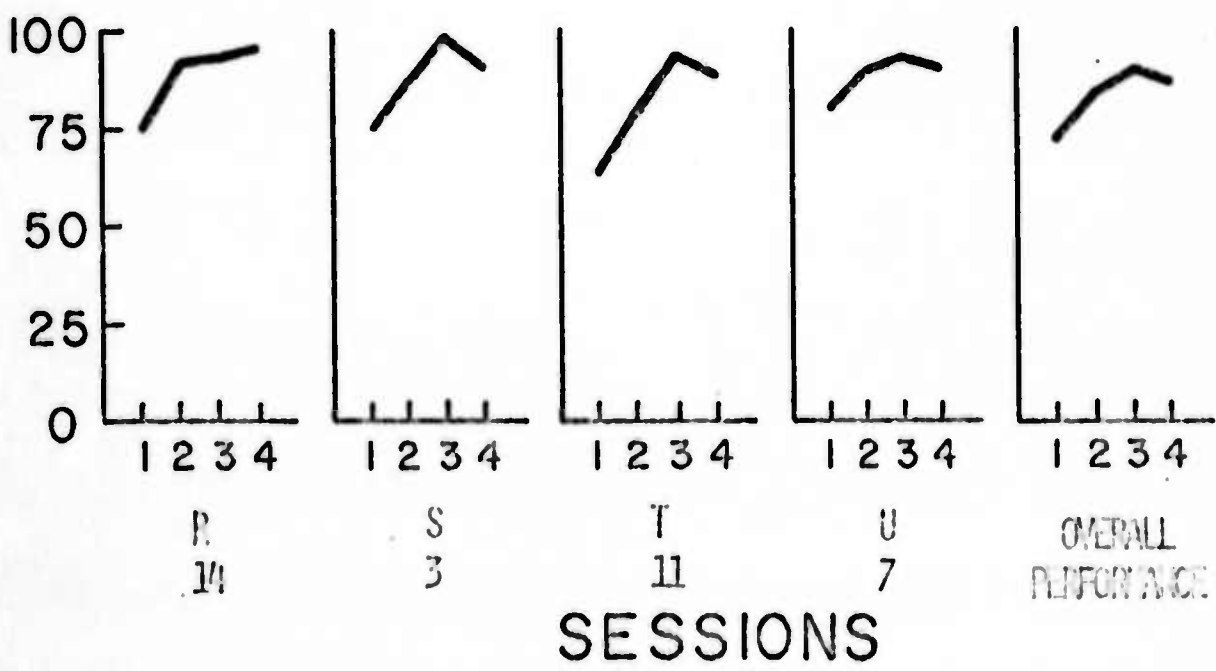
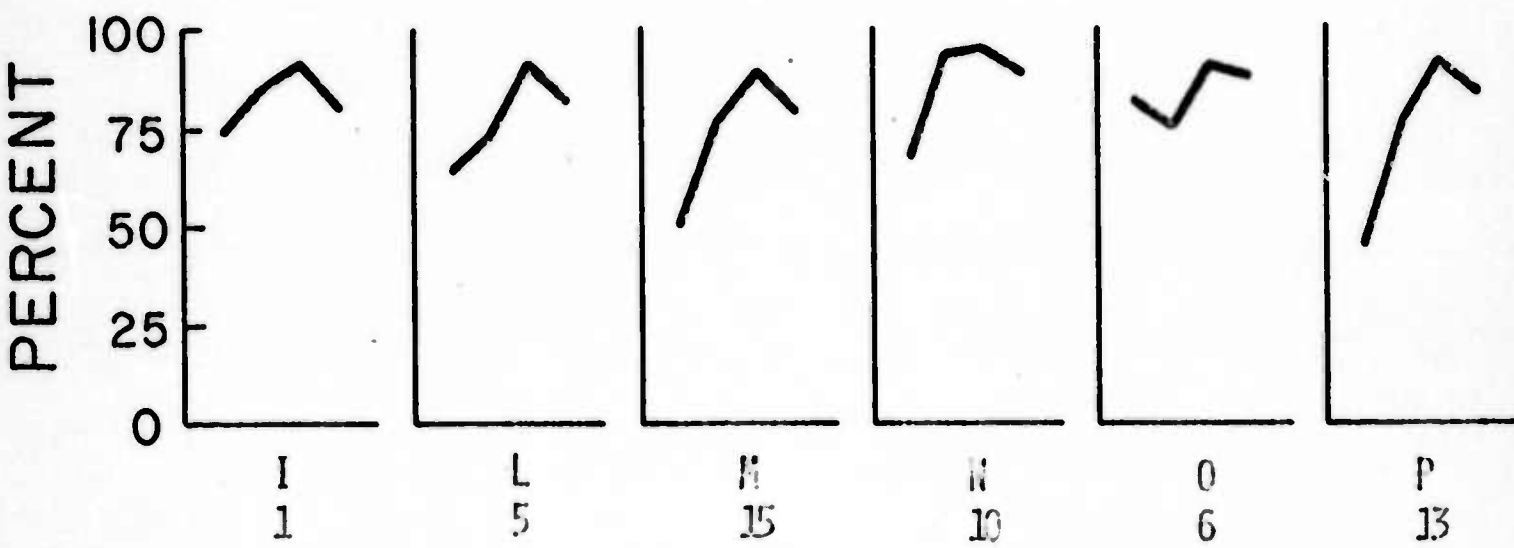
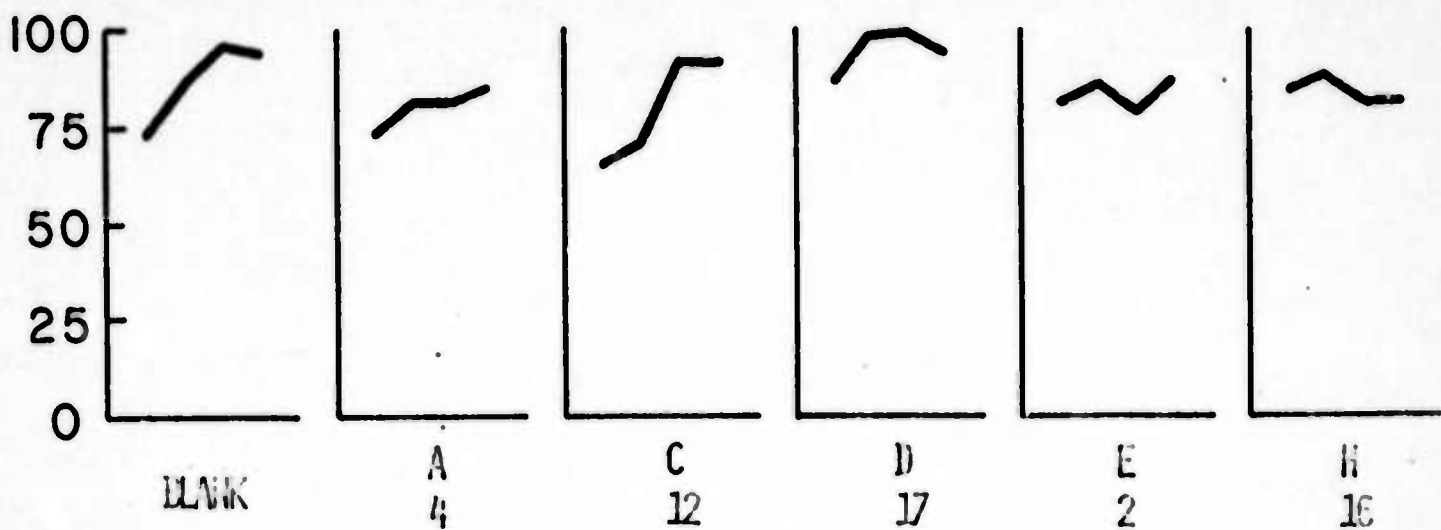
The project is designed to detect bioelectrical analysis of cognitive processes and to use these analogs in control and/or communication of external devices. One facet of this problem deals with the training of humans to use these analogs effectively. It is, therefore, necessary to assess training techniques to maximize the subject's performance through training. Most important is an understanding of what role information feedback derived from these analogs serves in task learning.

To address this issue we have run a multi-subject study in two parts. The first part provides auditory and visual biofeedback during the patterned light phase of training. The second part of the study is the alphabetic training procedure previously discussed.

The paradigm followed consists of four consecutive daily sessions with 256 trials of patterned light training and then four more consecutive daily sessions with 256 trials of alphabetic training with no patterned lights, either S or R Codes. During this study the display lights are presented for 1.5 seconds. Appendix E has the instructions which the subjects read prior to the first session.

Figure 18 shows the results of the patterned light training over the four sessions. These curves represent the averaged results from five subjects in terms of percent correct responses by pattern per session. Note that both the octal code of the pattern and the alphabetic assignment of that pattern are shown. This is to facilitate

Figure 18 Average performance for five subjects to light display match-to-sample by pattern for four sessions. Plotted are the sixteen response combinations and overall performance in percent correct. Display time is 2 seconds.



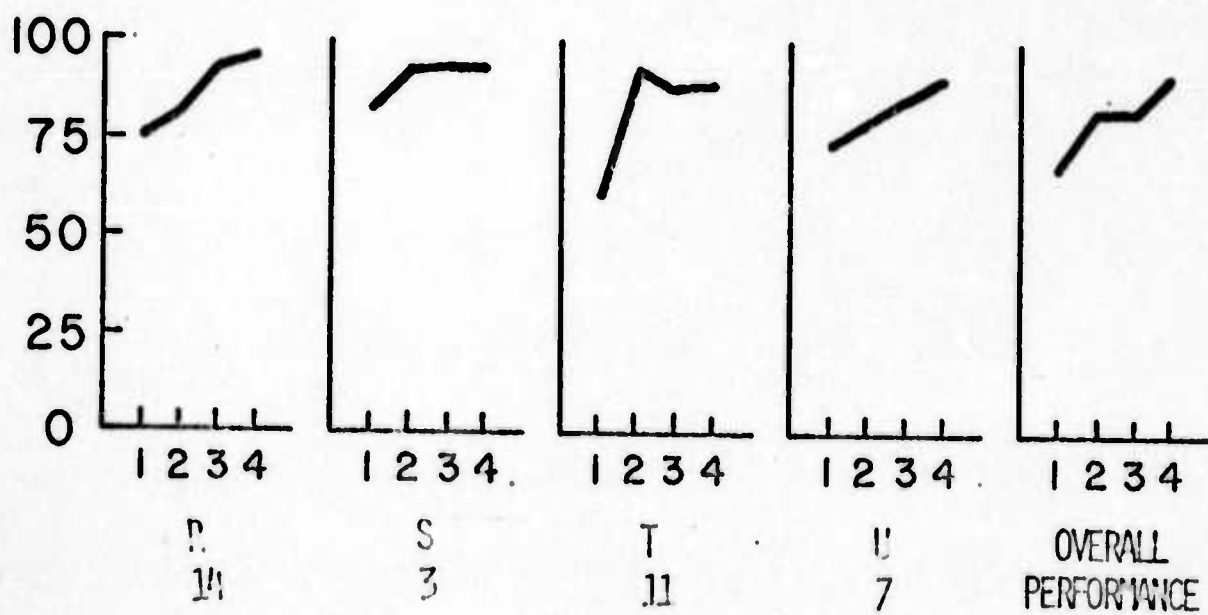
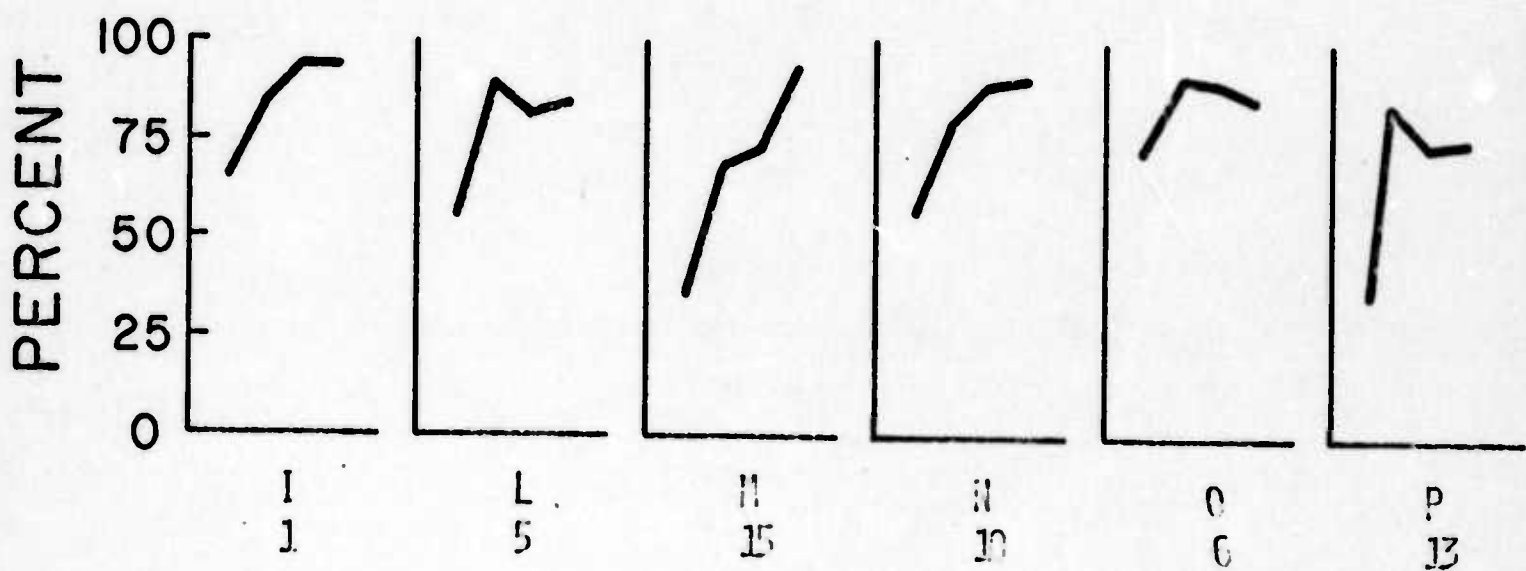
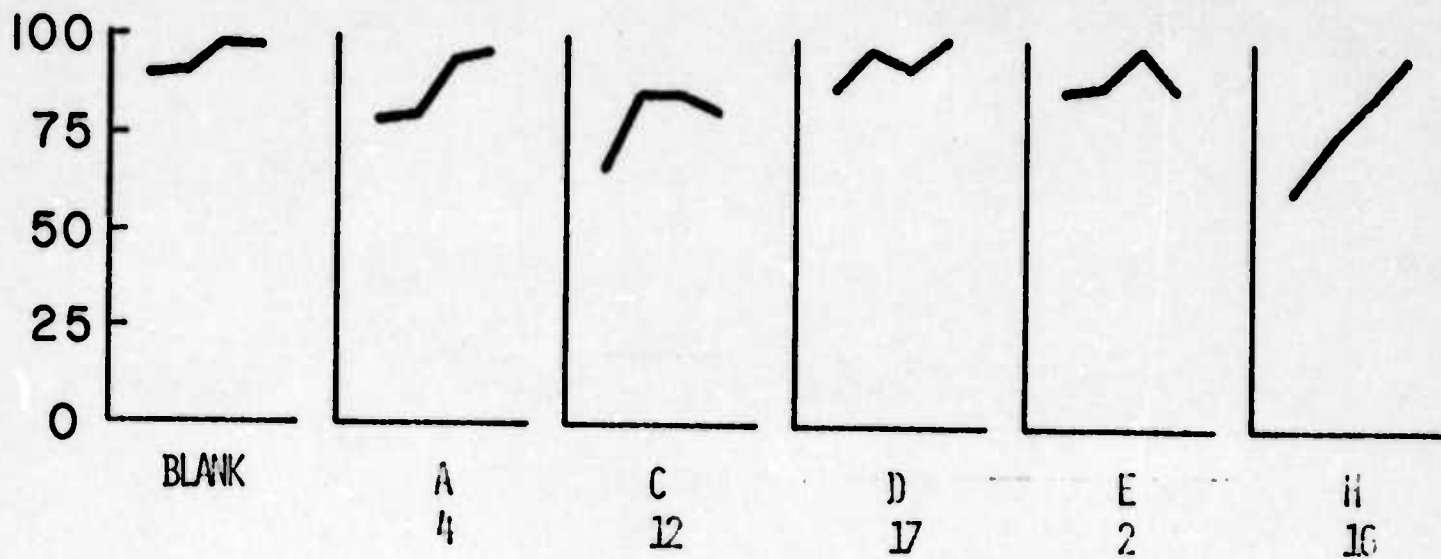
SESSIONS

comparison of patterned light training and alphabetic training results discussed below. At the end of the fourth session response accuracy to all patterns is 80% or above. The latency of EMG responses ranges 300 to 700 milliseconds during session four.

Figure 19 shows the averaged results of alphabetic training for four sessions. In this case response accuracy is above 80% in all but the responses to the letter "P" (76%). The latency for EMG response in this case ranges from 300 to 1000 milliseconds during session four.

It is clear that feedback enhances problem solving performance. However, a distinction must be made between problem solving and performance acquisition. The results here are very promising in terms of our training paradigm. However, before a more conclusive estimate of the paradigm's effectiveness can be made, we must run several control groups with varying degrees of training feedback. These groups will be run during the second year. It is clear that with these procedures subjects quickly learn to make the appropriate response.

Figure 19 Average performance for five subjects to alphabetic training for four sessions. Plotted are percent correct for overall performance and by letter. Display time is 2 seconds.



SESSIONS

### Conclusions

The original contract objectives for the first year were met in nine months elapsed time. Results of this year's effort provide a basic framework for accomplishing the subsequent year's tasks.

There are two essential objectives reached during the time period covered by this report. First, the training procedures we have devised have been validated. Second, the instrumentation and software development to support the project is well advanced and provides the capability to accomplish the objectives defined for subsequent years.

### References

- Hefferline, R. F. & Perera, T. B. Proprioceptive discrimination of a covert operant without its observation by the subject. Science, 1963, 139, 834-835.
- Leuba, C. & Dunlap, R. Conditioning imagery. J. exp Psychol., 1951, 41, 352-355.



### Appendix A

Below are the S Codes and their corresponding alphanumerics. The codes were devised with the following considerations in mind. First it was thought to be desirable to give the most commonly occurring alphabetic characters the simplest code. Thus the letter E received a simple code: the right brevis alone. Since we have 15 codes to issue we determined the 15 most frequent letters and tested them for intelligibility. The 15 letters below comprise a high percentage of those letters actually used in normal communication and can convey a good deal of information.

The codes are given octal representation merely as a convenience.

Alphabetic Character	Left Minimi 4	Left Brevis 3	Right Brevis 2	Right Minimi 1	Binary Code	Octal Code
E			X		0010	02
A		X			0100	04
I				X	0001	01
N	X				1000	10
O		X	X		0110	06
R	X	X			1100	14
S			X	X	0011	03
T	X			X	1001	11
L		X		X	0101	05
C	X		X		1010	12
U		X	X	X	0111	07
P	X		X	X	1011	13
M	X	X		X	1101	15
H	X	X	X		1110	16
D	X	X	X	X	1111	17

The Xs indicate which of the lamps are to be lit for a given alphabetic character.



## APPENDIX B

PROGRAM NAME: ARPA 1

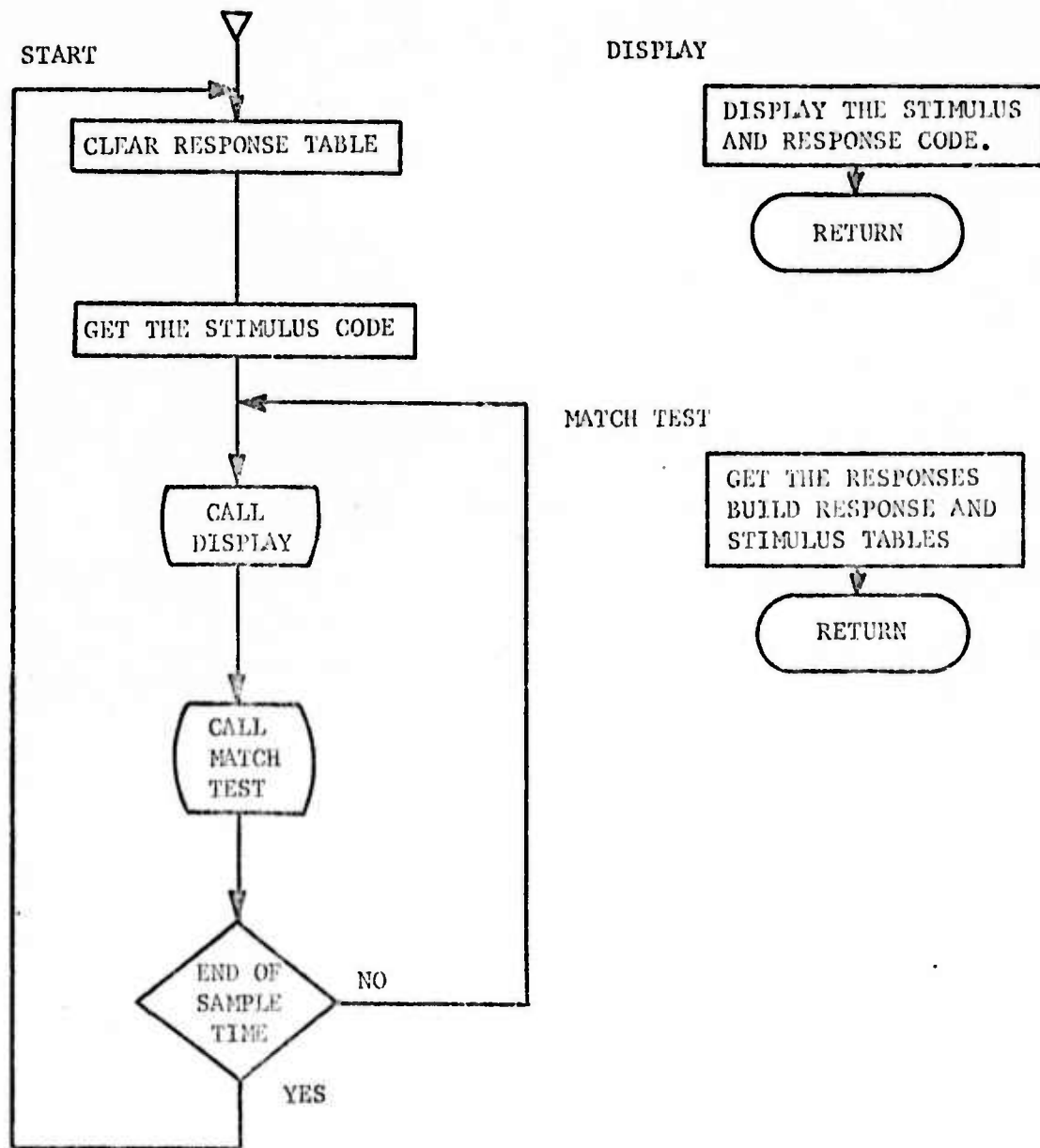
FUNCTION: This program displays two alpha numeric characters. The top character is the "S Code" or stimulus code, the bottom character is the "R Code" or response code.

LANGUAGE: DIAL-LAP6 (ASSEMBLY)

DESCRIPTION: The S Code is accepted from a teletype entry, or, if sense switch 5 is depressed, from the logic levels of external sense lines 5, 6, 7, 10, and 11. In the latter case, a zero volt level to sense line 12 indicates codification of lines 5-11 is complete and sampling may begin.

Simultaneously with displaying the alphanumeric symbol related to the S code, the program monitors external sense lines 0, 1, 2, 3 and 4 for a corresponding R code. If a match is detected relay K0 is set, indicating reinforcement.

## ARPA 1 FLOWCHART



```

0000
0001
0002
0003
0004
0005      0020 0011  AASTRT, CLR
0006      0021 0500      IOB
0007      0022 0046      TLS
0010      0023 0062      SET I 2
0011      0024 0312      HITTBL-1
0012      0025 0063      SET I 3
0013      0026 7767      -10
0014      0027 1062      STA I 2
0015      0030 0223      XSK I 3
0016      0031 6027      JMP .-2          /CLEAR HITTBL
0017      0032 0062      SET I 2
0020      0033 0302      DSCTBL-1
0021      0034 0063      SET I 3
0022      0035 7767      -10
0023      0036 1062      STA I 2
0024      0037 0223      XSK I 3
0025      0040 6036      JMP .-2          /CLEAR DSCTBL
0026      0041 0077      SET I 17
0027      0042 0302      DSCTBL-1
0030      0043 0075      SET I 15
0031      0044 7776      N,             -1
0032      0045 6147      JMP GETCHR
0033      0046 0067      SET I 7
0034      0047 7775      AAA,          -2
0035      0050 6054      JMP THIS
0036      0051 0227      XSK I 7
0037      0052 6050      JMP .-2
0040      0053 6020      JMP AASTRT
0041
0042      0054 1000      /
0042      0054 1000      THIS,        LDA
0043      0055 0000      0
0044      0056 4071      STC THISR
0045      0057 0066      SET I 6
0046      0060 0000      0
0047      0061 6250      JMP DISIT
0050      0062 0052      SET I 2
0051      0063 0044      N
0052      0064 0076      SET I 16
0053      0065 0312      HITTBL-1
0054      0066 6072      JMP MATCHT
0055      0067 0226      XSK I 6
0056      0070 6061      JMP .-7
0057      0071 0000      THISR,      0
0060
0061
0062      /SAMPLE SENSELINE
0063      0072 1000      MATCHT,     LDA
0064      0073 0000      0
0065      0074 4146      STC MTCRA
0066      0075 0011      CLR
0067      0076 1060      STA I
0070      0077 0000      SUM,        0
0071      0100 0070      SET I 10
0072      0101 0077      SUM
0073      0102 1020      LDA I
0074      0103 0001      1

```

0076	0105	1150		ADM 10	
0077	0106	1020		LDA I	
0100	0107	0002		2	
0101	0110	0401		SXL 1	
0102	0111	1150		ADM 10	
0103	0112	1020		LDA I	
0104	0113	0004		4	
0105	0114	0402		SXL 2	
0106	0115	1150		ADM 10	
0107	0116	1020		LDA I	
0110	0117	0010		10	
0111	0120	0403		SXL 3	
0112	0121	1150		ADM 10	
0113	0122	6250		JMP DISIT	/REFRESH
0114	0123	1020		LDA I	
0115	0124	0425		SNSCOD	
0116	0125	2077		ADD SUM	
0117	0126	4003		STC 3	
0120	0127	1003		LDA 3	/GET ASCII
0121	0130	1560		BCL I	
0122	0131	7700		7700	
0123	0132	0241		ROL 1	
0124	0133	1120		ADA I	
0125	0134	0323		CHRDIS	
0126	0135	1040		STA	
0127	0136	0003		3	
0130	0137	1003		LDA 3	/
0131	0140	1076		STA I 16	
0132	0141	1023		LDA I 3	
0133	0142	1076		STA I 16	/NEW HITS
0134	0143	6250		JMP DISIT	
0135	0144	0232		XSK I 12	
0136	0145	6075		JMP SUM-2	
0137	0146	0000	MTCHR, 0		/MATCH RET
0140			/		
0141	0147	1000	GETCHR, LDA		
0142	0150	0000		0	
0143	0151	4177		STC CHRRET	
0144	0152	0465		SNS I 5	
0145	0153	6200		JMP SENSIT	
0146	0154	0500		10B	
0147	0155	6031		KSF	
0150	0156	6154		JMP *-2	
0151	0157	0500		10B	
0152	0160	6036		KRB	
0153	0161	1060	STRIP, STA I		
0154	0162	0000	CHAR, 0		
0155	0163	1560		BCL I	
0156	0164	7700		7700	
0157	0165	0241		ROL 1	
0160	0166	1120		ADA I	
0161	0167	0323		CHRDIS	
0162	0170	4003		STC 3	
0163	0171	1003		LDA 3	
0164	0172	1077		STA I 17	
0165	0173	1023		LDA I 3	
0166	0174	1077		STA I 17	
0167	0175	0235		XSK I 15	
0170	0176	6152		JMP GETCHR+3	/MORE WORDS
0171	0177	0000	CHRRET, 0		700 BACK
0172	0200	0211	SENSIT, CLR		
0173	0201	0432		SXL I 12	
0174	0202	0001		JMP --1	

0175	0203	1060		STA I
0176	0204	0000	MATCH,	0
0177	0205	0070		SET I 10
0200	0206	0204		MATCH
0201	0207	1020		LDA I
0202	0210	0001		1
0203	0211	0405		SXL 5
0204	0212	1150		ADM 10
0205	0213	1020		LDA I
0206	0214	0002		2
0207	0215	0406		SXL 6
0210	0216	1150		ADM 10
0211	0217	1020		LDA I
0212	0220	0004		4
0213	0221	0407		SXL 7
0214	0222	1150		ADM 10
0215	0223	1020		LDA I
0216	0224	0010		10
0217	0225	0410		SXL 10
0220	0226	1150		ADM 10
0221	0227	1020		LDA I
0222	0230	0020		20
0223	0231	0411		SXL 11
0224	0232	1150		ADM 10
0225	0233	6250		JMP DISIT
0226	0234	1020		LDA I
0227	0235	0425		SNSCOD
0230	0236	2204		ADD MATCH
0231	0237	4003		STC 3
0232	0240	1003		LDA 3
0233	0241	6161		JMP STRIP
0234	0242	1020		LDA I
0235	0243	0425		SNSCOD
0236	0244	2204		ADD MATCH
0237	0245	4003		STC 3
0240	0246	1003		LDA 3
0241	0247	6161		JMP STRIP
0242			/	
0243			/	
0244	0250	1000	DISIT,	LDA
0245	0251	0000		0
0246	0252	4302		STC DISRET
0247	0253	0074		SET I 14
0250	0254	0302		DSC TBL-1
0251	0255	0061		SET I 1
0252	0256	0377		377
0253	0257	0063		SET I 3
0254	0260	7774		-3
0255	0261	0011		CLR
0256	0262	1774		DSC I 14
0257	0263	1774		DSC I 14
0260	0264	0223		XSK I 3
0261	0265	0261		JMP *-4
0262	0266	0073		SET I 13
0263	0267	0312		HIT TBL-1
0264	0270	0061		SET I 1
0265	0271	0377		377
0266	0272	0063		SET I 3
0267	0273	7774		-3
0270	0274	1020		LDA I
0271	0275	7737		-40
0272	0276	1773		DSC I 13
0273	0277	1773		DSC I 13

/BOTH HALVES

0274	0300	0223	XSK I 3	
0275	0301	6274	JMP --5	
0276	0302	0000	DISRET, 0	
0277			/	
0300			/	
0301	0303	0000	DSCTBL, 0	
0302	0304	0000	0	
0303	0305	0000	0	
0304	0306	0000	0	
0305	0307	0000	0	
0306	0310	0000	0	
0307	0311	0000	0	
0310	0312	0000	0	
0311			/	
0312	0313	0000	HITTBL, 0	
0313	0314	0000	0	
0314	0315	0000	0	
0315	0316	0000	0	
0316	0317	0000	0	
0317	0320	0000	0	
0320	0321	0000	0	
0321	0322	0000	0	
0322	0323	4020	CHRDIS, 4020	
0323	0324	2055	2055	/?
0324	0325	4477	4477	
0325	0326	7744	7744	/A
0326	0327	5177	5177	
0327	0330	2651	2651	/B
0330	0331	4136	4136	
0331	0332	2241	2241	/C
0332	0333	4177	4177	
0333	0334	3641	3641	/D
0334	0335	4577	4577	
0335	0336	4145	4145	/E
0336	0337	4477	4477	
0337	0340	4044	4044	/F
0340	0341	4136	4136	
0341	0342	2645	2645	/G
0342	0343	1077	1077	
0343	0344	7710	7710	
0344			/H	
0345	0345	7741	7741	
0346	0346	0041	0041	/I
0347	0347	4142	4142	
0350	0350	4072	4072	/J
0351	0351	1077	1077	
0352	0352	4324	4324	/K
0353	0353	0177	0177	
0354	0354	0301	0301	/L
0355	0355	3077	3077	
0356	0356	7730	7730	/M
0357	0357	3077	3077	
0360	0360	7706	7706	/N
0361	0361	4177	4177	
0362	0362	7741	7741	/O
0363	0363	4477	4477	
0364	0364	3044	3044	/P
0365	0365	4276	4276	
0366	0366	0376	0376	/Q
0367	0367	4477	4477	
0370	0370	3146	3146	
0371	0371	5121	5121	
0372	0372	4651	4651	



0373	0373	4040	4040	
0374	0374	4077	4077	/T
0375	0375	0177	0177	
0376	0376	7701	7701	/U
0377	0377	0176	0176	
0400	0400	7402	7402	/V
0401	0401	0677	0677	
0402	0402	7701	7701	/W
0403	0403	1463	1463	
0404	0404	6314	6314	/X
0405	0405	0770	0770	
0406	0406	7007	7007	/Y
0407	0407	4543	4543	
0410	0410	6151	6151	/Z
0411	0411	0000	0	
0412	0412	0000	0	
0413	0413	0000	0	
0414	0414	0000	0	
0415	0415	0000	0	
0416	0416	0000	0	
0417	0417	0000	0	
0420	0420	0000	0	
0421	0421	0000	0	
0422	0422	0000	0	
0423	0423	0000	0	
0424	0424	0000	0	
0425				/
0426				/
0427	0425	0240	SNSCOD, 240	
0430	0426	0311	311	
0431	0427	0305	305	
0432	0430	0323	323	
0433	0431	0301	301	
0434	0432	0314	314	
0435	0433	0317	317	
0436	0434	0325	325	
0437	0435	0316	316	
0440	0436	0324	324	
0441	0437	0303	303	
0442	0440	0320	320	
0443	0441	0322	322	
0444	0442	0315	315	
0445	0443	0310	310	
0446	0444	0304	304	
0447				/
0450	0445	0000	TTYCOD, 0	
0451	0446	0004	4	/A
0452	0447	0000	0	/B
0453	0450	0012	12	/C
0454	0451	0017	17	/D
0455	0452	0002	2	/E
0456	0453	0000	0	/F
0457	0454	0000	0	/G
0460	0455	0016	16	/H
0461	0456	0001	1	/I
0462	0457	0000	0	/J
0463	0460	0010	0	/K
0464	0461	0005	5	/L
0465	0462	0015	15	/M
0466	0463	0010	10	/N
0467	0464	0006	6	/O
0470	0465	0013	13	/P
0471	0466	0000	0	/Q

0472	0467	0014	14	/R
0473	0470	0003	3	/S
0474	0471	0011	11	/T
0475	0472	0007	7	/U
0476	0473	0000	0	/V
0477	0474	0000	0	/W
0500	0475	0000	0	/X
0501	0476	0000	0	/Y
0502	0477	0000	0	/Z
0503			/	
0504			/ARPA1	
0505			/	
0506			/PROGRAM ACCEPTS STIMULUS CODE FROM	
0507			/EITHER THE TTY (IF SENSE SWITCH 5 IS UP) OR VIA N	
			OCTAL CODE	
0510			/VIA SENSE LINES 5,6,7,10, AND 11	
0511			/(IF SNS 5 IS DOWN). A GROUND TO SXL 12	
0512			/INDICATES THAT SENSE LINE CODIFICATION IS COMPLETE	
0513			/	
0514			/PROGRAM THEN MONITORS THE RESPONSE CODE	
0515			/VIA SXL 0-4 FOR CORRESPONDANCE TO THE S-CODE	
0516			/THE ALPHA EQUIVALENT OF THE S-CODE IS DISPLAYED	
0517			/ON TOP, THE R-CODE IS DISPLAYED ON THE BOTTOM.	
0520			/1-DISIT	
0521			/2- UNUSED	
0522			/3-SCRATCH	
0523			/4-UNUSED	
0524			/5-UNUSED	
0525			/6-DISPLAY TIMER	
0526			/7-DISPLAY TIMER	
0527			/10 SUM AND MATCH POINTER	
0530			/11-UNUSED	
0531			/12- NUMBER OF CHARACTERS	
0532			/13-DISIT R-CODE	
0533			/14-DISIT S-CODE	
0534			/15 NUMBER OF CHARACTERS	
0535			/16-R-CODE	
0536			/17-S-CODE	

## NO ERRORS

AAA	4047
AASTHT	4020
CHAR	4162
CHRDIS	4323
CHRRET	4177
DISIT	4250
DISRET	4302
DSCIBL	4303
GETCHR	4147
HITTEL	4313
KRB	6036
KSF	6031
MATCH	4204
MATCHT	4072
MTCRR	4146
N	4044
SENSIT	4200
SNSCOD	4425
STRIP	4161
SUM	4077
THIS	4054
THISR	4071



TLS 6046  
TSF 6041  
TTYCOD 4445

## APPENDIX C

**PROGRAM NAME:** ARPA 6.

**FUNCTION:** Program displays two alphanumeric characters, determines coincidence of stimulus and response codes, determines latency to respond for each muscle, and provides hard and soft copy read outs of performance.

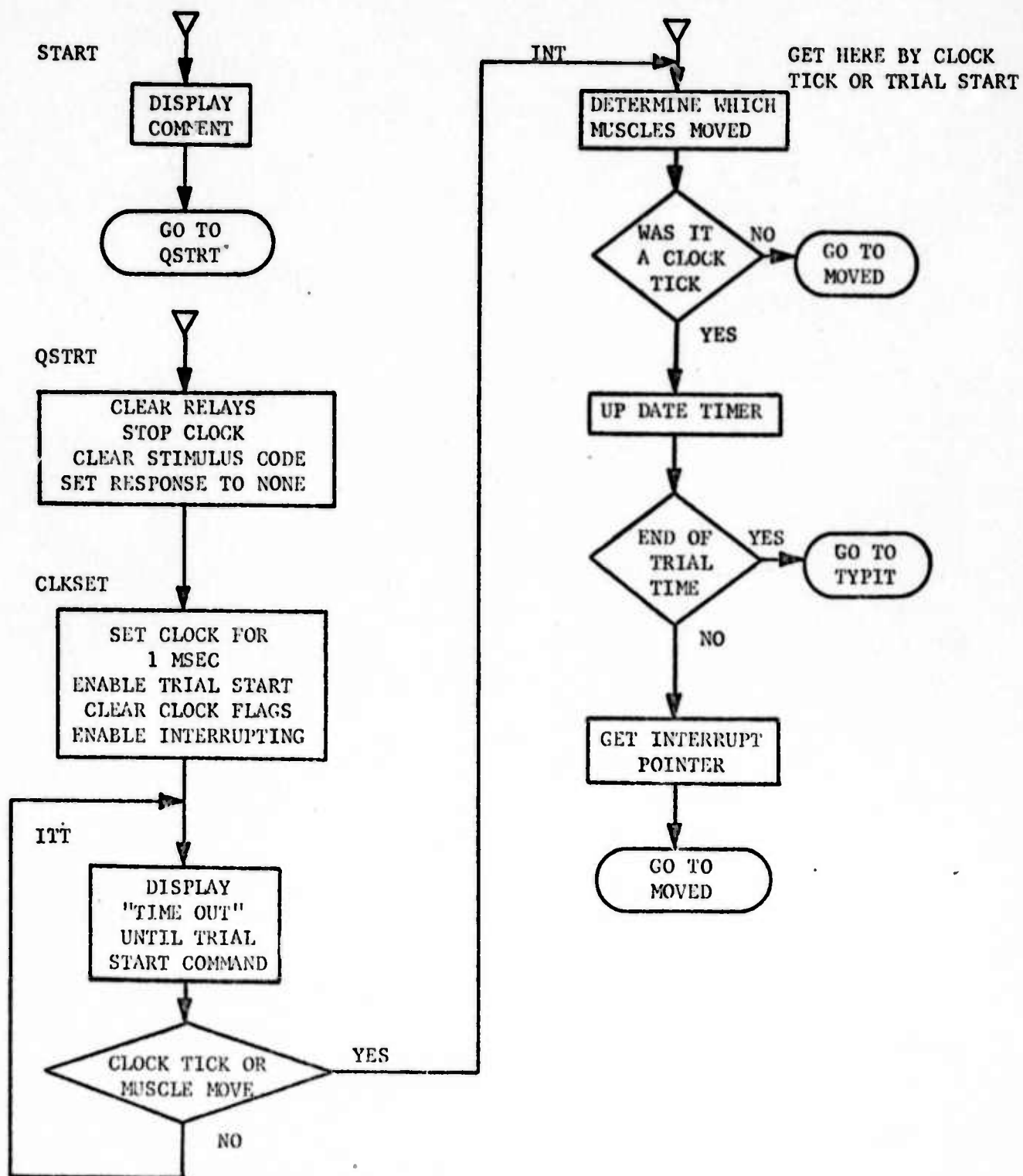
**LANGUAGE:** DIAL-LAP6 (ASSEMBLY)

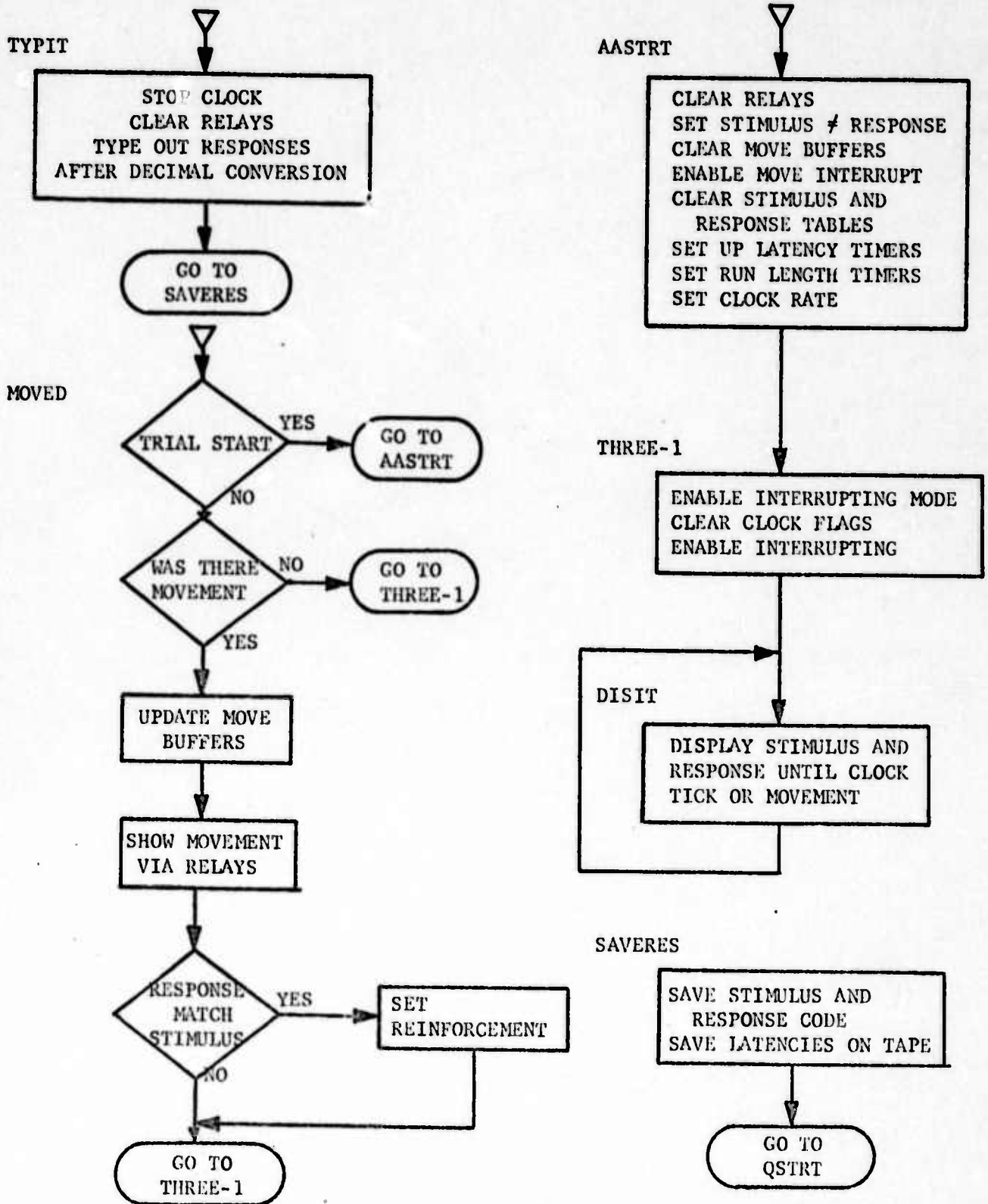
**DESCRIPTION:** The S code is accepted from a teletype entry, or if sense switch five is up, from external sense lines 5, 6, 7, 10, and 11. In the latter case, a zero volt level to sense line 12 indicates codification is complete and sampling may begin.

Simultaneously with displaying the alphanumeric symbol related to the S code, the program monitors muscle responses. If a muscle movement indication is detected the program scans external sense lines 0, 1, 2, 3, and 4 to determine which muscles were involved. Any movement occurring during the display period is classified as a component of the R code for the current trial. The first detected movement on each sense line stops its respective latency counter.

A trial is initiated by a synchronizing command to clock input #1. At this time the S code is decoded, the run length, or display length, times initialized, the latency times reset, the clock started and the S code displayed.

## ARPA 6 FLOWCHART





0000			*20		
0001				SEGMENT 0	
0002				*20	
0003	0020	0001	ONE,	1	
0004	0021	0002	TWO,	2	
0005	0022	0004	FOUR,	4	
0006	0023	0010	TEN,	10	
0007	0024	0020	TWENTY,	20	
0010				*40	
0011	0040	0000		0	
0012				KSF=6031	
0013				KRB=6036	
0014				TSF=6041	
0015				TLS=6046	
0016	0041	0011	INT,	CLR	
0017	0042	1000		LDA	
0020	0043	0020		ONE	
0021	0044	0400		SXL 0	
0022	0045	7055		JMP MOVED0	
0023	0046	1000		LDA	
0024	0047	0021		TWO	
0025	0050	0401		SXL 1	
0026	0051	7064		JMP MOVED1	
0027	0052	1000		LDA	
0030	0053	0022		FOUR	
0031	0054	0402		SXL 2	
0032	0055	7072		JMP MOVED2	
0033	0056	1000		LDA	
0034	0057	0023		TEN	
0035	0060	0403		SXL 3	
0036	0061	7100		JMP MOVED3	
0037	0062	1000		LDA	
0040	0063	0024		TWENTY	
0041	0064	0404		SXL 4	
0042	0065	7106		JMP MOVED4	
0043	0066	0011		CLR	
0044	0067	0500		IOB	
0045	0070	6135		CLSA	
0046	0071	0471		APO I	
0047	0072	6457		JMP MOVED	
0050	0073	1060		STA I	
0051	0074	0000	RCLSA,	0	
0052			/CLOCK	TIMED	
0053	0075	0231		XSK I 11	/TIMER
0054	0076	6136		JMP BUFF1-1	/PATCH TO CUT OUT TIMERS
0055	0077	6136		JMP BUFF1-1	
0056	0100	6147		JMP TYPIT	/TYPE OUT CHAR,HIT AND RE
			ACTIONS		
0057	0101	0224		XSK I 4	
0060	0102	6106		JMP TRY5	
0061	0103	4137		STC BUFF1	
0062	0104	0044		SET 4	
0063	0105	0655		NEG	
0064	0106	0225	TRY5,	XSK I 5	
0065	0107	6113		JMP TRY6	
0066	0110	4132		SIC BUFF2	
0067	0111	0045		SET 5	
0070	0112	0655		NEG	
0071	0113	0226	TRY6,	XSK I 6	
0072	0114	6120		JMP TRY7	
0073	0115	4133		STC BUFF3	
0074	0116	0046		SET 6	

0075	0117	0655		NEG	
0076	0120	0227	TRY7,	XSK I 7	
0077	0121	6125		JMP TRY10	
0100	0122	4134		STC BUFF4	/250 MSEC OVER
0101	0123	0047		SET 7	
0102	0124	0655		NEG	
0103	0125	0230	TRY10,	XSK I 10	
0104	0126	6136		JMP BUFF1-1	
0105	0127	0050		SET 10	
0106	0130	0655		NEG	
0107	0131	4135		STC BUFF5	
0110	0132	0000	BUFF2,	0	
0111	0133	0000	BUFF3,	0	
0112	0134	0000	BUFF4,	0	
0113	0135	0000	BUFF5,	0	
0114	0136	1020		LDA I	
0115	0137	0000	BUFF1,	0	
0116	0140	0232		XSK I 12	/RUN LENGTH TIMER
0117	0141	0456		SKP	
0120	0142	6147		JMP TYPIT	
0121	0143	1000		LDA	
0122	0144	0074		RCLSA	/TEST FOR MOVEMENT
0123	0145	6457		JMP MOVED	
0124	0146	6703		JMP THREE-1	
0125			/		
0126	0147	0011	TYPIT,	CLR	
0127	0150	0500		IOB	
0130	0151	6132		CLLR	/STOP CLOCK
0131	0152	0015		RTA	
0132	0153	1560		BCL I	
0133	0154	0037		0037	
0134	0155	0014		ATR	/CLEAR TRIAL R RELAYS
0135	0156	0464		SNS I 4	
0136	0157	6221		JMP TDONE	
0137	0160	0500		IOB	
0140	0161	6046		TLS	
0141	0162	6247		JMP CRLF	
0142	0163	1000	NXT,	LDA	
0143	0164	0741		CHAR	
0144	0165	6237		JMP PUT	
0145	0166	1020		LDA I	
0146	0167	0240	SPACE,	240	
0147	0170	6237		JMP PUT	
0150	0171	1000		LDA	
0151	0172	0630		HIT	
0152	0173	6237		JMP PUT	
0153	0174	1000		LDA	
0154	0175	0167		SPACE	
0155	0176	6237		JMP PUT	
0156	0177	1020		LDA I	
0157	0200	0275		275	/=
0160	0201	6237		JMP PUT	
0161	0202	1000		LDA	
0162	0203	0167		SPACE	
0163	0204	6237		JMP PUT	
0164	0205	1000		LDA	
0165	0206	0004		4	
0166	0207	6256		JMP CONVRT	
0167	0210	1000		LDA	
0170	0211	0005		5	
0171	0212	6256		JMP CONVRT	
0172	0213	1000		LDA	
0173	0214	0006		6	



0174	0215	6256		JMP CONVRT
0175	0216	1000		LDA
0176	0217	0007		7
0177	0220	6256		JMP CONVRT
0200				/LDA
0201				/10
0202				/JMP CONVRT
0203	0221	0602	TDONE,	LIF 2
0204	0222	6101		JMP SAVRES
0205			/	
0206	0223	1000	BLANK,	LDA
0207	0224	0000		0
0210	0225	4236		STC BNKRET
0211	0226	0062		SET I 2
0212	0227	7771		-6
0213	0230	1000		LDA
0214	0231	0167		SPACE
0215	0232	6237		JMP PUT
0216	0233	0222		XSK I 2
0217	0234	6230		JMP *-4
0220	0235	6454		JMP RETBIN-2
0221	0236	0000	BNKRET,	0
0222			/	
0223			/	
0224	0237	0041	PUT,	SET I
0225	0240	0000		0
0226	0241	0500		IOB
0227	0242	6041		TSF
0230	0243	6241		JMP *-2
0231	0244	0500		IOB
0232	0245	6046		TLS
0233	0246	6001		JMP I
0234			/	
0235	0247	1020	CRLF,	LDA I
0236	0250	0215		215
0237	0251	6237		JMP PUT
0240	0252	1020		LDA I
0241	0253	0212		212
0242	0254	6237		JMP PUT
0243	0255	6163		JMP NXT
0244			/	
0245	0256	4301	CONVRT,	STC VAR
0246	0257	1000		LDA
0247	0260	0000		0
0250	0261	4456		STC RETBIN
0251	0262	1000		LDA
0252	0263	0301		VAR
0253	0264	1460		SAE I
0254	0265	7777		7777
0255	0266	0456		SKP
0256	0267	6223		JMP BLANK
0257	0270	0077		SET I 17
0260	0271	7765		-12
0261	0272	0076		SET I 16
0262	0273	7765		-12
0263	0274	0075		SET I 15
0264	0275	7765		-12
0265	0276	0074		SET I 14
0266	0277	7765		-12
0267	0300	1020		LDA I
0270	0301	0000	VAR,	0
0271	0302	0471		AP0 I
0272	0303	6352		JMP R1024

/TYPE BLANKS IF 4093

0273	0304	0241	ROL	1	
0274	0305	0451	APO		
0275	0306	6331	JMP	K3072	
0276	0307	1000	LDA		
0277	0310	0301	VAR		
0300	0311	1560	BCL	1	
0301	0312	4000	4000		
0302	0313	4301	STC	VAR	
0303	0314	1020	LDA	I	
0304	0315	0011	11		
0305	0316	1140	ADM		
0306	0317	0017	17		
0307	0320	1020	LDA	I	
0310	0321	0004	4		
0311	0322	1140	ADM		
0312	0323	0016	16		
0313	0324	1020	LDA	I	
0314	0325	0002	2		
0315	0326	1140	ADM		
0316	0327	0014	14		
0317	0330	6372	JMP	CONV-6	
0320					
0321	0331	1020	/		
0322	0332	0002	K3072,	LDA	I
0323	0333	1157	2		
0324	0334	1020	ADM	17	
0325	0335	0007	LDA	I	
0326	0336	1140	7		
0327	0337	0016	ADM		
0330	0340	1020	16		
0331	0341	0003	LDA	I	
0332	0342	1140	3		
0333	0343	0014	ADM		
0334	0344	1000	14		
0335	0345	0301	LDA		
0336	0346	1560	VAR		
0337	0347	4000	BCL	1	
0340	0350	4301	4000		
0341	0351	6372	STC	VAR	
0342			JMP	CONV-6	
0343	0352	0241	/		
0344	0353	0471	K1024,	ROL	1
0345	0354	6372	AP0	I	
0346	0355	1020	JMP	CONV-6	
0347	0356	0004	LDA	I	
0350	0357	1140	4		
0351	0360	0017	ADM		
0352	0361	1020	17		
0353	0362	0002	LDA	I	
0354	0363	1140	2		
0355	0364	0016	ADM		
0356	0365	1020	16		
0357	0366	0001	LDA	I	
0360	0367	1140	1		
0361	0370	0014	ADM		
0362	0371	6372	14		
0363			JMP	CONV-6	
0364	0372	1000	/		
0365	0373	0301	LDA		
0366	0374	1120	VAR		
0367	0375	0001	ADA	I	
0370	0376	0017	1		
0371	0377	4000	COM		
			STC	3	



0372	0400	0223	CONV,	XSK I 3	
0373	0401	0456		SKP	
0374	0402	6422		JMP CNVCMP	
0375	0403	0237		XSK I 17	
0376	0404	6400		JMP CONV	
0377	0405	0077		SET I 17	
0400	0406	7765		-12	
0401	0407	0236		XSK I 16	
0402	0410	6400		JMP CONV	
0403	0411	0076		SET I 16	
0404	0412	7765		-12	
0405	0413	0235		XSK I 15	
0406	0414	6400		JMP CONV	
0407	0415	0075		SET I 15	
0410	0416	7765		-12	
0411	0417	0234		XSK I 14	
0412	0420	6400		JMP CONV	
0413	0421	6400		JMP CONV	
0414			/		
0415	0422	1000	CNVCMP,	LDA	
0416	0423	0014		14	
0417	0424	1120		ADA I	
0420	0425	0272	MINUS1,	272	
0421	0426	6237		JMP PUT	
0422	0427	1000		LDA	
0423	0430	0015		15	
0424	0431	1100		ADA	
0425	0432	0425		MINUS1	
0426	0433	6237		JMP PUT	
0427	0434	1000		LDA	
0430	0435	0016		16	
0431	0436	1100		ADA	
0432	0437	0425		MINUS1	
0433	0440	6237		JMP PUT	
0434	0441	1000		LDA	
0435	0442	0017		17	
0436	0443	1100		ADA	
0437	0444	0425		MINUS1	
0440	0445	6237		JMP PUT	
0441	0446	1000		LDA	
0442	0447	0167		SPACE	
0443	0450	6237		JMP PUT	
0444	0451	1000		LDA	
0445	0452	0167		SPACE	
0446	0453	6237		JMP PUT	
0447	0454	0500		IOB	
0450	0455	6244		RMF	
0451	0456	0000	RETBIN, 0		/RETURN
0452			/		
0453				RMF=6244	
0454			/SHOW MOVEMENT BY RELAY AND SET CAPTURE		
0455			/TIMER IF NO MOVEMENT BEFORE		
0456	0457	0246	MOVED,	ROL 6	/EVENT 1?
0457	0460	0471		APO I	
0460	0461	0456		SKP	
0461	0462	6543		JMP TRLSRT	/YES
0462	0463	0244		ROL 4	/EVENT 3
0463	0464	0471		APO I	
0464	0465	6703		JMP THREE-1	
0465	0466	1000		LDA	
0466	0467	0137		BUFF1	
0467	0470	2132		ADD BUFF2	
0470	0471	2133		ADD BUFF3	

0471	0472	2134	ADD	BUFF4	
0472	0473	2135	ADD	BUFF5	
0473	0474	1060	STA	I	
0474	0475	0000	RRTEMP,	0	
0475	0476	0015	RTA		
0476	0477	1560	ECL	I	
0477	0500	0037	37		
0500	0501	1600	BSE		
0501	0502	0475	RRTEMP		
0502	0503	0014	ATR		/SHOW MOVEMENT
0503	0504	0643	LDF	3	
0504	0505	1020	LDA	I	
0505	0506	2122	SNSCOD	!2000	
0506	0507	1100	ADA		
0507	0510	0475	RRTEMP		
0510	0511	4003	STC	3	
0511	0512	1003	LDA	3	
0512	0513	1040	STA		
0513	0514	0630	HIT		
0514	0515	1560	ECL	I	
0515	0516	7700	7700		
0516	0517	0241	ROL	1	
0517	0520	1120	ADA	I	
0520	0521	2020	CHRDIS	!2000	
0521	0522	4003	STC	3	
0522	0523	1003	LDA	3	
0523	0524	0076	SET	I 16	
0524	0525	2007	HITBL	-1!2000	
0525	0526	1076	STA	I 16	
0526	0527	1023	LDA	I 3	
0527	0530	1076	STA	I 16	
0530	0531	1000	LDA		
0531	0532	0741	CHAR		
0532	0533	1440	SAE		
0533	0534	0630	HIT		
0534	0535	0703	JMP	THREE-1	
0535	0536	0015	RTA		
0536	0537	1620	BSE	I	
0537	0540	0040	0040		
0540	0541	0014	ATR		/SET REINFORCEMENT
0541	0542	6703	JMP	THREE-1	
0542			/		
0543	0543	6615	TRLSRT,	JMP AASTRT	
0544			/		
0545	0544	1020	ERRORS,	LDA I	
0546	0545	0277	277		
0547	0546	6237	JMP	PUT	
0550	0547	0063	SET	I 3	
0551	0550	7774	-3		
0552	0551	1020	LDA	I	
0553	0552	0207	207		
0554	0553	6237	JMP	PUT	
0555	0554	0223	XSK	I 3	
0556	0555	6551	JMP	.-4	
0557	0556	0000	HLT		
0560			/		
0561			/START	OF MAIN FROM CUANDA IN LF 2	
0562	0557	0011	QSTRT,	CLR	
0563	0560	0014	ATR		/CLEAR RELAY <sup>c</sup>
0564	0561	0011	CLR		
0565	0562	0500	IOB		
0566	0563	6132	CLR		/STOP CLOCK
0567	0564	0016	NOP	/SET I 17	

0570	0565	0016		NOP/3777	
0571	0566	0016		NOP/LDF 4	
0572	0567	0016		NOP/STA I 17	
0573	0570	0016		NOP/XSK 17	
0574	0571	0016		NOP/JMP .-2	/CLR STORAGE
0575	0572	4741		STC CHAR	
0576	0573	1020		LDA I	
0577	0574	0243	K243,	243	
0600	0575	4630		STC HIT	
0601	0576	1020	CLKSET,	LDA I	
0602	0577	7776	TIME,	7776	/ 1 MSEC TICK
0603	0600	0500		IOB	
0604	0601	6133		CLAB	
0605	0602	1020		LDA I	
0606	0603	0060		60	/ENABLE INPUT 1
0607	0604	0500		IOB	
0610	0605	6134		CLEN	
0611	0606	0500		IOB	
0612	0607	6135		CLSA	/CLR FLAG
0613	0610	0500		IOB	
0614	0611	6001		ION	
0615	0612	0602		LIF 2	
0616	0613	6057		JMP ITI	/DISPLAY ITICOMMENT
0617	0614	6614		JMP .	/WAIT FOR TRIAL START
0620	0615	0011	AASTR,	CLR	
0621	0616	0015		RTA	
0622	0617	1560		BCL I	
0623	0620	0037		0037	
0624	0621	0014		ATR	
0625	0622	1020		LDA I	
0626	0623	0244	K244,	244	
0627	0624	4741		STC CHAR	
0630	0625	1000		LDA	
0631	0626	0574		K243	
0632	0627	1060		STA I	
0633	0630	0000	HIT,	0	
0634	0631	1020		LDA I	
0635	0632	0103		103	
0636	0633	4704		STC THREE	/SET INT FOR EVENT 3
0637	0634	4137		STC BUFF1	
0640	0635	4132		STC BUFF2	
0641	0636	4133		STC BUFF3	
0642	0637	4134		STC BUFF4	
0643	0640	4135		STC BUFF5	
0644	0641	0643		LDF 3	
0645	0642	0062		SET I 2	
0646	0643	7776		DSCTEL-1!2000	
0647	0644	0063		SET I 3	
0650	0645	7767		-10	
0651	0646	0064		SET I 4	
0652	0647	2007		HITTEL-1!2000	
0653	0650	1062		STA I 2	
0654	0651	1064		STA I 4	
0655	0652	0223		XSK I 3	
0656	0653	6651		JMP .-2	/CLEAR DSCTEL
0657	0654	0075		SET I 15	
0660	0655	7776	NEG,	-1	
0661	0656	0077		SET I 17	
0662	0657	7776		DSCTEL-1!2000	
0663	0660	6717		JMP GETCHR	/CHANGE CHAR
0664					
0665	0661	0064		SET I 4	
0666	0662	7777		7777	

0667	0663	0065		SET I 5	
0670	0664	7777		7777	
0671	0665	0066		SET I 6	
0672	0666	7777		7777	
0673	0667	0067		SET I 7	
0674	0670	7777		7777	
0675	0671	0070		SET I 10	
0676	0672	7777		7777	
0677	0673	0071		SET I 11	
0700	0674	0000		0	
0701	0675	0072		SET I 12	
0702	0676	6027	SAMTIM,	-1750	
0703	0677	1020		LDA I	
0704	0700	4100		4100	/IKC AND PRESET
0705	0701	0500		IOB	
0706	0702	6132		CLLR	
0707				CLAB=6133	
0710				CLLR=6132	
0711				CLEN=6134	
0712				CLSA=6135	
0713				CLSK=6131	
0714				ION=6001	
0715				IOF=6002	
0716	0703	1020		LDA I	
0717	0704	0103	THREE,	103	/MOVEMENT OR CLOCK
0720	0705	0500		IOB	
0721	0706	6134		CLEN	/ENABLE INPUT 3
0722	0707	0500		IOB	
0723	0710	6135		CLSA	/CLEAR INTERRUPT
0724	0711	1020		LDA I	
0725	0712	0240		240	
0726	0713	0004		ESF	/LOCK OUT TTY
0727	0714	0500		IOB	
0730	0715	6001		ION	
0731	0716	7020		JMP DISIT	
0732			/		
0733	0717	1000	GETCHR,	LDA	
0734	0720	0000		0	
0735	0721	4756		STC CHRRET	
0736	0722	0072		SET I 12	
0737	0723	7776		DSCTBL-112000	
0740	0724	0070		SET I 10	
0741	0725	7767		-10	
0742	0726	1072		STA I 12	
0743	0727	0230		XSK I 10	
0744	0730	6726		JMP *-2	
0745	0731	0445		SNS 5	
0746	0732	6757		JMP SENSIT	
0747	0733	0500		IOB	
0750	0734	6031		KSF	
0751	0735	6731		JMP *-4	
0752	0736	0500		IOB	
0753	0737	6036		KRB	
0754	0740	1060	STRIP,	STA I	
0755	0741	0000	CHAR,	0	
0756	0742	1560		BCL I	
0757	0743	7700		7700	
0760	0744	0041		ROL I	
0761	0745	1120		ADA I	
0762	0746	2020		CHDIS!2000	
0763	0747	4003		STC 3	
0764	0750	1000		LDA 3	
0765	0751	1077		STA I 17	

0766	0752	1023	LDA I 3	
0767	0753	1077	STA I 17	
0770	0754	0235	XSK I 15	
0771	0755	6722	JMP GETCHR+3	/MORE WORDS
0772	0756	0000	CHRRET, 0	/GO BACK
0773	0757	0011	SENSIT, CLR	
0774	0760	0016	NOP	/SXL I 12
0775	0761	0016	NOP	/JMP --1
0776	0762	1060	STA I	
0777	0763	0000	MATCH, 0	
1000	0764	0070	SET I 10	
1001	0765	0763	MATCH	
1002	0766	1020	LDA I	
1003	0767	0001	1	
1004	0770	0405	SXL 5	
1005	0771	1150	ADM 10	
1006	0772	1020	LDA I	
1007	0773	0002	2	
1010	0774	0406	SXL 6	
1011	0775	1150	ADM 10	
1012	0776	1020	LDA I	
1013	0777	0004	4	
1014	1000	0407	SXL 7	
1015	1001	1150	ADM 10	
1016	1002	1020	LDA I	
1017	1003	0010	10	
1020	1004	0410	SXL 10	
1021	1005	1150	ADM 10	
1022	1006	1020	LDA I	
1023	1007	0020	20	
1024	1010	0411	SXL 11	
1025	1011	1150	ADM 10	
1026	1012	1020	LDA I	
1027	1013	2122	SNSCOD!2000	
1030	1014	2763	ADD MATCH	
1031	1015	4003	STC 3	
1032	1016	1003	LDA 3	
1033	1017	6740	JMP STRIP	
1034			/	
1035	1020	1000	DISIT, LDA	
1036	1021	0000	0	
1037	1022	5054	STC DISRET	
1040	1023	0643	LDF 3	
1041	1024	0074	SET I 14	
1042	1025	7776	DSC TBL-1!2000	
1043	1026	0061	SET I 1	
1044	1027	0377	377	
1045	1030	0063	SET I 3	
1046	1031	7776	-1	
1047	1032	0011	CLR	
1050	1033	1774	DSC I 14	
1051	1034	1774	DSC I 14	/BOTH HALVES
1052	1035	0223	XSK I 3	
1053	1036	7032	JMP --4	
1054	1037	0073	SET I 13	
1055	1040	2007	HIT TBL-1!2000	
1056	1041	0061	SET I 1	
1057	1042	0377	377	
1060	1043	0063	SET I 3	
1061	1044	7776	-1	
1062	1045	1020	LDA I	
1063	1046	7737	-40	
1064	1047	1773	DSC I 13	/HIT

1065	1050	1773	DSC I 13	
1066	1051	0223	XSK I 3	
1067	1052	7045	JMP .-5	
1070	1053	7023	JMP DISIT+3	
1071	1054	0000	DISRET, 0	
1072			/	
1073	1055	4137	MOVED0, STC BUFF1	
1074	1056	0204	XSK 4	
1075	1057	6000	JMP 0	/MOVED ALREADY
1076	1060	0044	SET 4	
1077	1061	0011	11	/MOVE REACTION
1100	1062	6000	JMP 0	
1101			/	
1102	1063	7727	TIMER, -50	
1103	1064	4132	MOVED1, STC BUFF2	
1104	1065	0205	XSK 5	
1105	1066	6000	JMP 0	
1106	1067	0045	SET 5	
1107	1070	0011	11	
1110	1071	6000	JMP 0	
1111			/	
1112	1072	4133	MOVED2, STC BUFF3	
1113	1073	0206	XSK 6	
1114	1074	6000	JMP 0	
1115	1075	0046	SET 6	
1116	1076	0011	11	
1117	1077	6000	JMP 0	
1120			/	
1121	1100	4134	MOVED3, STC BUFF4	
1122	1101	0207	XSK 7	
1123	1102	6000	JMP 0	
1124	1103	0047	SET 7	
1125	1104	0011	11	
1126	1105	6000	JMP 0	
1127			/	
1130	1106	4135	MOVED4, STC BUFF5	
1131	1107	0210	XSK 10	
1132	1110	6000	JMP 0	
1133	1111	0050	SET 10	
1134	1112	0011	11	
1135	1113	6000	JMP 0	
1136			/	
1137			SEGMENT 2	
1140			*20	
1141	0020	0077	SET I 17	
1142	0021	7677	-100	
1143	0022	7000	JMP QAINIT	
1144	0023	0043	COMNT	
1145	0024	0033	ANSWER	
1146	0025	0237	XSK I 17	
1147	0026	6002	JMP .-4	
1150	0027	0067	SET I 7	
1151	0030	3777	3777	
1152	0031	0600	LIF 0	
1153	0032	6557	JMP QSTRT	
1154	0033	0200	ANSWER, 0	
1155	0034	0000	0	
1156	0035	0000	0	
1157	0036	0000	0	
1160	0037	0000	0	
1161	0040	0000	0	
1162	0041	0000	0	
1163	0042	0000	0	

1164	0043	0610		
1164	0044	0522		
1164	0045	0540		
1164	0046	2705		
1164	0047	4007		
1164			COMNT,	TEXT ZFHRE WE GO
1165	0050	1743		
1165	0051	0640		
1165	0052	4040		
1165	0053	4040		
1165	0054	0107		
1165	0055	0111		
1165	0056	1634		
1165			F	AGAINZ
1166	0057	7000	ITI,	JMP QAINIT
1167	0060	0064		ITIC
1170	0061	0033		ANSWER
1171	0062	7053		JMP QARFSH
1172	0063	7053		JMP QARFSH
1173			ITIC,	TEXT Z
1174			F	
1175	0064	4306		
1175			F	
1176	0065	4306		
1176			F	
1177	0066	4306		
1177			F	
1200	0067	4306		
1200	0070	4306		
1200	0071	4040		
1200	0072	4040		
1200	0073	4040		
1200	0074	2411		
1200	0075	1505		
1200	0076	4017		
1200	0077	2524		
1200	0100	3400		
1200			F	TIME OUTZ
1201			/	
1202	0101	0640	SAVRES,	LDF 0
1203	0102	1000		LDA
1204	0103	2741		CHAR!2000
1205	0104	1060		STA I
1206	0105	0000	CSAV,	0
1207	0106	1000		LDA
1210	0107	2630		HIT12000
1211	0110	1060		STA I
1212	0111	0000	HSAV,	0
1213	0112	1000		LDA
1214	0113	2004		2004
1215	0114	1060		STA I
1216	0115	0000	FIN1,	0
1217	0116	1000		LDA
1220	0117	2005		2005
1221	0120	1060		STA I
1222	0121	0000	FIN2,	0
1223	0122	1000		LDA
1224	0123	2006		2006
1225	0124	1060		STA I
1226	0125	0000	FIN3,	0
1227	0126	1000		LDA
1230	0127	2007		2007
1231	0130	1060		STA I



1232	0131	0000	FIN4,	0
1233	0132	0644		LDF 4
1234	0133	1000		LDA
1235	0134	0105		CSAV
1236	0135	1067		STA I 7
1237	0136	0207		XSK 7
1240	0137	0456		SKP
1241	0140	6224		JMP END
1242	0141	1000		LDA
1243	0142	0111		HSAV
1244	0143	1067		STA I 7
1245	0144	0207		XSK 7
1246	0145	0456		SKP
1247	0146	6224		JMP END
1250	0147	1000		LDA
1251	0150	0115		FIN1
1252	0151	1067		STA I 7
1253	0152	0207		XSK 7
1254	0153	0456		SKP
1255	0154	6224		JMP END
1256	0155	1000		LDA
1257	0156	0121		FIN2
1260	0157	1067		STA I 7
1261	0160	0207		XSK 7
1262	0161	0456		SKP
1263	0162	6224		JMP END
1264	0163	1000		LDA
1265	0164	0125		FIN3
1266	0165	1067		STA I 7
1267	0166	0207		XSK 7
1270	0167	0456		SKP
1271	0170	6224		JMP END
1272	0171	1000		LDA
1273	0172	0131		FIN4
1274	0173	1067		STA I 7
1275	0174	0207		XSK 7
1276	0175	0456		SKP
1277	0176	6224		JMP END
1300	0177	0461		SNS I 1
1301	0200	6224		JMP END
1302	0201	0600		LIF 0
1303	0202	6557		JMP OSTRT
1304			/	
1305	0203	0057	ORLF1,	SET 17
1306	0204	0000		0
1307	0205	1020		LDA I
1310	0206	0215		215
1311	0207	6214		JMP PUT1
1312	0210	1020		LDA I
1313	0211	0212		212
1314	0212	6214		JMP PUT1
1315	0213	6017		JMP 17
1316			/	
1317	0214	0056	PUT1,	SET 16
1320	0215	0000		0
1321	0216	0500		IOB
1322	0217	6041		TSF
1323	0220	6216		JMP --2
1324	0221	0500		IOB
1325	0222	6046		TLS
1326	0223	6016		JMP 16
1327			/	
1330			/	



1331	0224	0644	END,	LDF 4
1332	0225	6203		JMP CRLF1
1333	0226	0061		SET I 1
1334	0227	3777		3777
1335	0230	0016	SETIT,	NOP
1336	0231	0063		SET I 3
1337	0232	7737		-40
1340	0233	6203		JMP CRLF1
1341	0234	6203	PUTIT,	JMP CRLF1
1342	0235	1021		LDA I 1
1343	0236	6214		JMP PUT1
1344	0237	1020		LDA I
1345	0240	0240		240
1346	0241	6214		JMP PUT1
1347	0242	1021		LDA I 1
1350	0243	6214		JMP PUT1
1351	0244	1020		LDA I
1352	0245	0240		240
1353	0246	6214		JMP PUT1
1354	0247	1020		LDA I
1355	0250	0240		240
1356	0251	6214		JMP PUT1
1357	0252	0062		SET I 2
1360	0253	7773		-4
1361	0254	1021		LDA I 1
1362	0255	0600		LIF 0
1363	0256	6256		JMP CONVRT
1364	0257	0222		XSK I 2
1365	0260	6254		JMP .-4
1366	0261	0462		SNS I 2
1367	0262	0000		HLT
1370	0263	0223		XSK I 3
1371	0264	6234		JMP PUTIT
1372	0265	0201		XSK I
1373	0266	6230		JMP SETIT
1374	0267	0000		HLT
1375				NOLIST
2354				SEGMENT 3
2355				*0
2356			/	
2357	0000	0000	DSC TBL,	0
2360	0001	0000		0
2361	0002	0000		0
2362	0003	0000		0
2363	0004	0000		0
2364	0005	0000		0
2365	0006	0000		0
2366	0007	0000		0
2367			/	
2370	0010	0000	HIT TBL,	0
2371	0011	0000		0
2372	0012	0000		0
2373	0013	0000		0
2374	0014	0000		0
2375	0015	0000		0
2376	0016	0000		0
2377	0017	0000		0
2400	0020	4020	CHRDIS,	4020
2401	0021	2055		2055
2402	0022	4477		4477
2403	0023	7744		7744
2404	0024	5177		5177
2405	0025	2651		2651

2406	0026	4136	4136	
2407	0027	2241	2241	/C
2410	0030	4177	4177	
2411	0031	3641	3641	/D
2412	0032	4577	4577	
2413	0033	4145	4145	/E
2414	0034	4477	4477	
2415	0035	4044	4044	/F
2416	0036	4136	4136	
2417	0037	2645	2645	/G
2420	0040	1077	1077	
2421	0041	7710	7710	
2422				/H
2423	0042	7741	7741	
2424	0043	0041	0041	/I
2425	0044	4142	4142	
2426	0045	4072	4072	/J
2427	0046	1077	1077	
2430	0047	4324	4324	/K
2431	0050	0177	0177	
2432	0051	0301	0301	/L
2433	0052	3077	3077	
2434	0053	7730	7730	/M
2435	0054	3077	3077	
2436	0055	7706	7706	/N
2437	0056	4177	4177	
2440	0057	7741	7741	/O
2441	0060	4477	4477	
2442	0061	3044	3044	/P
2443	0062	4276	4276	
2444	0063	0376	0376	/Q
2445	0064	4477	4477	
2446	0065	3146	3146	/R
2447	0066	5121	5121	
2450	0067	4651	4651	/S
2451	0070	4040	4040	
2452	0071	4077	4077	/T
2453	0072	0177	0177	
2454	0073	7701	7701	/U
2455	0074	0176	0176	
2456	0075	7402	7402	/V
2457	0076	0677	0677	
2460	0077	7701	7701	/W
2461	0100	1463	1463	
2462	0101	6314	6314	/X
2463	0102	0770	0770	
2464	0103	7007	7007	/Y
2465	0104	4543	4543	
2466	0105	6151	6151	/Z
2467	0106	0000	0	
2470	0107	0000	0	
2471	0110	0000	0	
2472	0111	0000	0	
2473	0112	0000	0	
2474	0113	0000	0	
2475	0114	0000	0	
2476	0115	0000	0	
2477	0116	0000	0	
2500	0117	0000	0	
2501	0120	0000	0	
2502	0121	0000	0	
2503				
2504				

2505	0122	0240	SNSCOD,	240
2506	0123	0311		311
2507	0124	0305		305
2510	0125	0323		323
2511	0126	0301		301
2512	0127	0314		314
2513	0130	0317		317
2514	0131	0325		325
2515	0132	0316		316
2516	0133	0324		324
2517	0134	0303		303
2520	0135	0320		320
2521	0136	0322		322
2522	0137	0315		315
2523	0140	0310		310
2524	0141	0304		304

2525			/	
2526	0142	0000	TTYCOD,	0
2527	0143	0004		4
2530	0144	0000		0
2531	0145	0012		12
2532	0146	0017		17
2533	0147	0002		2
2534	0150	0000		0
2535	0151	0000		0
2536	0152	0016		16
2537	0153	0001		1
2540	0154	0000		0
2541	0155	0000		0
2542	0156	0005		5
2543	0157	0015		15
2544	0160	0010		10
2545	0161	0006		6
2546	0162	0013		13
2547	0163	0000		0
2550	0164	0014		14
2551	0165	0003		3
2552	0166	0011		11
2553	0167	0007		7
2554	0170	0000		0
2555	0171	0000		0
2556	0172	0000		0
2557	0173	0000		0
2560	0174	0000		0

2561	/	
2562	/	
2563	/	
2564	/PROGRAM ACCEPTS STIMULUS CODE FROM	
2565	/EITHER THE TTY (IF SENSE SWITCH 5 IS UP) OR VIA A	
	OCTAL CODE	
2566	/VIA SENSE LINES 5,6,7,10, AND 11	
2567	/(IF SNS 5 IS DOWN). A GROUND TO SXL 12	
2570	/INDICATES THAT SENSE LINE (SCODE) CODIFICATION IS	
	COMPLETE	
2571	/	
2572	/DISPLAY IS MAINTAINED AS LONG AS SENSE LINE	
2573	/12 IS GROUNDED	
2574	/PROGRAM THEN MONITORS THE RESPONSE CODE	
2575	/VIA SXL 0-4 FOR CORRESPONDANCE TO THE S-CODE	
2576	/THE ALPHA EQUIVALENT OF THE S-CODE IS DISPLAYED	
2577	/ON TOP, THE R-CODE IS DISPLAYED ON THE BOTTOM.	
2600	/1-DISIT	
2601	/2- UNUSED	

2602 /3-SCRATCH  
 2603 /4-UNUSED  
 2604 /5-UNUSED  
 2605 /6-UNUSED  
 2606 /7-UNUSED  
 2607 /10 SUM AND MATCH POINTER  
 2610 /11-MSEC TIMER  
 2611 /12- NUMBER OF CHARACTERS  
 2612 /13-DISIT R-CODE  
 2613 /14-DISIT S-CODE  
 2614 /15 NUMBER OF CHARACTERS  
 2615 /16-R-CODE  
 2616 /17-S-CODE  
 2617 /TESTS FOR ANY R CODE, SETS TIMER  
 2620 /SETS RELAYS  
 2621 /SHOWS REINFORCEMENT  
 2622 /  
 2623 /  
 2624 /WIRING CONFIGURATION  
 2625 /  
 2626 /  
 2627 / IN CPU ROOM  
 2630 /  
 2631 /RESPONSES COME TO CPU ROOM VIA COAX A-F  
 2632 /THESE ARE CONNECTED VIA PATCH CORD TO  
 2633 /COMPARATORS 5-10  
 2634 /  
 2635 /REFERENCE IS ADJUSTED TO GIVE PULSE OUT  
 2636 /OF COMPARATORS WHEN THE SELECTED LEVEL IS  
 2637 /EXCEEDED.  
 2640 /  
 2641 /COMPARATOR 5 POS OUT IS CONNECTED TO DIODE GATE A  
 2642 / 6 POS OUT IS CONNECTED TO DIODE GATE B  
 2643 / 7 POS OUT IS CONNECTED TO DIODE GATE C  
 2644 / 10 POS OUT IS CONNECTED TO DIODE GATE D  
 2645 /OUTPUT OF THESE GATES IS PATCHED TO INPUT 3  
 2646 /SET SOURCE TO - AND THRESHOLD TO JUST +  
 2647 /  
 2650 /SENSE LINE 5 TO HUMAN 7  
 2651 / 6 8  
 2652 / 7 9  
 2653 / 10 10  
 2654 /  
 2655 /HUMAN 5 TO COMPARATOR 2- POS OUT OF 2 TO INPUT  
 1  
 /+ SOURCE, +THRESHOLD  
 2656 /VERIFY  
 2657 /  
 2660 /  
 2661 /K0 IS CONNECTED TO PATCH 1 AT BOTTOM OF CPU  
 2662 /K1 IS CONNECTED TO PATCH 2 AT BOTTOM OF CPU  
 2663 /K2 IS CONNECTED TO PATCH 5  
 2664 /K3 IS CONNECTED TO PATCH 6  
 2665 /K4 IS CONNECTED TO PATCH 7  
 2666 /K5 IS CONNECTED TO PATCH 8  
 2667 /  
 2670 //  
 2671 / IN HUMAN ROOM  
 2672 /  
 2673 /VERIFY CONNECTIONS TO CPU INTERFACE  
 2674 /GREEN TO 1 HI  
 2675 /BROWN TO 5 HI  
 2676 /RED TO 6 HI  
 2677 /ORANGE TO 7 HI

2700 /YELLOW TO 8 HI  
 2701 /  
 2702 /WHITE TO 8 LOW  
 2703 /THE LOWS OF 1, 2, 5, 6, 7, AND 8 ARE  
 2704 /TIED TOGETHER  
 2705 /  
 2706 /SOUNDPROOF ROOM CONNECTIONS  
 2707 /OSCILLATOR PATCH CORD TO HEAD SET IN ROOM  
 2710 /  
 2711 /OPERATING INSTRUCTIONS  
 2712 /  
 2713 /TURN POWER STRIP TO ON  
 2714 / THIS APPLIES POWER TO ALL POWER SUPPLIES  
 2715 / THE POLYGRAPH  
 2716 / THE TAPE TIMER  
 2717 / THE TAPE MARKER  
 2720 /  
 2721 /YOU MUST TURN ON THE TAPE MARKER WHEN READY TO RUN  
 2722 /  
 2723 /S CODE, R CODE, AND AUDITORY R CODE PRESENTATIONS  
 ARE CONTROLLED  
 /AS FOLLOWS  
 2724 /  
 2725 /  
 2726 / TO DISABLE AUDITORY FEEDBACK, UNPLUG OSC CONT  $\square$   
 PLUG  
 2727 / TO DISABLE S CODE PRESENTATION, PLACE S CODE SW  
 TCHES UP  
 2730 / TO DISABLE R CODE PRESENTATION, PLACE R CODE SW  
 TCHES UP  
 /  
 2731 /SNS 1 DOWN FORCES PRINTOUT OF ALL PREVIOUS TRIALS  
 2732 /THIS SPACE IS RESERVED FOR DANISH COMMENTS  
 2733 /

## NO ERRORS

AASTRT 0615  
 ANSWER 4033  
 BLANK 0223  
 BNKRET 0236  
 BUFF1 0137  
 BUFF2 0132  
 BUFF3 0133  
 BUFF4 0134  
 BUFF5 0135  
 CHAR 0741  
 CHRDIS 0020  
 CHRRET 0756  
 CLAB 0133  
 CLEN 0134  
 CLKSET 0576  
 CLLR 0132  
 CLSA 0135  
 CLSK 0131  
 CNVCOMP 0422  
 COMNT 4043  
 CONV 0400  
 CONVRT 0256  
 CRLF 0247  
 CRLF1 4203  
 CSAV 0105  
 DISIT 1020  
 DISRET 1054  
 DSECTBL 0300

END	4224
ERRORS	0544
FIN1	4115
FIN2	4121
FIN3	4125
FIN4	4131
FOUR	0022
GETCHR	0717
GETKBD	5521
HIT	0630
HITBL	6010
HSAV	4111
INT	0041
IOF	6002
ION	6001
ITI	4057
ITIC	4064
KRB	6036
KSF	6031
K1024	0352
K243	0574
K244	0623
K3072	0331
MATCH	0763
MINUS1	0425
MOVED	0457
MOVED0	1055
MOVED1	1064
MOVED2	1072
MOVED3	1100
MOVED4	1106
NEG	0655
NXT	0163
ONE	0020
PUT	0237
PUTIT	4234
PUTI	4214
QAB	5004
QACA	5015
QACHAR	5655
QACKLF	5621
QACNTR	5604
QAD	5026
QAE	5050
QAEEXIT	5635
QAF	5516
QAG	5062
QAH	5114
QAI	5131
QAINIT	5008
QAJ	5136
QAK	5305
QAKRB	6036
QAL	5175
QALEGL	5575
QAM	5101
QAN	5223
QAO	5231
QAP	5242
QAQ	5263
QARFSH	5053
QAT	5270
QATLS	6046

QATPE	5644
QATSF	6041
QATY	5536
QAU	5506
QAV	5316
QAW	5512
QAX	5424
QAY	5412
QAZ	5301
QSTRT	0557
RCLSA	0074
RETBIN	0456
RMF	6244
RRTEMP	0475
SAMTIM	0676
SAVRES	4101
SENSIT	0757
SETIT	4230
SNSCOD	6122
SPACE	0167
STRIP	0740
TDONE	0221
TEN	0023
THREE	0704
TIME	0577
TIMER	1063
TLS	6046
TRLSRT	0543
TRY10	0125
TRY5	0106
TRY6	0113
TRY7	0120
TSF	6041
TTYCOD	6142
TWENTY	0024
TWO	0021
TYPIT	0147
VAR	0301



## APPENDIX D

## DATA ANALYSIS SOFTWARE

The programs described in this appendix deal with the analysis of data acquired by program ARPA6 (Appendix C). These programs operate sequentially in a chained manner. The sequence is initiated by starting ARPAXFR, the other programs are then automatically called in sequence.



PROGRAM NAME: ARPAXFR

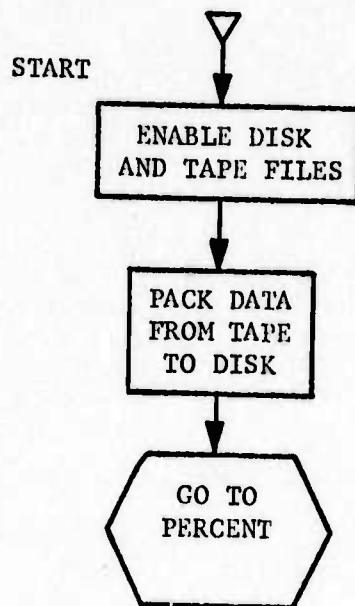
FUNCTION: Transfer S code, R code, and latency data from tape and store on disk in a packed format.

LANGUAGE: FOCAL-12

DESCRIPTION: Data acquired by ARPA6 are saved on sequential LINC tape blocks. This program retrieves data from LINC tape and stores them in consecutive locations on the disc facility.

PROGRAM CALLED: PERCENT

## FLOWCHART FOR ARPAXFR



W  
C FOCAL-12

01.05 T 24.0  
01.06 L O,F2,I,#001,14  
01.10 L O,F1,I,#001,1  
01.20 F I=0,256;D 2  
01.30 O S  
01.90 L G,SPERCENT,13  
  
02.10 F J=0,5;S A(J)=F1(I\*256+J)  
02.11 I (A(1)-163)2.12,2.12,2.2  
02.12 S A(1)=160  
02.20 F J=0,5;S F2(I\*6+J)=A(J)  
\*

PROGRAM NAME: PERCENT

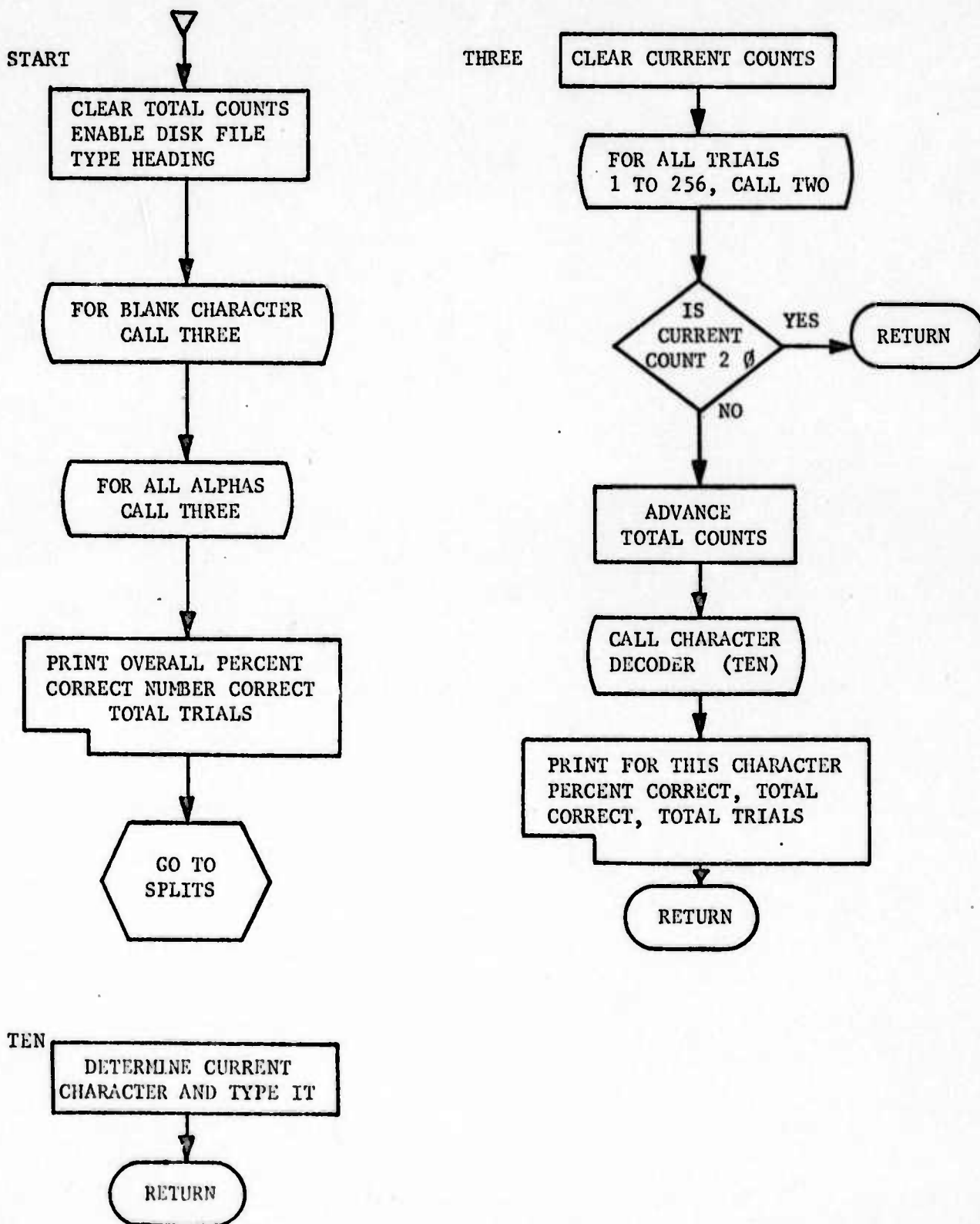
FUNCTION: Determine the percent of responses which were correct for each of 16 characters.

LANGUAGE: FOCAL-12

DESCRIPTION: S code data records packed on the disc are examined for correspondance to each of 16 characters sequentially. If the S code matches the current character, the current counter is incremented, and the R code is then tested for correspondance. If the R code matches the S code then the current correct counter is incremented. At the conclusion of testing all trials for S code correspondance the percent of correct responses are printed out.

PROGRAM CALLED: SPLIT

## FLOWCHART FOR PERCENT



TWO

GET S & R CODES FROM  
DISK FOR THIS TRIAL

DOES  
S CODE  
=  
CURRENT  
CHARACTER

NO

RETURN

YES

ADVANCE TOTAL COUNT  
AND CURRENT COUNT

S CODE  
=  
R CODE

YES

ADVANCE CURRENT  
CORRECT COUNT

NO

RETURN

## C FOCAL-12

01.05 T Z4.0  
 01.06 O T;S N3=0;S N4=0  
 01.10 L O,F1,1,#001,14  
 01.15 T "OVERALL",!  
 01.20 S C=160;D 3  
 01.21 F C=193,215;D 3  
 01.85 T !,(N3\*100)/N4,N3,N4,1;O S  
 01.90 L G,5SPLITS,13

02.10 S D=I\*6  
 02.11 S A2=F1(D);S A3=F1(D+1)  
 02.20 I (A2-C)2.21,2.22;  
 02.21 R  
 02.22 S N2=N2+1;S N4=N4+1  
 02.23 I (A2-A3)2.21,2.3,2.21  
 02.30 S N=N+1

03.20 S N2=0;S N=0  
 03.25 F I=0,255;D 2  
 03.30 I (N)3.31,3.31,3.32  
 03.31 R  
 03.32 S N3=N3+N;S A1=C;D 10;T " "  
 03.40 T Z4.1,N\*100/N2,N,N2,!



10.10 I (A1-190)10.6;  
10.11 I (A1-194)10.66;  
10.12 I (A1-196)10.67;  
10.13 I (A1-197)10.68;  
10.14 I (A1-198)10.69;  
10.15 I (A1-201)10.7;  
10.16 I (A1-202)10.71;  
10.17 I (A1-205)10.72;  
10.18 I (A1-206)10.73;  
10.19 I (A1-207)10.74;  
10.20 I (A1-208)10.75;  
10.21 I (A1-209)10.76;  
10.22 I (A1-211)10.77;  
10.23 I (A1-212)10.78;  
10.24 I (A1-213)10.79;  
10.25 I (A1-214)10.8;  
10.60 I (A1-160)10.61,10.81,10.61  
10.61 I (A1-163)10.62,10.82,10.62  
10.62 T "?" ;R  
10.66 T "A" ;R  
10.67 T "C" ;R  
10.68 T "D" ;R  
10.69 T "E" ;R  
10.70 T "H" ;R  
10.71 T "I" ;R  
10.72 T "L" ;R  
10.73 T "M" ;R  
10.74 T "N" ;R  
10.75 T "O" ;R  
10.76 T "P" ;R  
10.77 T "R" ;R  
10.78 T "S" ;R  
10.79 T "T" ;R  
10.80 T "U" ;R  
10.81 T " " ;R  
10.82 T "#" ;R

\*

PROGRAM NAME: SPLIT

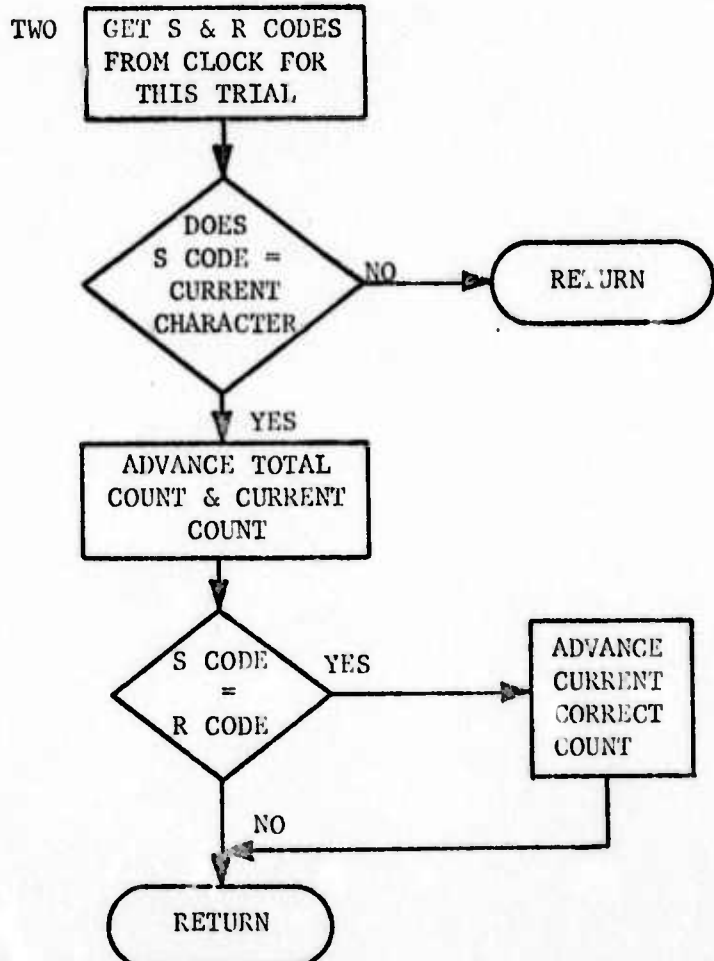
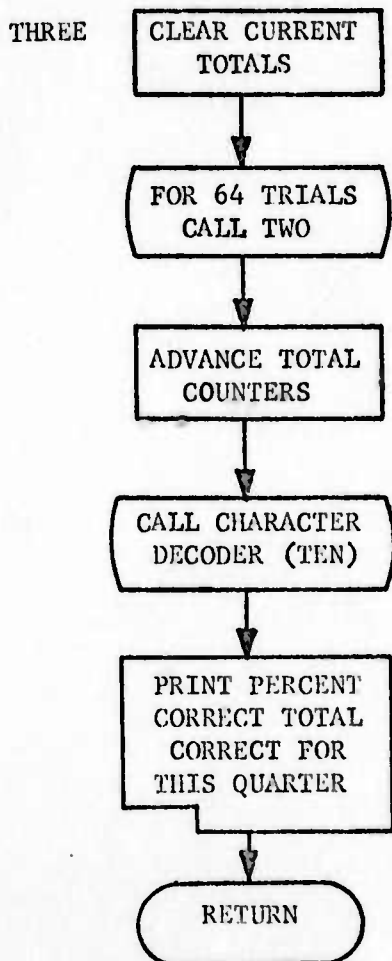
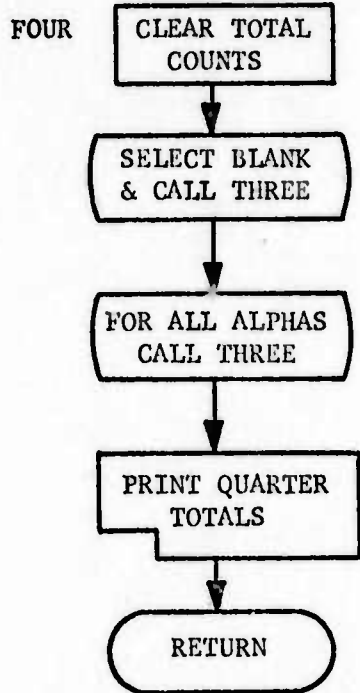
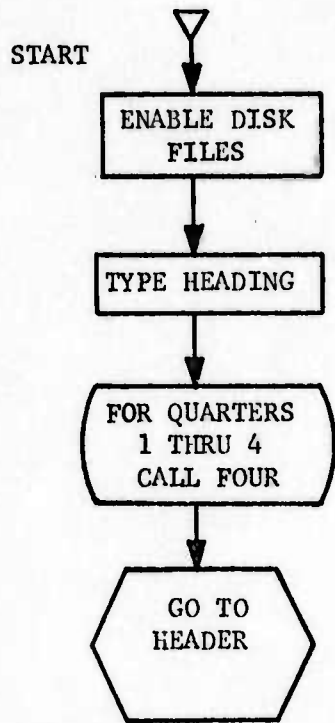
FUNCTION: Determine the percent of responses which were correct for each of 16 characters in quarters (64) of the total session.

LANGUAGE: FOCAL-12

DESCRIPTION: For each successive 64 trials, the S code data records packed on the disc are examined for correspondence to each of 16 characters sequentially. If the S code matches the current character, the current counter is incremented, and the R code is then tested for correspondence. If the R code matches the S code then the current correct counter is incremented. At the conclusion of testing all trials for S code correspondence the percent of correct responses are printed out.

PROGRAM CALLED: HEADER

FLOWCHART FOR SPLITS



## C FOCAL-12

01.05 T Z4.0  
 01.06 O T  
 01.10 L O,F1,I,#001,14  
 01.15 T !,"QUARTER ANALYSIS",!  
 01.20 F J=0,3;T "QUARTER",J+1,1;D 4  
 01.85 O S  
 01.90 L G,\$HEADER,13

02.10 S D=((J\*64)+J1)\*6  
 02.11 S A2=F1(D);S A3=F1(D+1)  
 02.20 I (A2-C)2.21,2.22;  
 02.21 R  
 02.22 S N2=N2+1;S N4=N4+1  
 02.23 I (A2-A3)2.21,2.3,2.21  
 02.30 S N=N+1

03.20 S N2=0;S N=0  
 03.25 F J1=0,63;D 2  
 03.30 I (N)3.31,3.31,3.32  
 03.31 R  
 03.32 S N3=N3+N;S A1=C;D 10;T " "  
 03.40 T Z4.1,N\*100/N2,N,N2,!

04.05 S N3=0;S N4=0  
 04.10 S C=160;D 3  
 04.20 F C=193,215;D 3  
 04.30 T !,(N3\*100)/N4,N3,N4,!

10.10 I (A1-190)10.6;  
10.11 I (A1-194)10.66;  
10.12 I (A1-196)10.67;  
10.13 I (A1-197)10.68;  
10.14 I (A1-198)10.69;  
10.15 I (A1-201)10.7;  
10.16 I (A1-202)10.71;  
10.17 I (A1-205)10.72;  
10.18 I (A1-206)10.73;  
10.19 I (A1-207)10.74;  
10.20 I (A1-208)10.75;  
10.21 I (A1-209)10.76;  
10.22 I (A1-211)10.77;  
10.23 I (A1-212)10.78;  
10.24 I (A1-213)10.79;  
10.25 I (A1-214)10.8;  
10.60 I (A1-160)10.61,10.81,10.61  
10.61 I (A1-163)10.62,10.82,10.62  
10.62 T "?" ;R  
10.66 T "A" ;R  
10.67 T "C" ;R  
10.68 T "D" ;R  
10.69 T "E" ;R  
10.70 T "H" ;R  
10.71 T "I" ;R  
10.72 T "L" ;R  
10.73 T "M" ;R  
10.74 T "N" ;R  
10.75 T "O" ;R  
10.76 T "P" ;R  
10.77 T "R" ;R  
10.78 T "S" ;R  
10.79 T "T" ;R  
10.80 T "U" ;R  
10.81 T " " ;R  
10.82 T "#" ;R

\*

PROGRAM NAME: HEADER

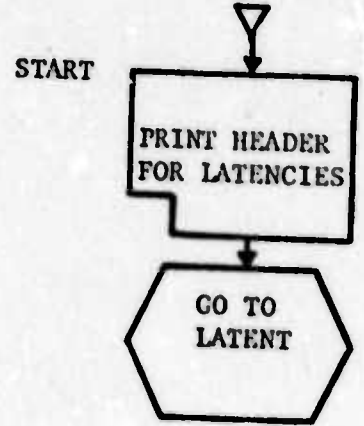
FUNCTION: Print heading for latency analysis.

LANGUAGE: FOCAL-12

DESCRIPTION: Same as function.

PROGRAM CALLED: LATENT

FLOWCHART FOR HEADER





C FOCAL-12

01.10 O T  
01.15 T " PERCENTS  
01.20 T " MUSCLES", I  
01.21 T " LT LL", I RL RT"  
01.90 O S  
01.99 L G, SLATENT, 13  
\*

**PROGRAM NAME:** LATENT

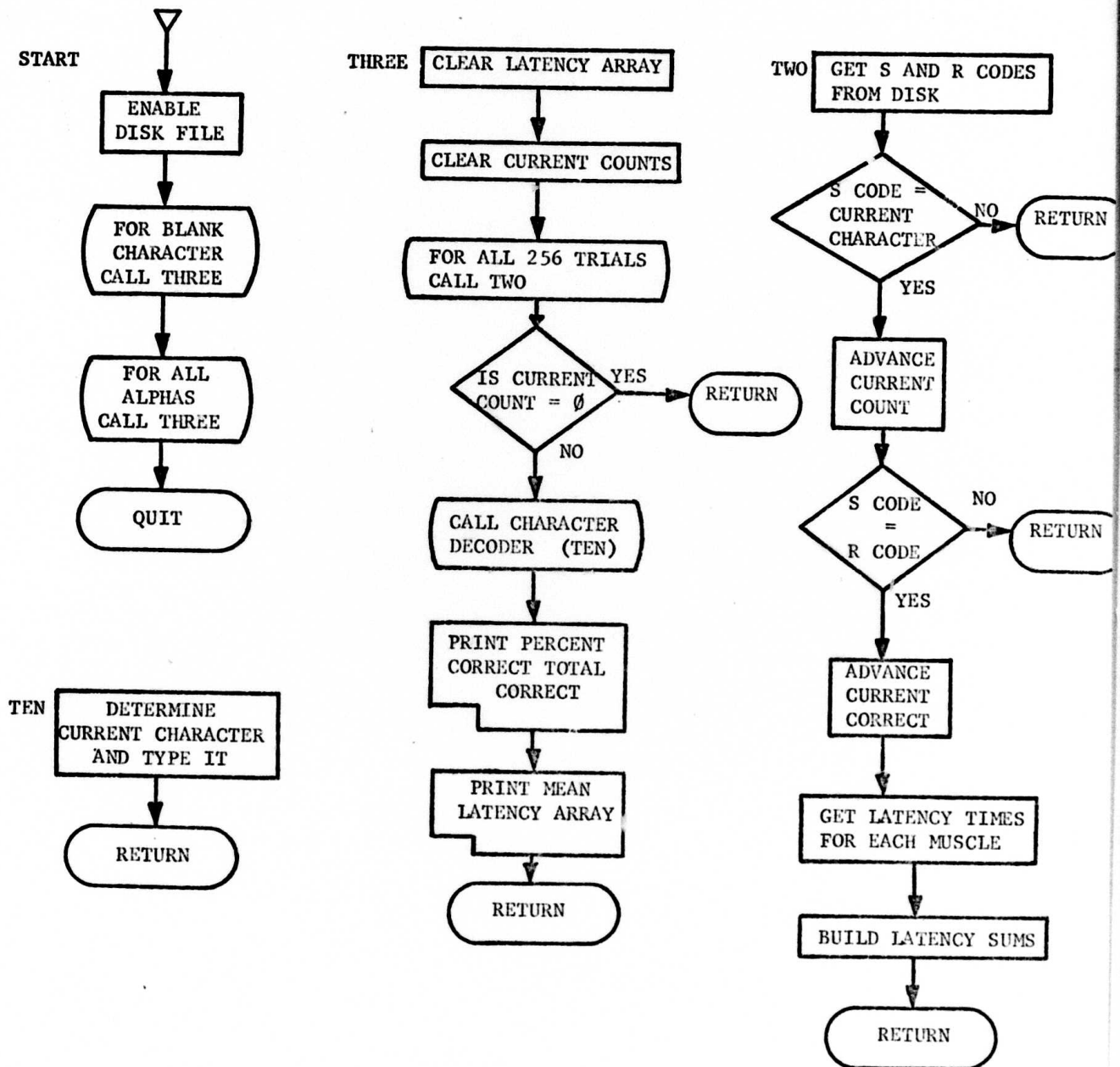
**FUNCTION:** Determine average latency to respond for each muscle associated with a character.

**LANGUAGE:** FOCAL-12

**DESCRIPTION:** S code data packed on the disc are examined for correspondence to, sequentially, each of 16 characters. If the S code matches the current character and the R code, then the latency data for each of four muscle responses are retrieved and used to update running averages.

**PROGRAM CALLED:** none

## FLOWCHART FOR LATENT



## C FOCAL-12

01.06 O T

01.10 L O, F1, 1, #001, 14

01.20 S C=160; D 3

01.21 F C=193, 215; D 3

01.85 O

02.10 S D=1+6

02.11 S A2=F1(D); S A3=F1(D+1)

02.20 I (A2-C)2.21, 2.22;

02.21 R

02.22 S N2=N2+1

02.23 I (A2-A3)2.21, 2.3, 2.21

02.30 S N=N+1

02.40 F K=1, 4; S S(K)=S(K)+F1(D+K+1)

02.50 F K=5, 8; S S(K)=S(K)+F1(D+K-3)+F1(D+K-3)

03.10 F K=1, 8; S S(K)=0

03.20 S N2=0; S N=0

03.25 F I=0, 255; D 2

03.30 I (N)3.31, 3.31, 3.32

03.31 R

03.32 S A1=C; D 10; T " "

03.40 T %4.1, N=100/N2, N, N2

03.50 F K=1, 4; D 5

03.60 T 1, 1

05.10 I (S(K))5.11, 5.2, 5.2

05.11 T " " ; R

05.20 T S(K)/N

10.10 I (A1-190)10.63  
10.11 I (A1-194)10.663  
10.12 I (A1-196)10.673  
10.13 I (A1-197)10.683  
10.14 I (A1-198)10.693  
10.15 I (A1-201)10.73  
10.16 I (A1-202)10.713  
10.17 I (A1-205)10.723  
10.18 I (A1-206)10.733  
10.19 I (A1-207)10.743  
10.20 I (A1-208)10.753  
10.21 I (A1-209)10.763  
10.22 I (A1-211)10.773  
10.23 I (A1-212)10.783  
10.24 I (A1-213)10.793  
10.25 I (A1-214)10.83  
10.60 I (A1-160)10.61,10.81,10.61  
10.61 I (A1-163)10.62,10.82,10.62  
10.62 T "?" ;R  
10.66 T "A" ;R  
10.67 T "C" ;R  
10.68 T "D" ;R  
10.69 T "E" ;R  
10.70 T "H" ;R  
10.71 T "I" ;R  
10.72 T "L" ;R  
10.73 T "M" ;R  
10.74 T "N" ;R  
10.75 T "O" ;R  
10.76 T "P" ;R  
10.77 T "R" ;R  
10.78 T "S" ;R  
10.79 T "T" ;R  
10.80 T "U" ;R  
10.81 T " " ;R  
10.82 T "/" ;R

**APPENDIX E**

**ARPA INSTRUCTIONS TO SUBJECT**

ARPA Instructions to Subjects

This is a study of human performance. We are interested in ways to improve human performance. You will be given various signals, each of which calls for a specific response from you. You will make many wrong responses at first, but your performance will improve with the number of trials. Don't worry about making a wrong response--they are useful to us too, but try your best to make the right one.

The signal will consist of a pattern of lights which are arranged in a horizontal row. There is a total of four lights, and the pattern may consist of any combination of lights from "all off" to "all on".

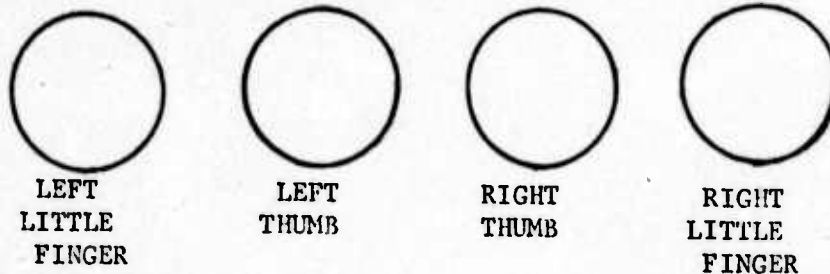
Your response will consist of a movement of your thumbs and 4th fingers on both hands either one at a time or in various combinations. This movement causes a change in the electrical potential of the activated muscle. We can monitor and record this change of potential as an electromyogram (EMG). This is done by placing a surface electrode on the skin immediately overlying the activated muscle. (This involves no pins or clamps--the electrode merely lies flat on the skin). There is no shock involved. With this electrode system we can only record--not stimulate. When you make a response, we will monitor the EMG only--we are not interested in the actual, overt movement. If you can generate a potential of adequate magnitude without a large amount of movement--by all means, do so.



### Assignment of Fingers and Lights

Basically, the experiment works like this: When one or more of the four top, yellow, lights is lit, it is a signal for you to move the muscle which has been assigned to that light.

The assignments are as follows:



Place your open hands palms down on the armrests of the chair. The lights and muscles are in the same sequence horizontally.

As different combinations of lights flash on, try to match them with the appropriate combination of movements. Your response should come as soon as possible after the lights appear. A new trial will be given every 6-10 seconds, and there will be a total of 256 trials per day. A run will last about one hour.

#### (Errors):

You can make two types of errors in your response: 1) you can fail to match with an EMG a light which is lit; 2) you can make a muscle-response which is not called for--that is, the corresponding light is not lit.

In both cases, you will fail to see the square red light on the right side of the panel light up. This light is only turned on by a correct response. When you see it lit up after a trial, you know that you have made the desired response. Please try to get accuracy first, and speed second.

The following information is only given to the biofeedback subjects.

Obviously, this is a learning task, and you are learning to give the correct response to the "stimulus" lights. To aid you in learning, you receive several kinds of feedback.

First, feedback is represented by the green "response" lights directly under the "stimulus" lights. You turn on these lights yourself, with the EMGs generated by your muscles. Again, each light corresponds to a muscle--the same muscle as the light directly above it. These lower lights light up individually as soon as you make the response. If the pattern of the "response"-lights matches that of the lit "stimulus"-lights exactly, you have made the correct response and the red light on the right will light up.

In addition to the lights, there are four speakers arranged around you in the booth. These correspond to the various muscles we are recording from and each will emit a beep-tone when the appropriate muscle is activated. The speaker on your immediate right will be activated by your right little finger, the speaker in front of you on the right corresponds to your right thumb, and the correspondence is the same on the left: rear speaker--little finger, front speaker--thumb. These speakers, like the lights, will tell you when you are activating the muscles they are linked to.

We have designed these visual and auditory signals to let you know what sort of response you are making. They are meant to help you in your task--learning to match the "stimulus"-light pattern presented to you with the greatest possible accuracy and speed. Use them to your advantage.