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BIOCYBERNETICS: AN INTERACTIVE MAN-MACHINE INTERFACE

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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 (laynyx, 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.

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 addon 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-numerics 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.

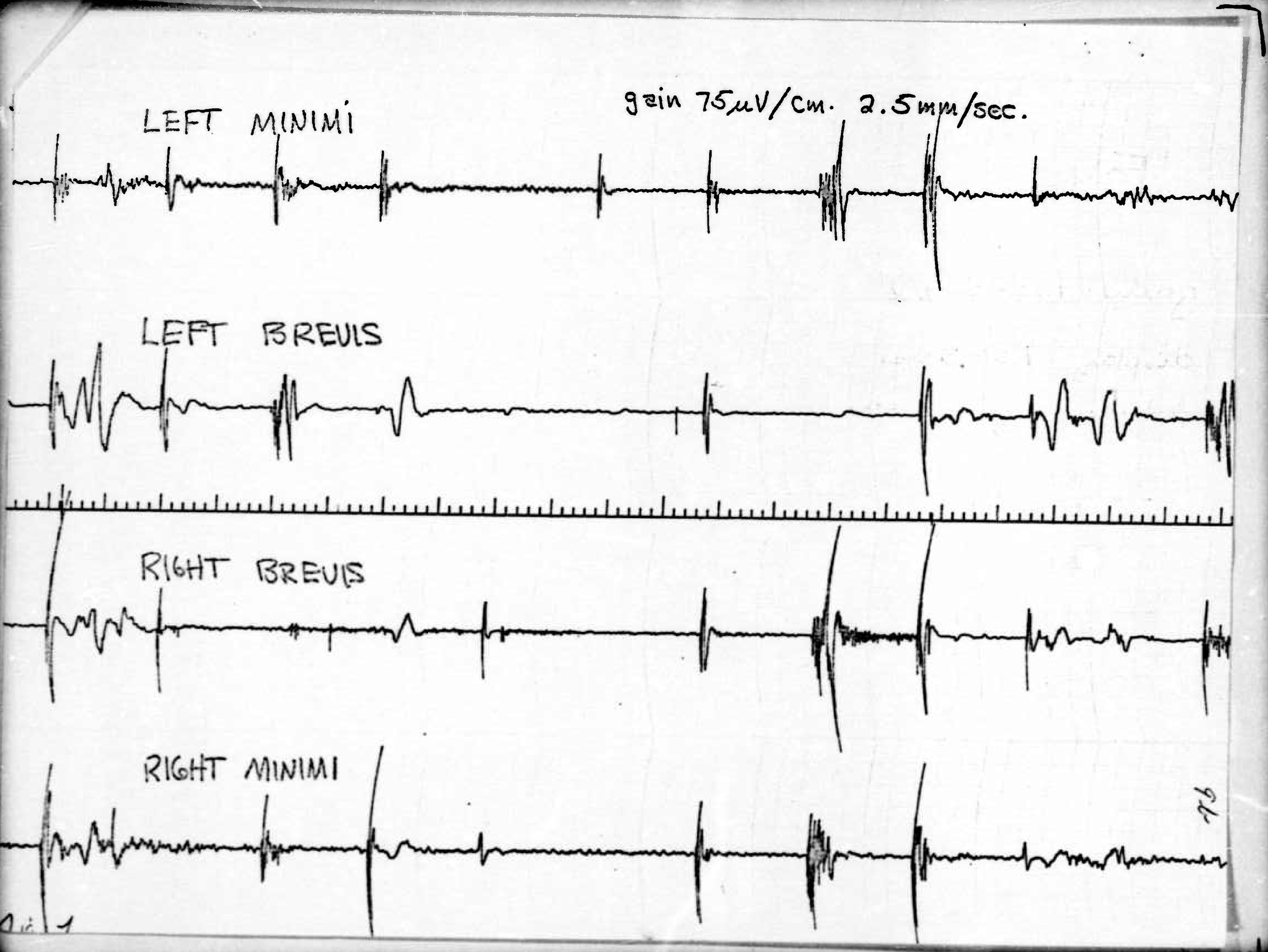
Muscles that were considered and rejected for one or more of the above reasons included: frontal and occipital epicranius, orbicularis oculi, superior auricular, depressor labii inferioris, maseter, trapesius, biceps brachii, brachioradialis and other superficial muscles of the forearm. The muscles deemed 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 pollicus brevis (thumb).

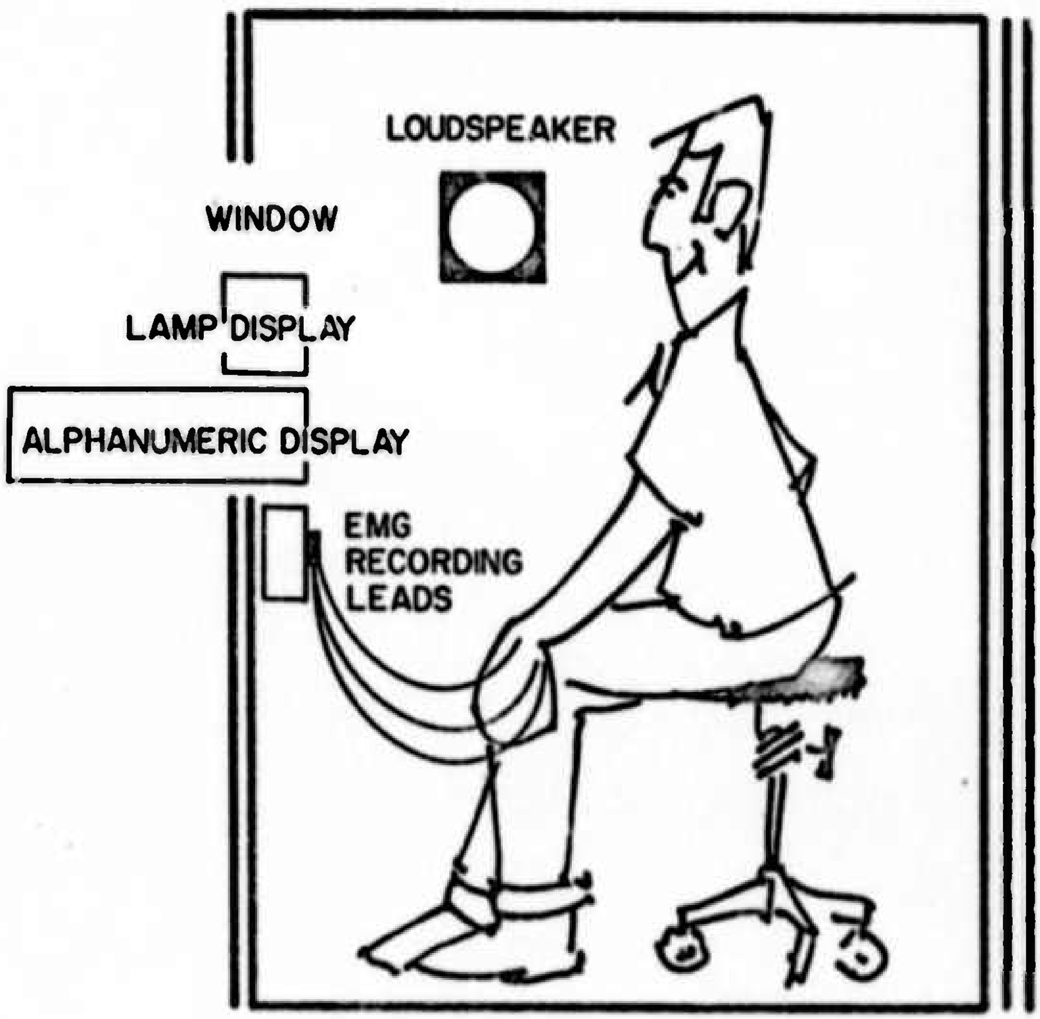
Gain = 75 μV/cm; speed = 2.5 mm/sec.



gain 75μV/cm. 2.5mm/sec.
LEFT MINIMI
LEFT BREVIS
RIGHT BREVIS
RIGHT MINIMI

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.

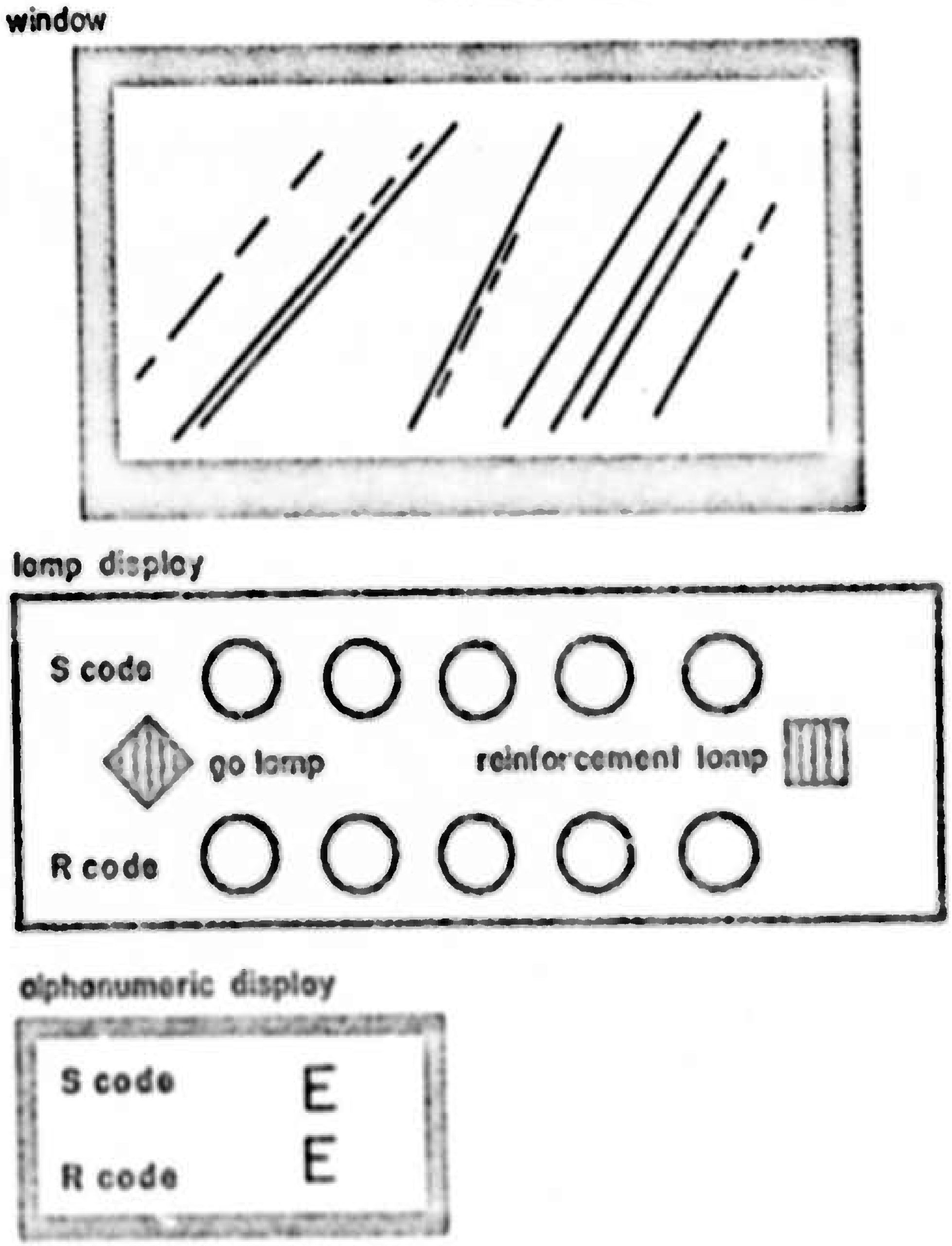
Patterned Light Training

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



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.

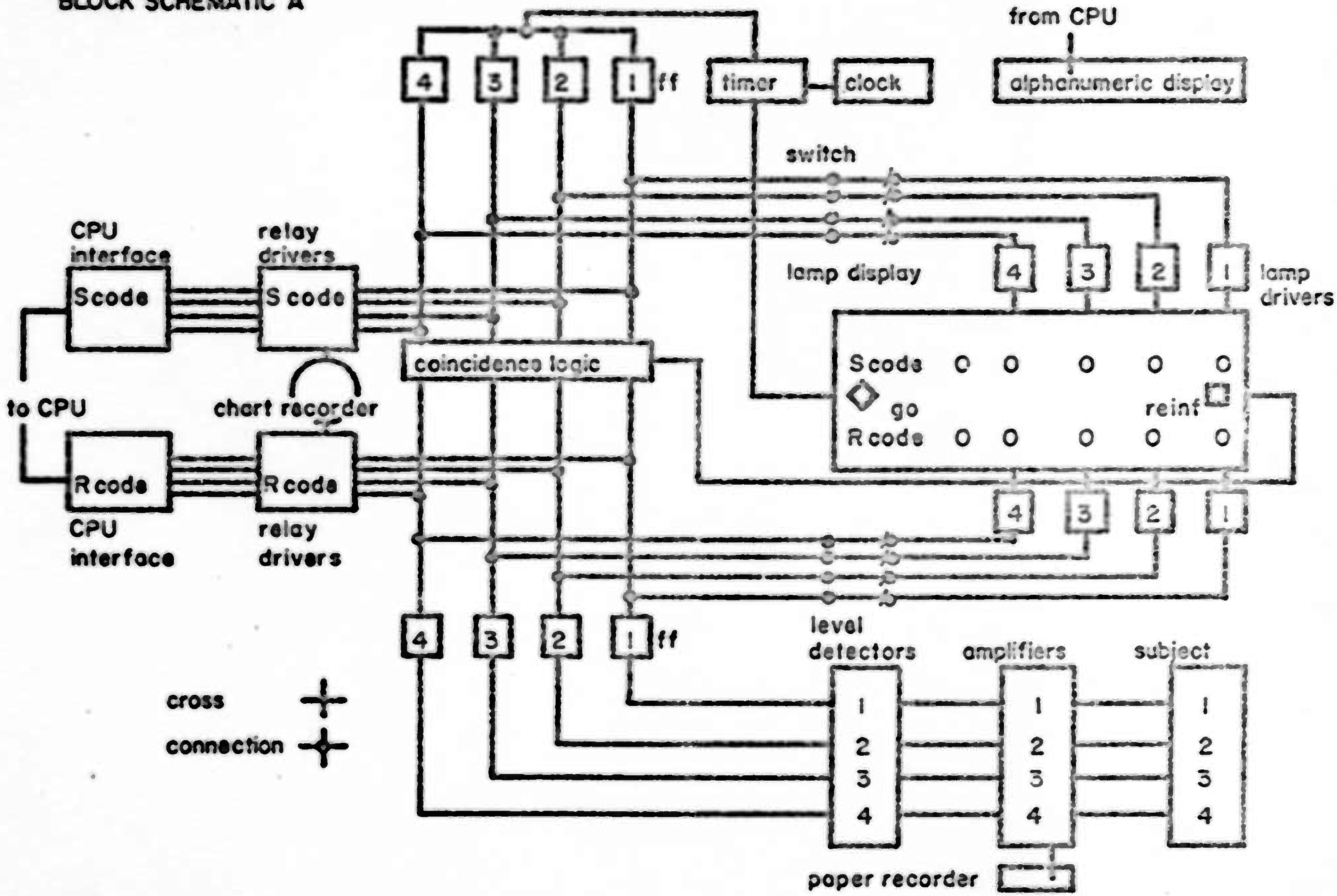
The initial training was accomplished with logic devices as shown in Figure 4. The four channels of EMG information were amplified and simultaneously written onto a pen-writing polygraph. The amplified and filtered EMG was fed into a series of level detectors which produced standard logic level pulses 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.

14b

BLOCK SCHEMATIC A

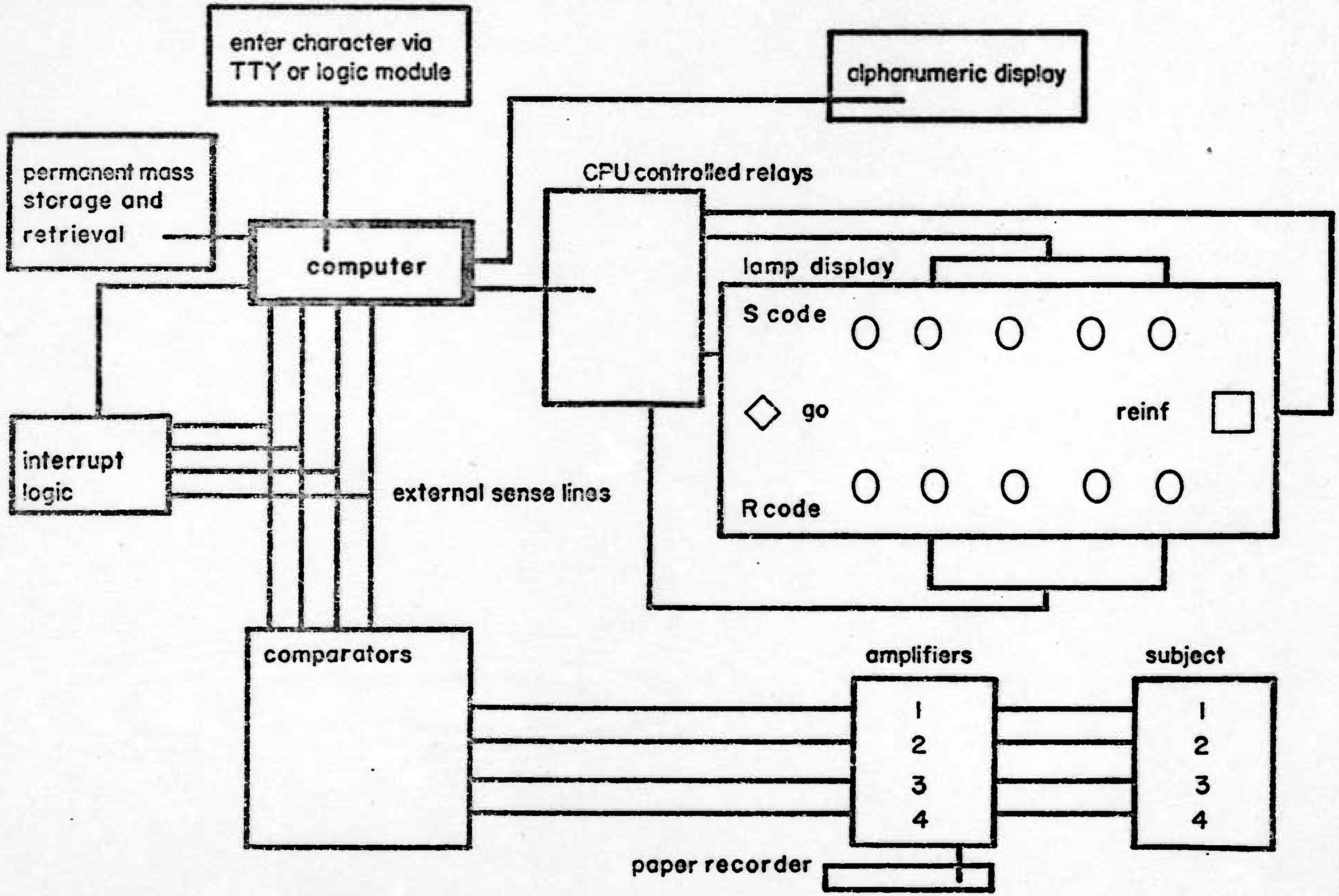


The next phase of training and system development involved the association of the S Code lamps with a particular alphanumeric display. Referring back to Block Schematic A (Figure 4) note that the S Code was relayed to the computer. A program was developed (Appendix B) to decode the S Code and display 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 sytems 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 tel-type 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 implimentation 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 μV) without any apparent movement.

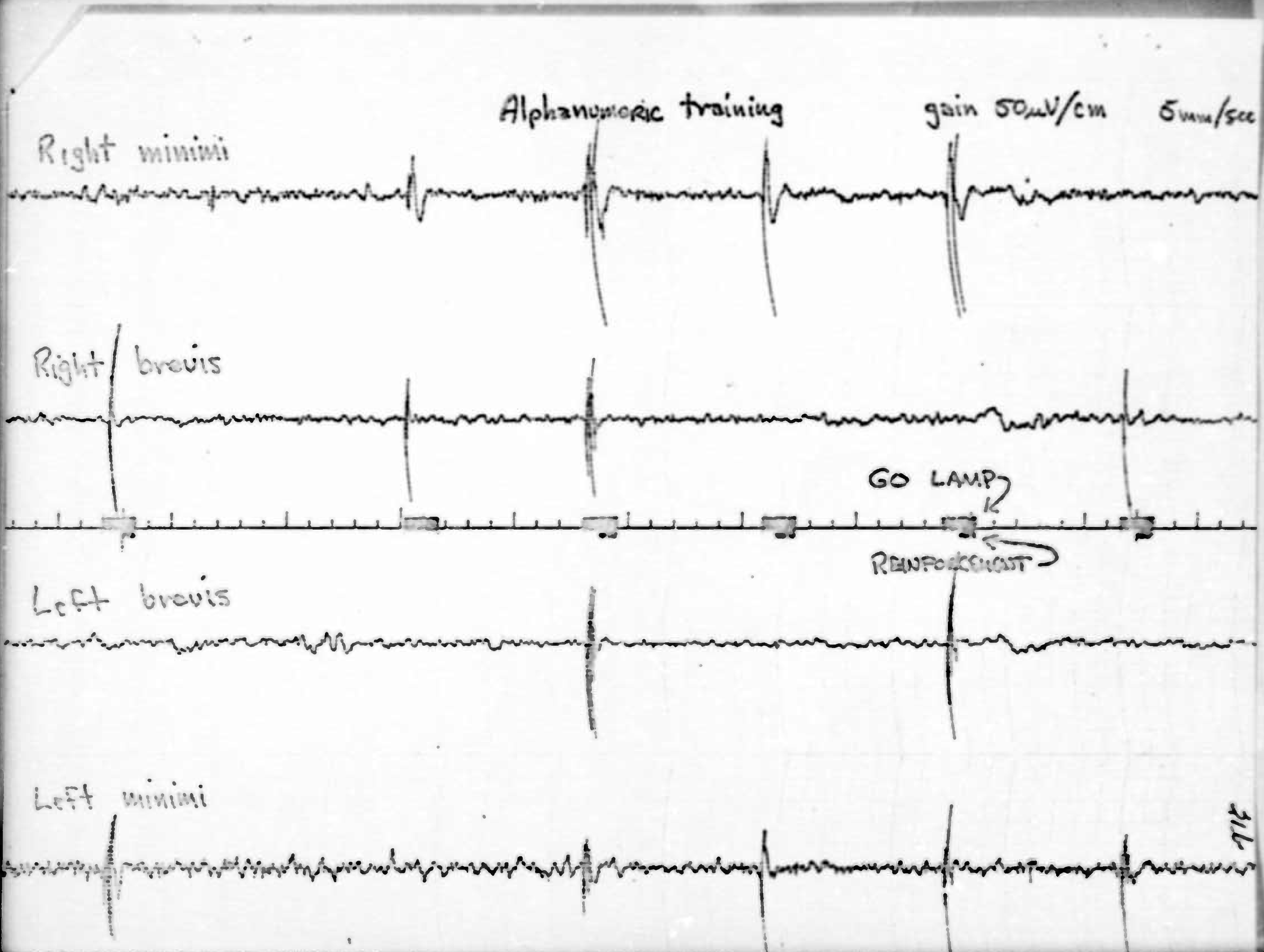
PERMANENT SUBJECT ONE

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.

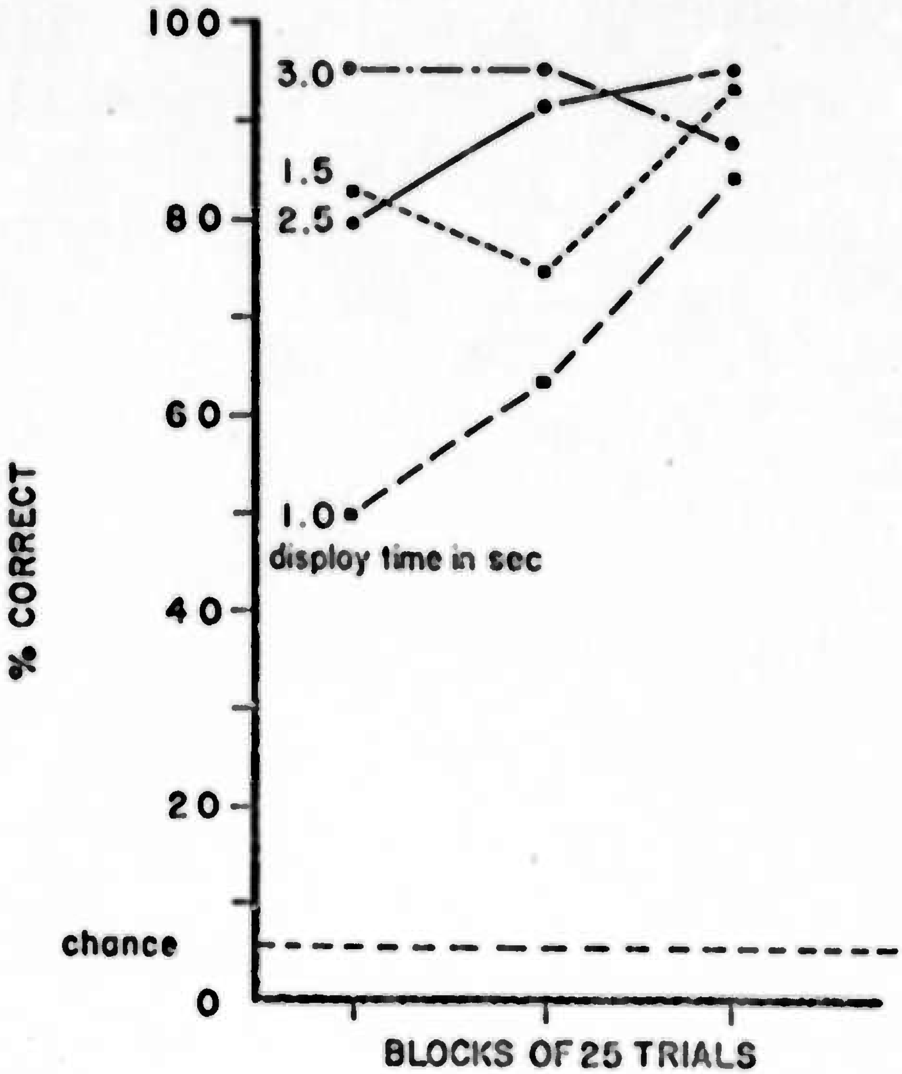
Figure 7 presents the results of a session after the subject had mastered the match-to-sample task. In this particular session the subject was exposed to four different display times: 3.0, 2.5, 1.5 and 1 sec. Plotted are the percent correct responses per block for the various display times. As can be 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 EMG's obtained from a subject well trained on the lamp display match-to-sample task. Gain = 50 μV/cm; speed = 5 mm/sec.



Alphanumeric training
gain 50μV/cm
5mm/sec
Right minimi
Right brevis
GO LAMP
REINFORCEMENT
Left brevis
Left minimi

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.


100
80
60
40
20
0
% CORRECT
chance
3.0
1.5
2.5
1.0
display time in sec
BLOCKS OF 25 TRIALS

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.

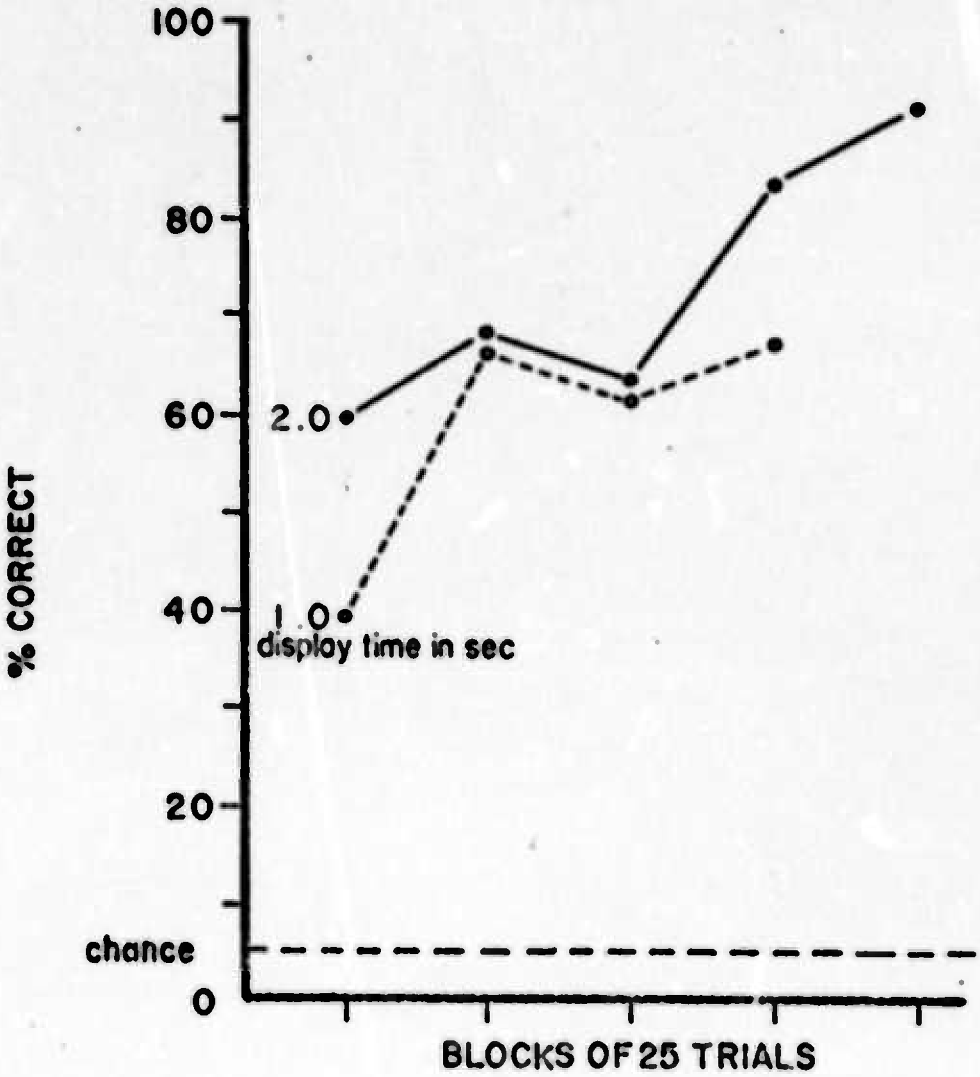

100
80
60
40
20
0
2.0
1.0
display time in sec
chance
% CORRECT
BLOCKS OF 25 TRIALS

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).

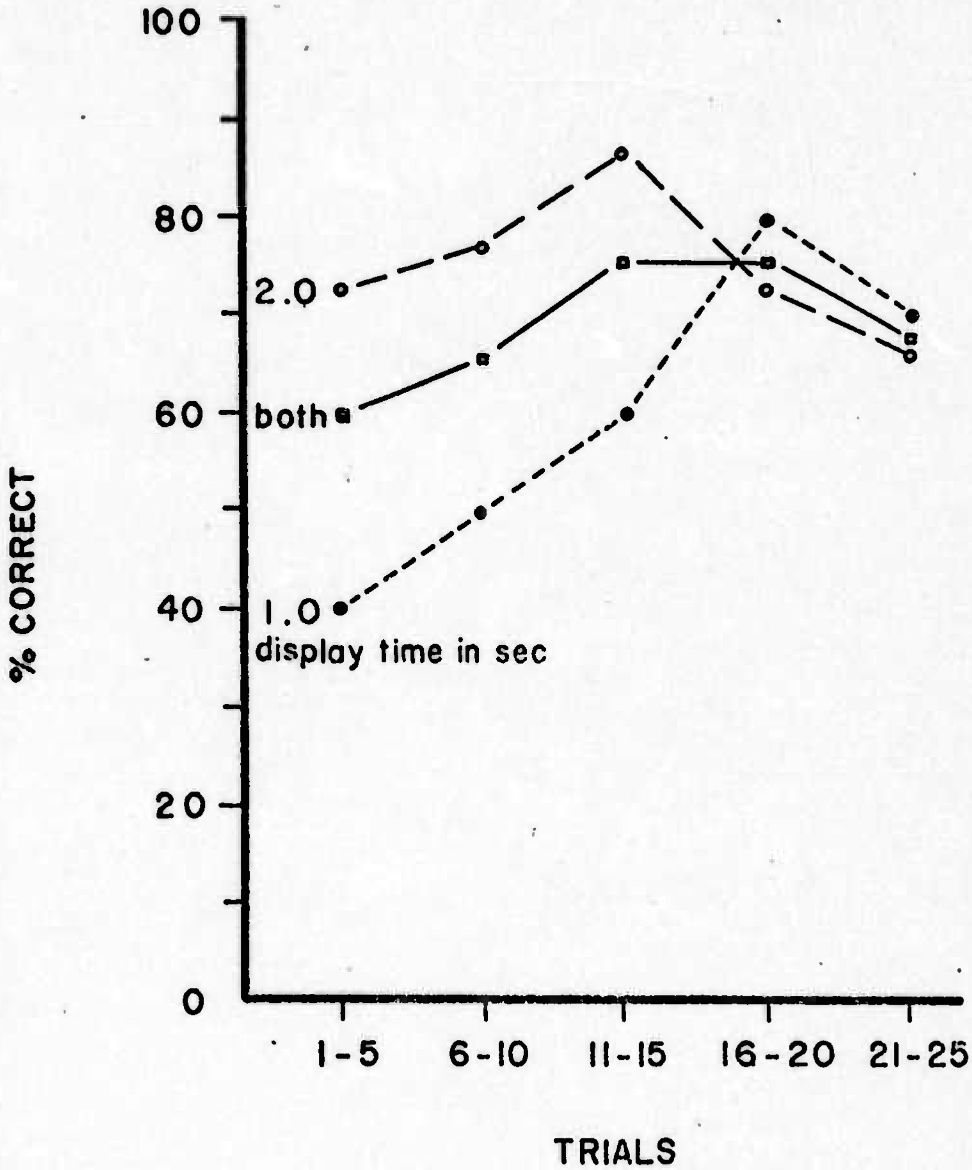

100
80
60
40
20
0
% CORRECT
2.0
both
1.0
display time in sec
1-5
6-10
11-15
16-20
21-25
TRIALS

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.

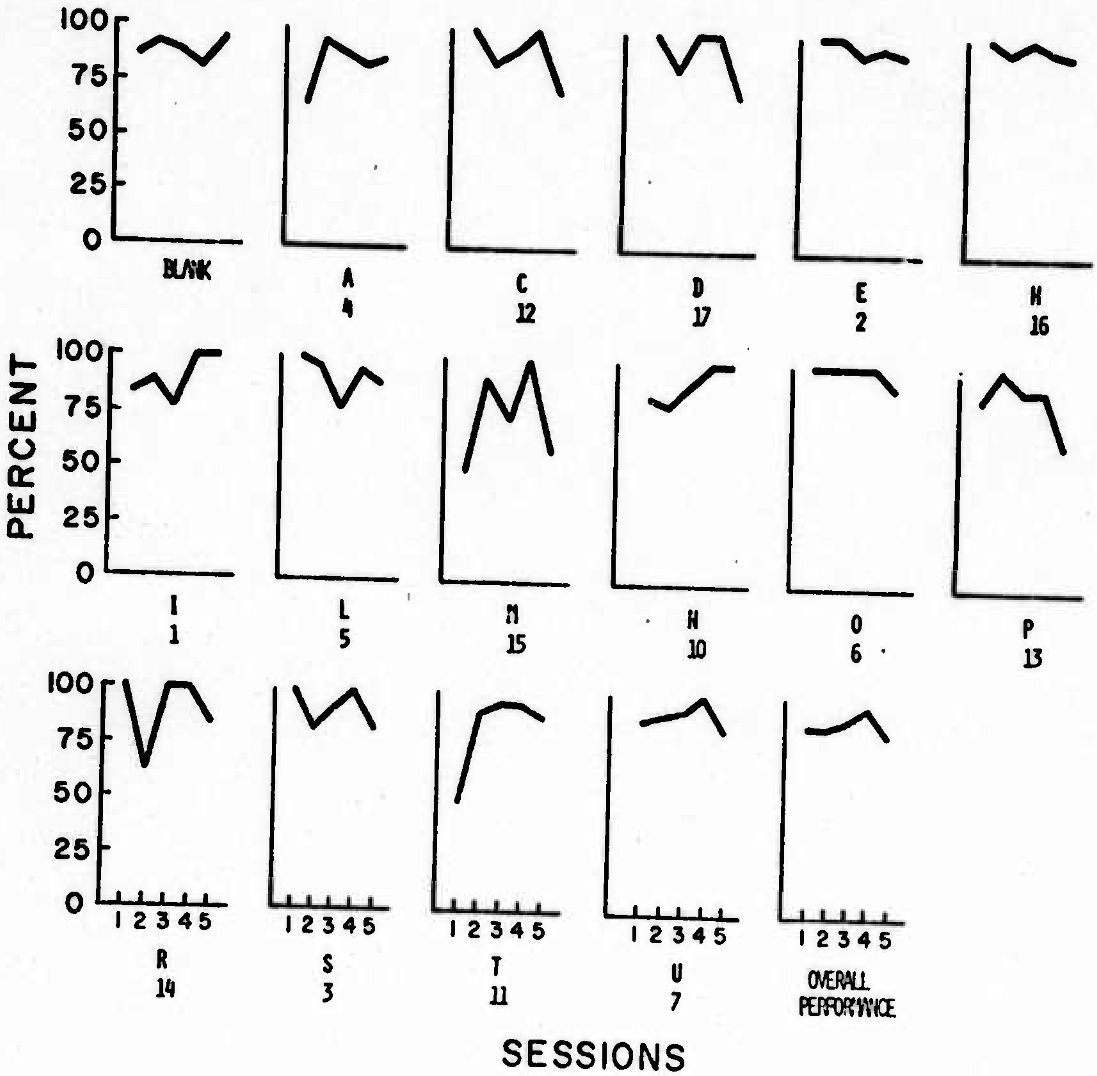

PERCENT
100
75
50
25
0
BLANK
A 4
C 12
D 17
E 2
H 16
I 1
L 5
M 15
N 10
O 6
P 13
R 14
S 3
T 11
U 7
OVERALL PERFORMANCE
1 2 3 4 5
SESSIONS

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.

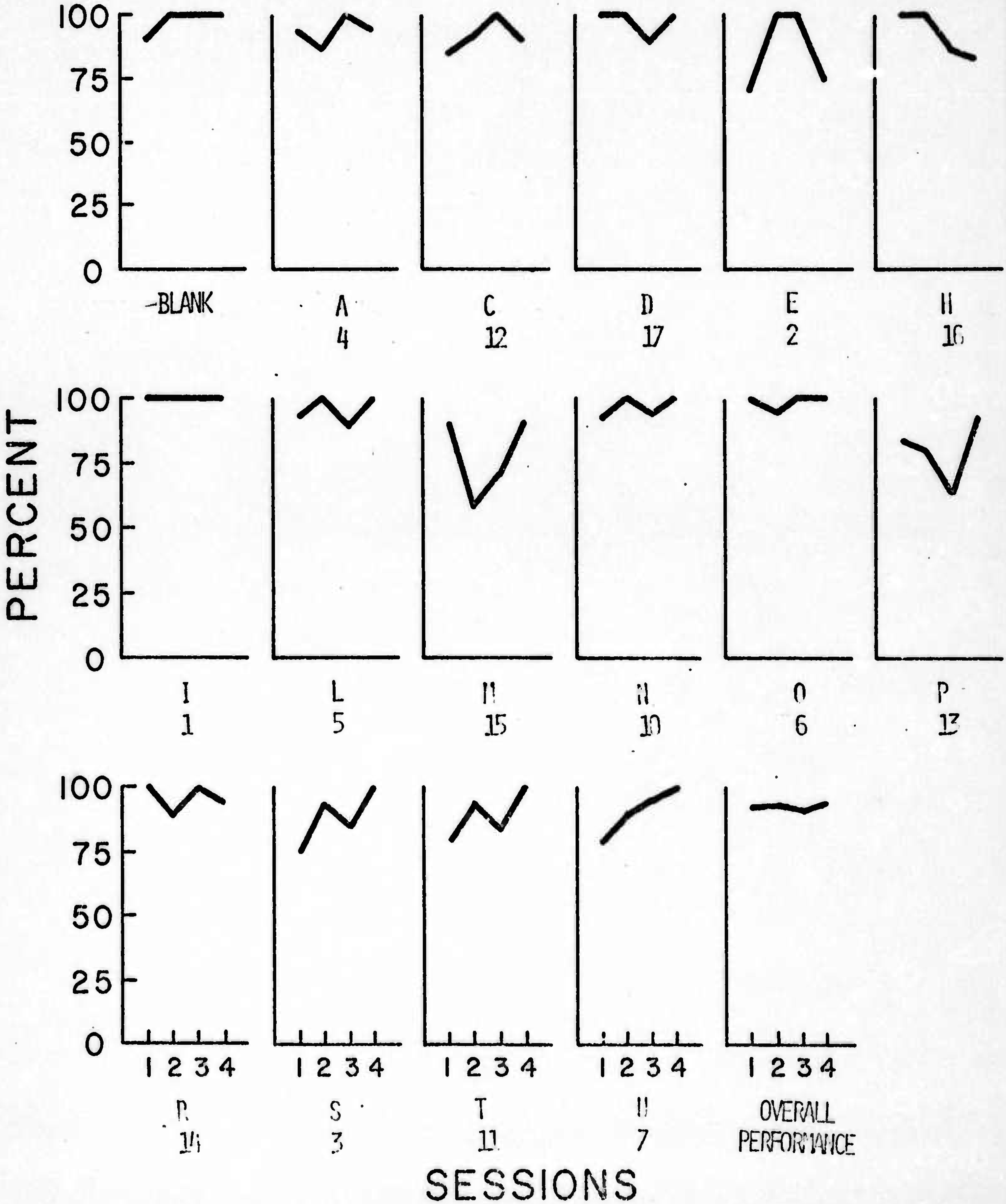
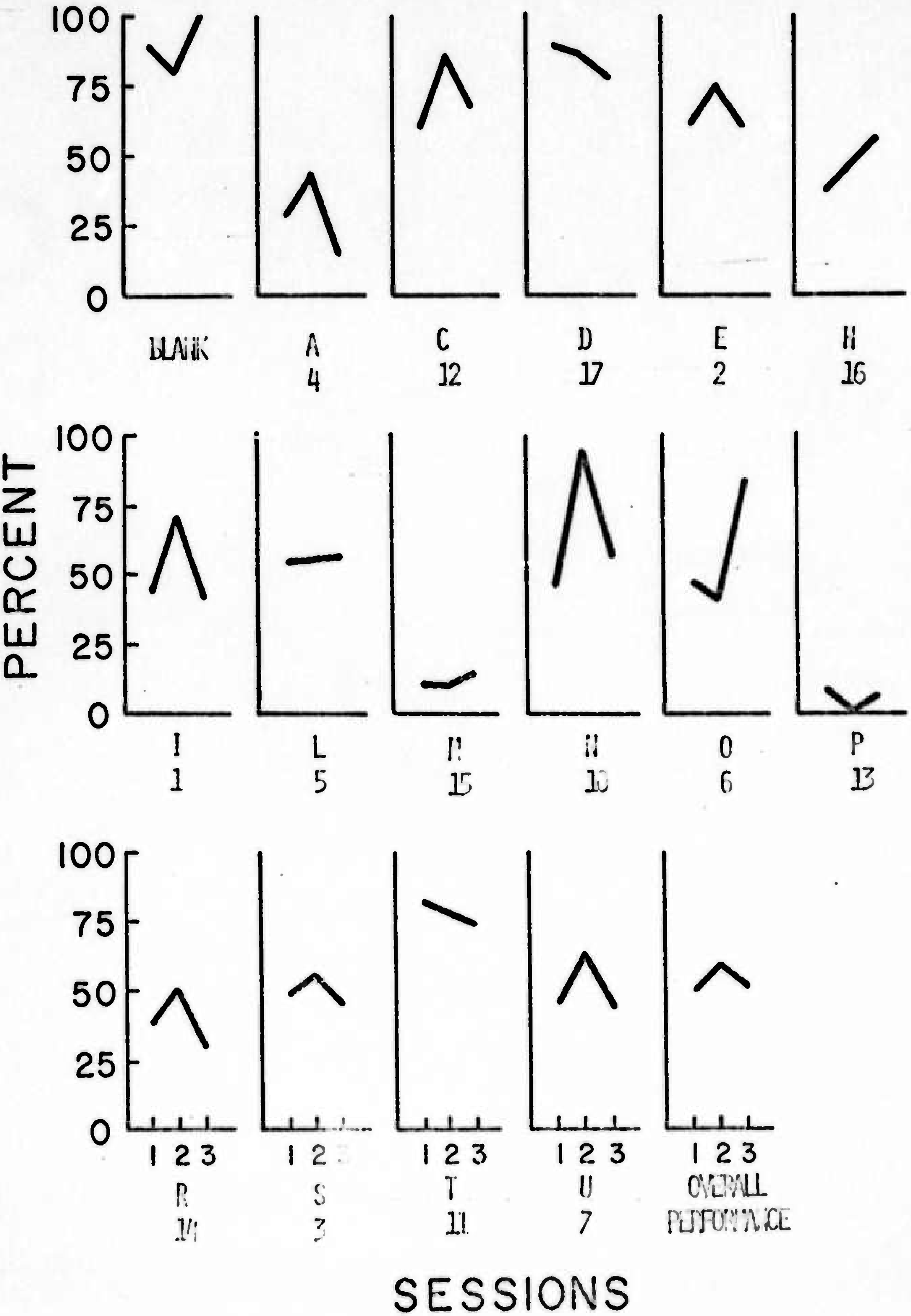

PERCENT
100
75
50
25
0
BLANK
A
4
C
12
D
17
E
2
H
16
I
1
L
5
M
15
N
10
O
6
P
13
R
14
S
3
T
11
U
7
OVERALL PERFORMANCE
1 2 3 4
SESSIONS

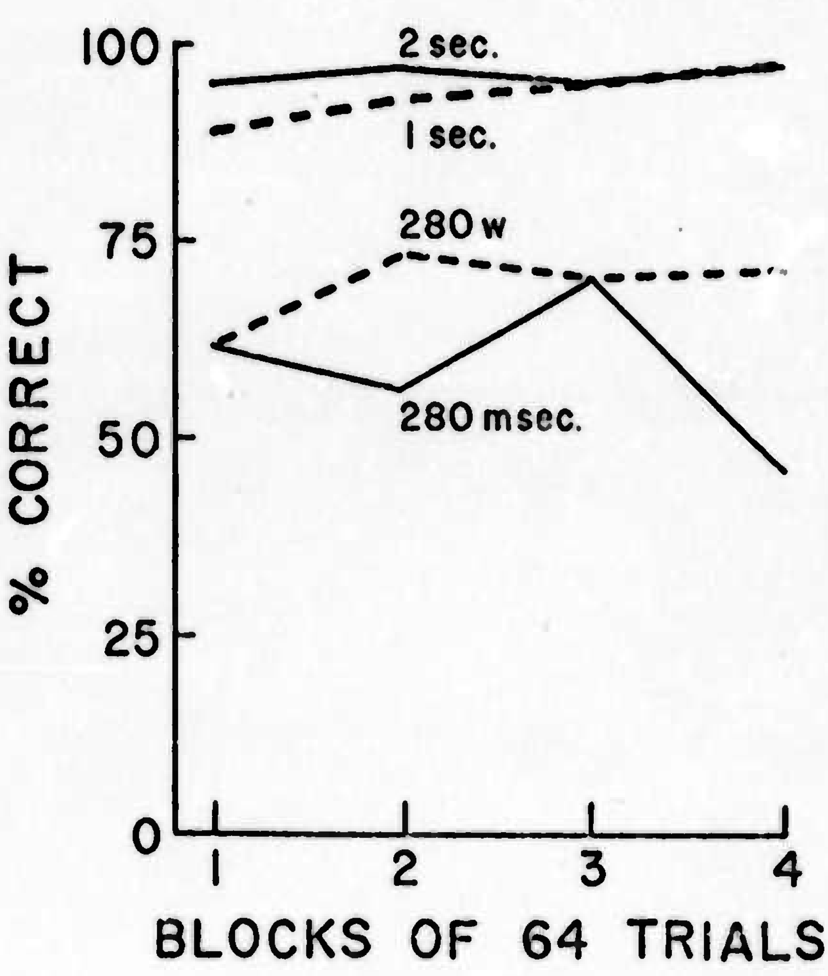
Figure 12 Results for alphabetic training from three daily sessions of 256 trials each. Plotted are the sixteen alphabetic responses and overall performance in percent correct responses. Display time is 280 milliseconds.


100
75
50
25
0
BLANK
A
4
C
12
D
17
E
2
H
16
PERCENT
I
1
L
5
M
15
N
10
O
6
P
13
1 2 3
R
14
S
3
T
11
U
7
OVERALL
PERFORMANCE
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 vigalence 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 trials 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 precent correct responses per 64 trial block as a function of display time (2 seconds, 1 second, 280 milliseconds and 280 milliseconds preceeded by a warning light).


100
75
50
25
0
% CORRECT
2 sec.
1 sec.
280 w
280 msec.
1
2
3
4
BLOCKS OF 64 TRIALS

the late trial dimunition 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 (± 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% controversal. 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.

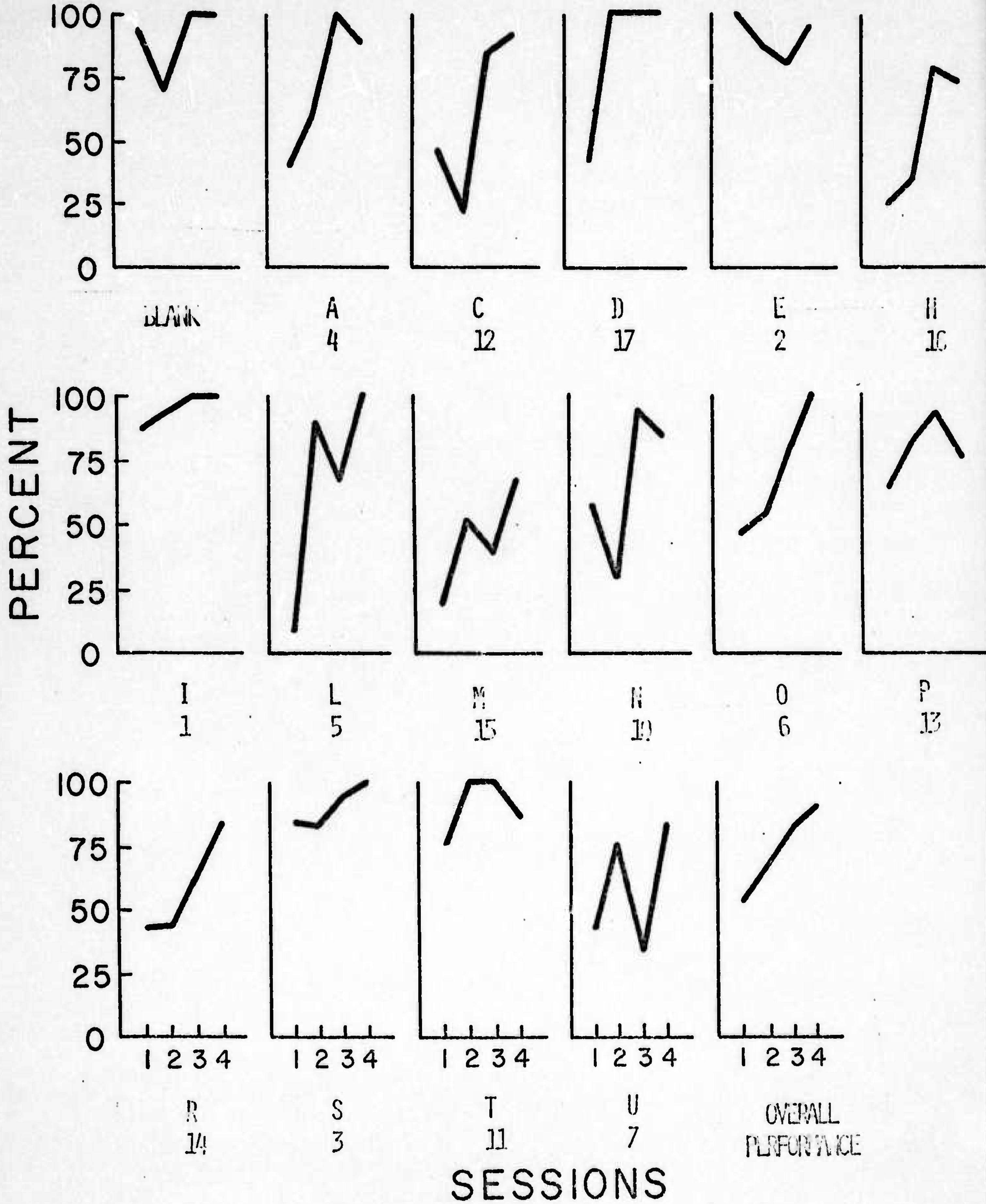

PERCENT
100
75
50
25
0
BLANK
A
4
C
12
D
17
E
2
H
I
1
L
5
M
15
N
O
6
P
13
R
14
S
3
T
11
U
7
OVERALL
PERFORMANCE
1 2 3 4
SESSIONS

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.

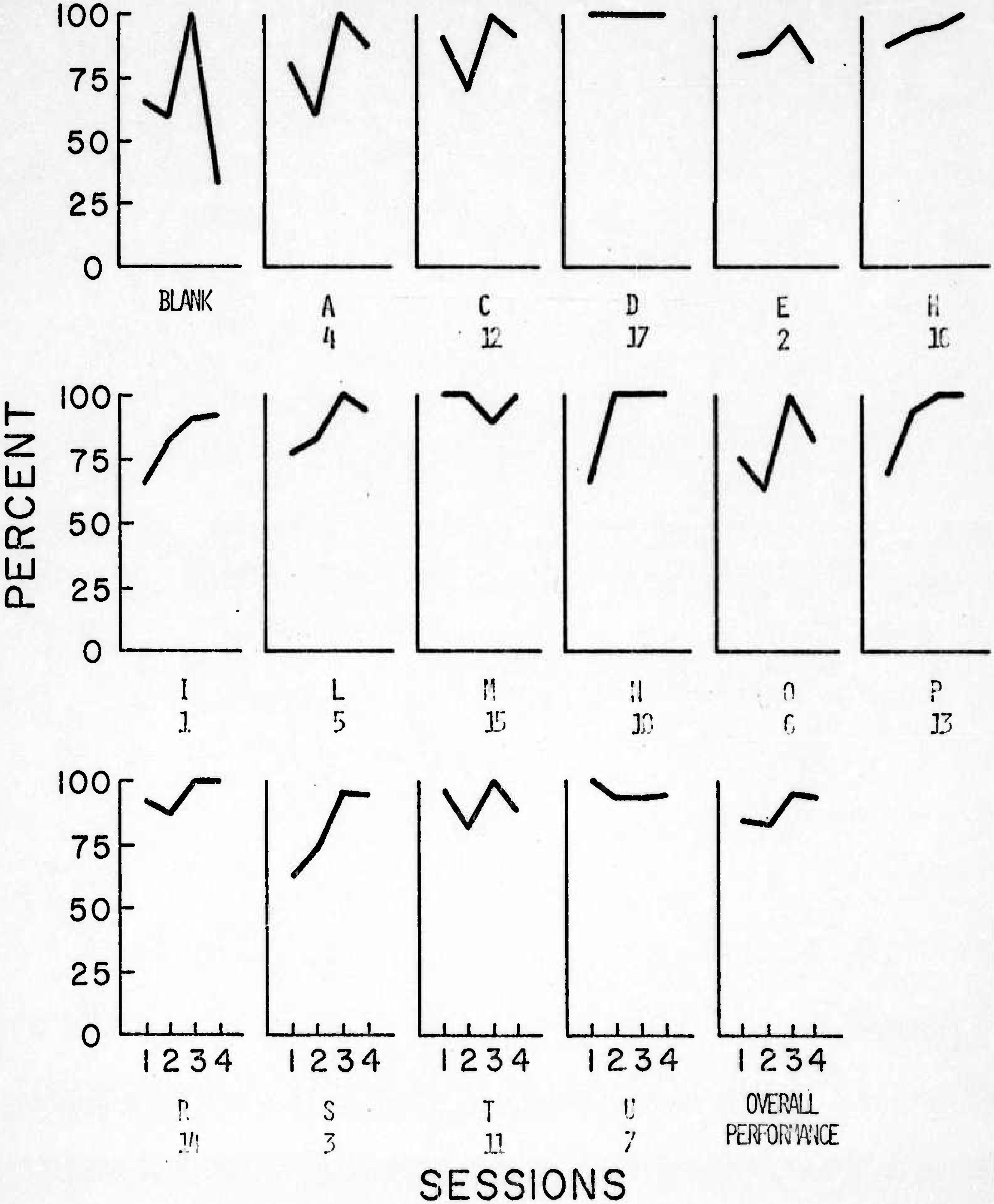

100
75
50
25
0
PERCENT
BLANK
A 4
C 12
D 17
E 2
H 16
I 1
L 5
M 15
N 10
O 6
P 13
R 14
S 3
T 11
U 7
OVERALL PERFORMANCE
1 2 3 4
SESSIONS

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.

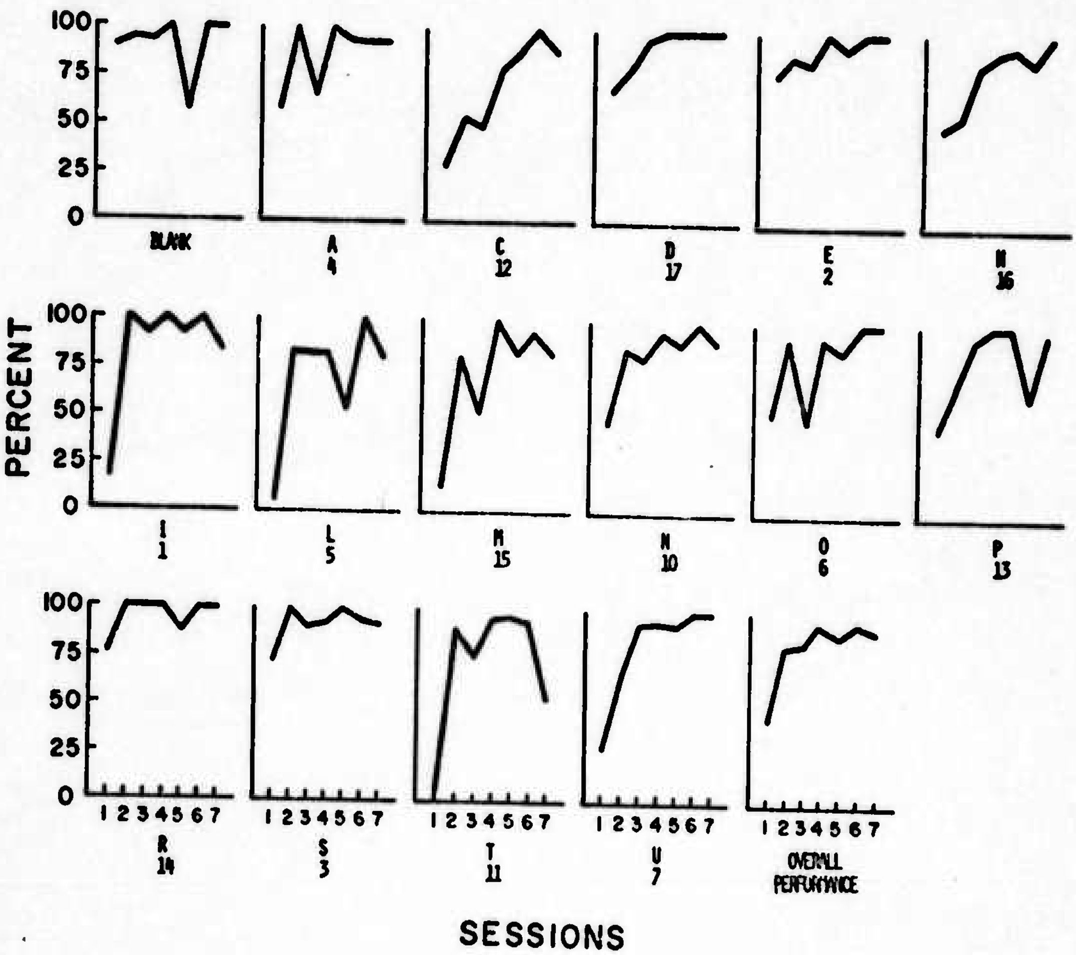
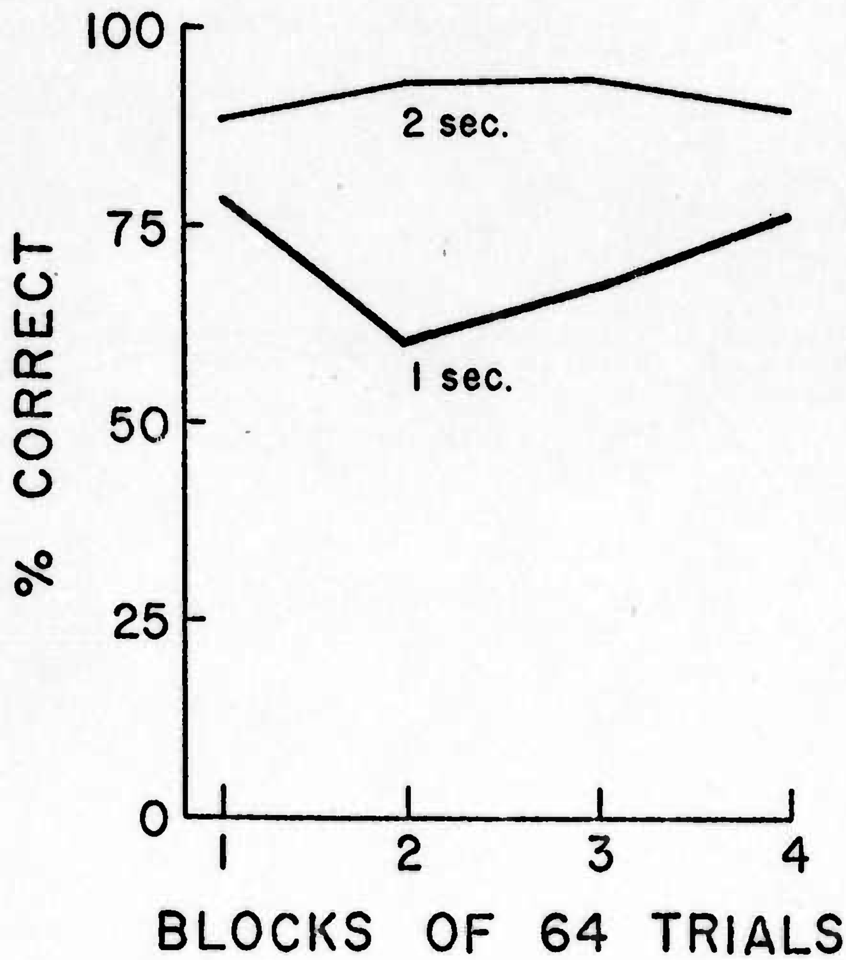

PERCENT
100
75
50
25
0
BLANK
A 4
C 12
D 17
E 2
H 16
I 1
L 5
M 15
N 10
O 6
P 13
R 14
S 3
T 11
U 7
OVERALL PERFORMANCE
1 2 3 4 5 6 7
SESSIONS

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).


100
75
50
25
0
% CORRECT
2 sec.
1 sec.
1
2
3
4
BLOCKS OF 64 TRIALS

BIOFEEDBACK STUDY

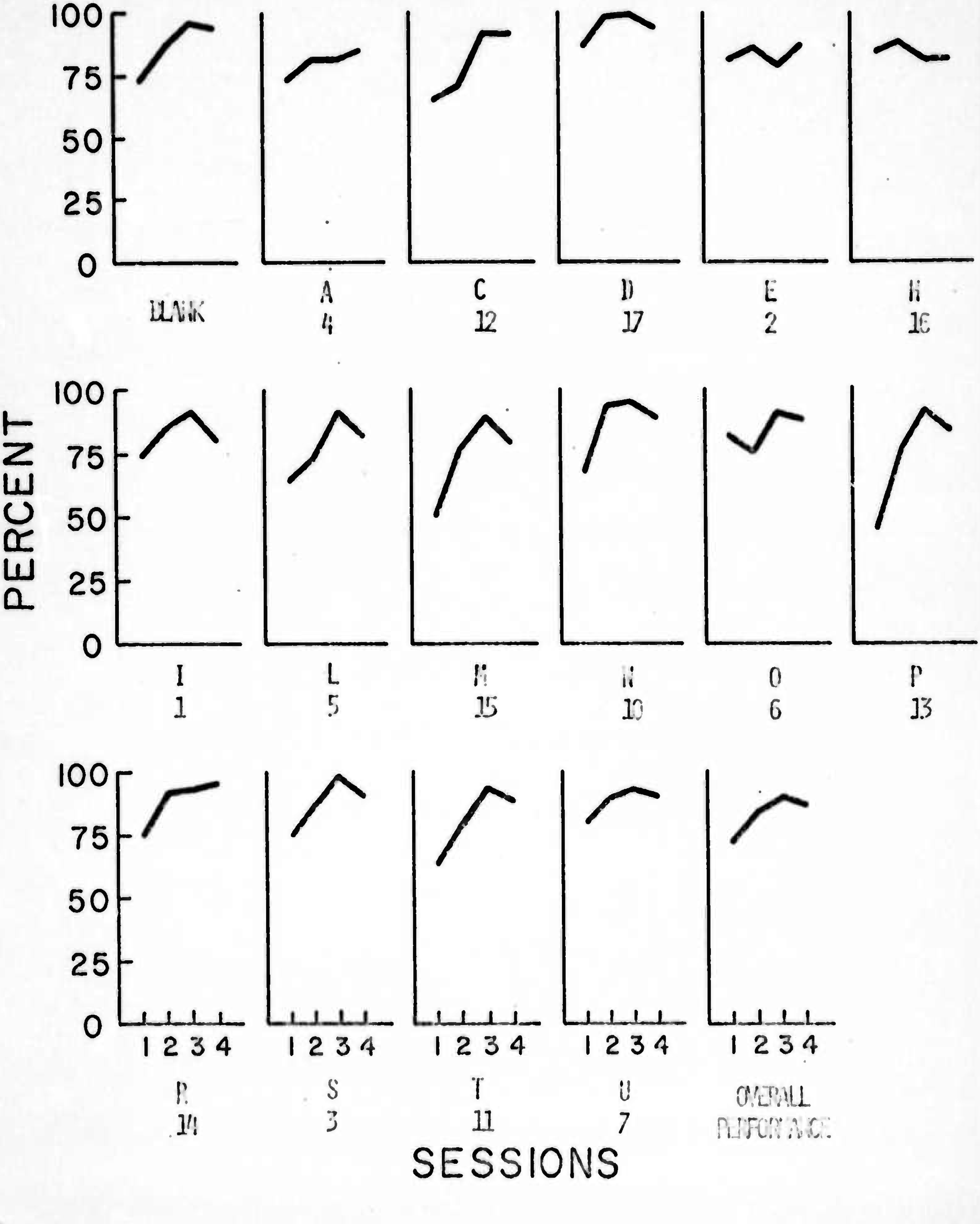
The project is designed to detect bioelectrical analysis of cognitive processes and to use these analogs in control and/or communication of external devices. One facet of this problem deals with the training of humans to use these analogs effectively. It is, therefore, necessary to assess training techniques 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.

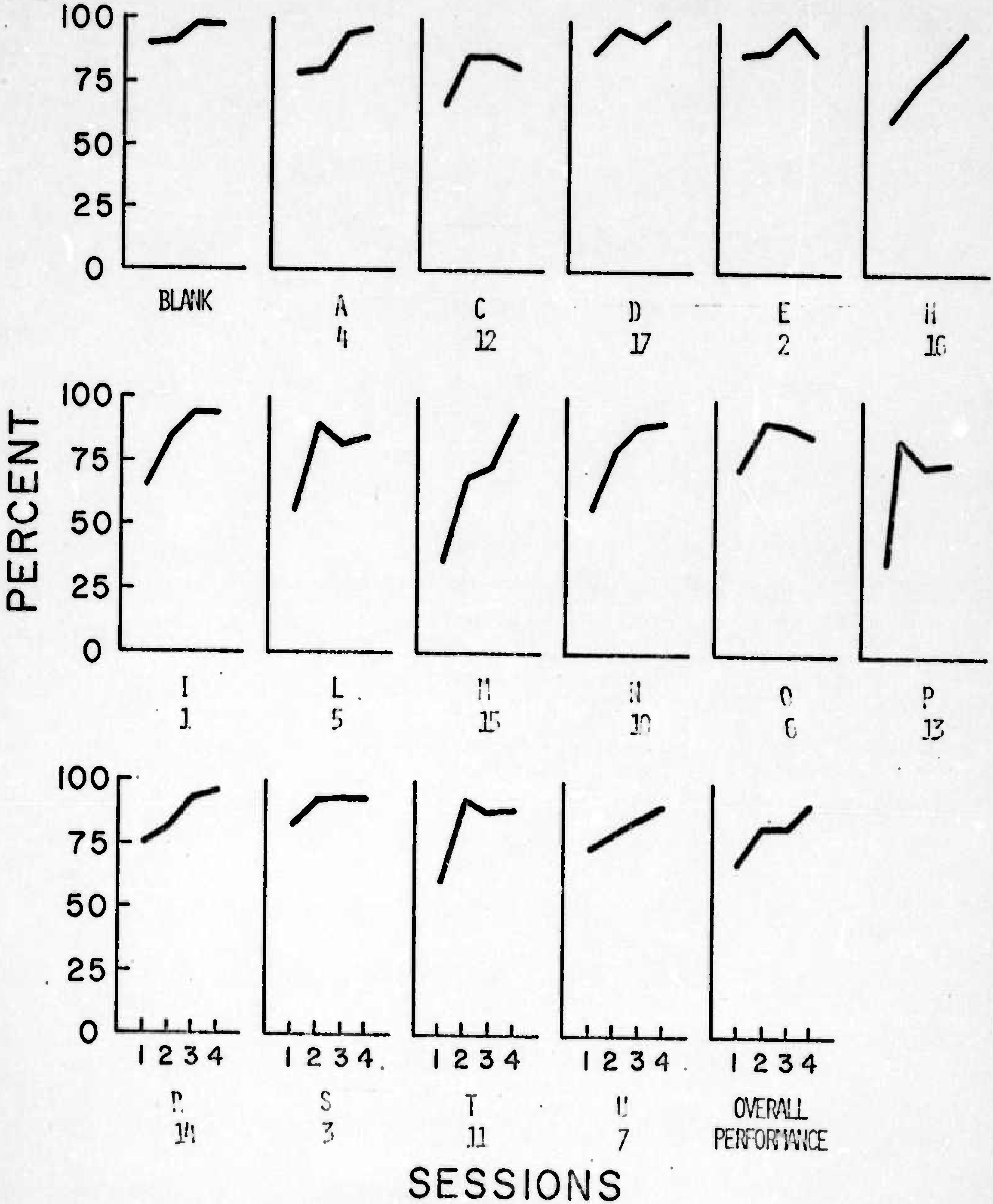

PERCENT
100
75
50
25
0
BLANK
A
4
C
12
D
17
E
2
H
16
I
1
L
5
M
15
N
10
O
6
P
13
R
14
S
3
T
11
U
7
OVERALL PERFORMANCE
1 2 3 4
SESSIONS

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.


PERCENT
100
75
50
25
0
BLANK
A
4
C
12
D
17
E
2
16
I
L
5
O
P
13
S
3
T
11
7
1 2 3 4
OVERALL PERFORMANCE
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 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

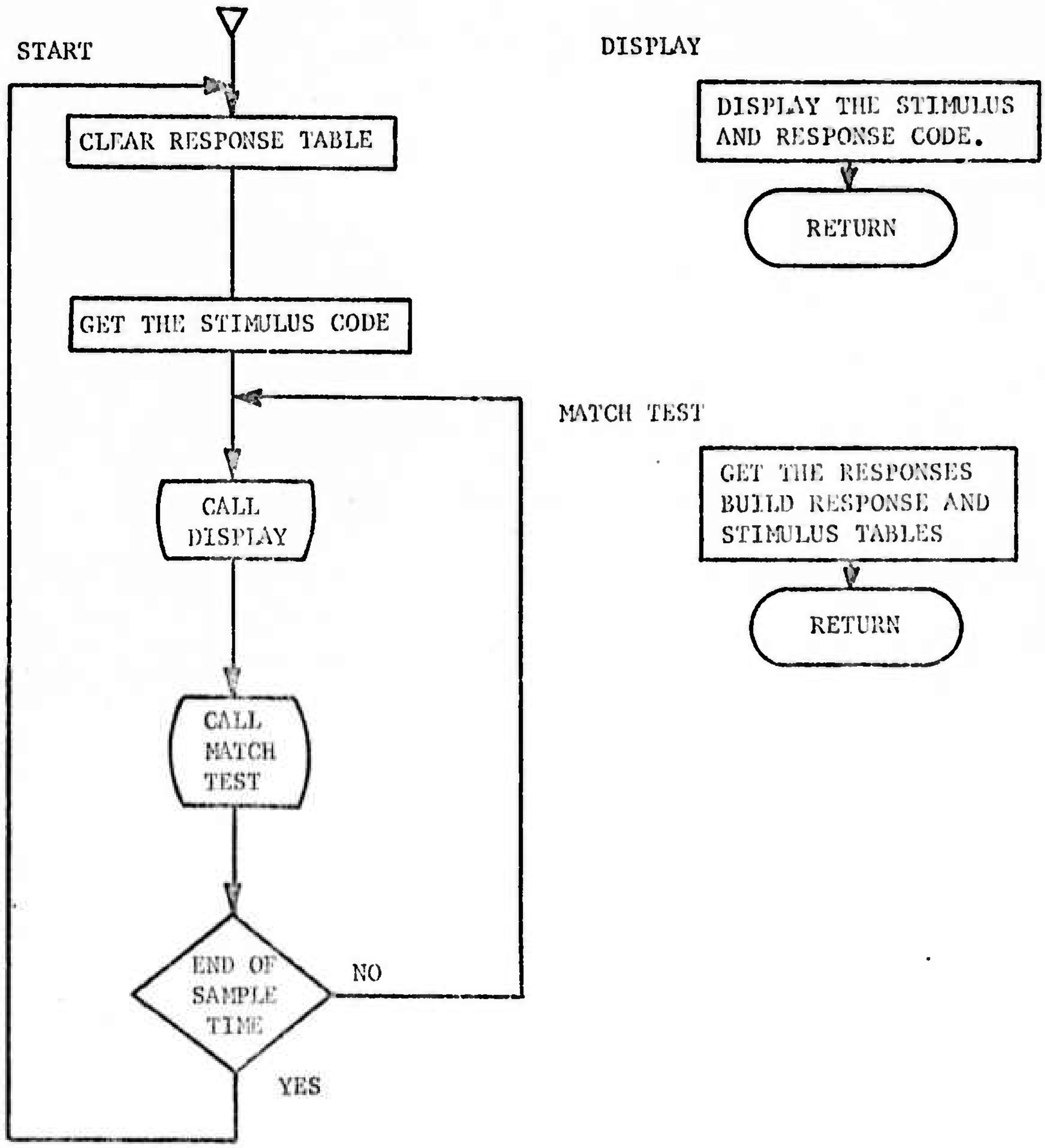
FUNCTION: This program displays two alpha numeric characters. The top character is the "S Code" or stimulus code, the bottom character is the "R Code" or response code.

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 Ø, 1, 2, 3 and 4 for a corresponding R code. If a match is detected relay KO is set, indicating reinforcement.

ARPA 1 FLOWCHART



```
                      *20
                                 KSF=6031
                                 KRB=6036
                                 TSF=6041
                                 TLS=6046
     0020  0011  AASTRT, CLR
     0021  0500          IOB
     0022  6046          TLS
     0023  0062          SET I 2
     0024  0312          HITTBL-1
     0025  0063          SET I 3
     0026  7767          -10
     0027  1062          STA I 2
     0030  0223          XSK I 3
     0031  6027          JMP .-2            /CLEAR HITTBL
     0032  0062          SET I 2
     0033  0302          DSCTBL-1
     0034  0063          SET I 3
     0035  7767          -10
     0036  1062          STA I 2
     0037  0223          XSK I 3
     0040  6036          JMP .-2            /CLEAR DSCTBL
     0041  0077          SET I 17
     0042  0302          DSCTBL-1
     0043  0075          SET I 15
     0044  7776  N,      -1
     0045  6147          JMP GETCHR
     0046  0067          SET I 7
     0047  7775  AAA,    -2
     0050  6054          JMP THIS
     0051  0227          XSK I 7
     0052  6050          JMP .-2
     0053  6020          JMP AASTRT
                 /
     0054  1000  THIS,   LDA
     0055  0000          0
     0056  4071          STC THISR
     0057  0066          SET I 6
     0060  0000          0
     0061  6250          JMP DISIT
     0062  0052          SET 12
     0063  0044          N
     0064  0076          SET I 16
     0065  0312          HITTBL-1
     0066  6072          JMP MATCHT
     0067  0226          XSK I 6
     0070  6061          JMP .-7
     0071  0000  THISR,  0
                 /
                 /
                 /SAMPLE SENSELINE
     0072  1000  MATCHT, LDA
     0073  0000          0
     0074  4146          STC MTCHR
     0075  0011          CLR
     0076  1060          STA I
     0077  0000  SUM,    0
     0100  0070          SET I 10
     0101  0077          SUM
     0102  1020          LDA I
     0103  0001          1
```

```
0105  1150             ADM 10
0106  1020             LDA I
0107  0002             2
0110  0401             SXL 1
0111  1150             ADM 10
0112  1020             LDA I
0113  0004             4
0114  0402             SXL 2
0115  1150             ADM 10
0116  1020             LDA I
0117  0010             10
0120  0403             SXL 3
0121  1150             ADM 10
0122  6250             JMP DISIT          /REFRESH
0123  1020             LDA I
0124  0425             SNSCOD
0125  2077             ADD SUM
0126  4003             STC 3
0127  1003             LDA 3              /GET ASCII
0130  1560             BCL I
0131  7700             7700
0132  0241             ROL 1
0133  1120             ADA I
0134  0323             CHRDIS
0135  1040             STA
0136  0003             3
0137  1003             LDA 3              /
0140  1076             STA I 16
0141  1023             LDA I 3
0142  1076             STA I 16           /NEW HITS
0143  6250             JMP DISIT
0144  0232             XSK I 12
0145  6075             JMP SUM-2
0146  0000   MTCHR,    0                  /MATCH RET
             /
0147  1000   GETCHR,   LDA
0150  0000             0
0151  4177             STC CHRRET
0152  0465             SNS I 5
0153  6200             JMP SENSIT
0154  0500             IOB
0155  6031             KSF
0156  6154             JMP .-2
0157  0500             IOB
0160  6036             KRB
0161  1060   STRIP,    STA I
0162  0000   CHAR,     0
0163  1560             BCL I
0164  7700             7700
0165  0241             ROL 1
0166  1120             ADA I
0167  0323             CHRDIS
0170  4003             STC 3
0171  1003             LDA 3
0172  1077             STA I 17
0173  1023             LDA I 3
0174  1077             STA I 17
0175  0235             XSK I 15
0176  6152             JMP GETCHR+3       /MORE WORDS
0177  0000   CHRRET,   0                  /GO BACK
0200  0011   SENSIT,   CLR
0201  0432             SXL I 12           /WAIT FOR OK TO SAMPLE
0202  6201             JMP .-1
```

```
0203  1060             STA I
0204  0000  MATCH,     0
0205  0070             SET I 10
0206  0204             MATCH
0207  1020             LDA I
0210  0001             1
0211  0405             SXL 5
0212  1150             ADM 10
0213  1020             LDA I
0214  0002             2
0215  0406             SXL 6
0216  1150             ADM 10
0217  1020             LDA I
0220  0004             4
0221  0407             SXL 7
0222  1150             ADM 10
0223  1020             LDA I
0224  0010             10
0225  0410             SXL 10
0226  1150             ADM 10
0227  1020             LDA I
0230  0020             20
0231  0411             SXL 11
0232  1150             ADM 10
0233  6250             JMP DISIT
0234  1020             LDA I
0235  0425             SNSCOD
0236  2204             ADD MATCH
0237  4003             STC 3
0240  1003             LDA 3
0241  6161             JMP STRIP
0242  1020             LDA I
0243  0425             SNSCOD
0244  2204             ADD MATCH
0245  4003             STC 3
0246  1003             LDA 3
0247  6161             JMP STRIP
                 /
                 /
0250  1000  DISIT,     LDA
0251  0000             0
0252  4302             STC DISRET
0253  0074             SET I 14
0254  0302             DSCTBL-1
0255  0061             SET I 1
0256  0377             377
0257  0063             SET I 3
0260  7774             -3
0261  0011             CLR
0262  1774             DSC I 14
0263  1774             DSC I 14          /BOTH HALVES
0264  0223             XSK I 3
0265  6261             JMP .-4
0266  0073             SET I 13
0267  0312             HITTBL-1
0270  0061             SET I 1
0271  0377             377
0272  0063             SET I 3
0273  7774             -3
0274  1020             LDA I
0275  7737             -40
0276  1773             DSC I 13          /HIT
0277  1773             DSC I 13
```

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

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

```
        0467  0014          14            /R
        0470  0003          3             /S
        0471  0011          11            /T
        0472  0007          7             /U
        0473  0000          0             /V
        0474  0000          0             /W
        0475  0000          0             /X
        0476  0000          0             /Y
        0477  0000          0             /Z
                      /
                      /ARPA1
                      /
                      /PROGRAM ACCEPTS STIMULUS CODE FROM
                      /EITHER THE TTY (IF SENSE SWITCH 5 IS UP) OR VIA A
                       OCTAL CODE
                      /VIA SENSE LINES 5,6,7,10, AND 11
                      /(IF SNS 5 IS DOWN). A GROUND TO SXL 12
                      /INDICATES THAT SENSE LINE CODIFICATION IS COMPLEE
                      /
                      /PROGRAM THEN MONITORS THE RESPONSE CODE
                      /VIA SXL 0-4 FOR CORRESPONDANCE TO THE S-CODE
                      /THE ALPHA EQUIVALENT OF THE S-CODE IS DISPLAYED
                      /ON TOP, THE R-CODE IS DISPLAYED ON THE BOTTOM.
                      /1-DISIT
                      /2- UNUSED
                      /3-SCRATCH
                      /4-UNUSED
                      /5-UNUSED
                      /6-DISPLAY TIMER
                      /7-DISPLAY TIMER
                      /10 SUM AND MATCH POINTER
                      /11-UNUSED
                      /12- NUMBER OF CHARACTERS
                      /13-DISIT R-CODE
                      /14-DISIT S-CODE
                      /15 NUMBER OF CHARACTERS
                      /16-R-CODE
                      /17-S-CODE

NO ERRORS

AAA     4047
AASTRT  4020
CHAR    4162
CHRDIS  4323
CHRRET  4177
DISIT   4250
DISRET  4302
DSCTBL  4303
GETCHR  4147
HITTBL  4313
KRB     6036
KSF     6031
MATCH   4204
MATCHT  4072
MTCHR   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.

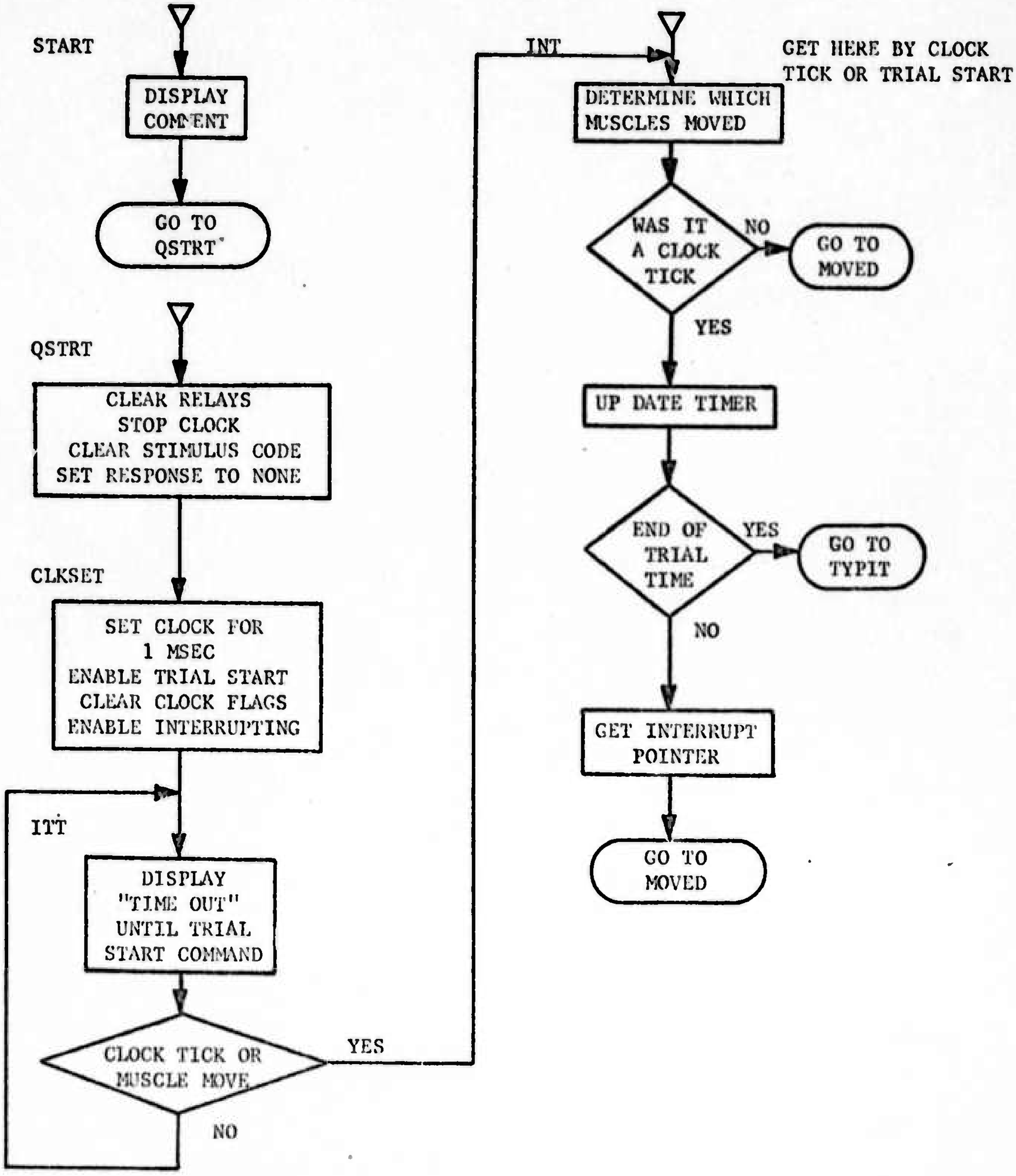
LANGUAGE: DIAL-LAP6 (ASSEMBLY)

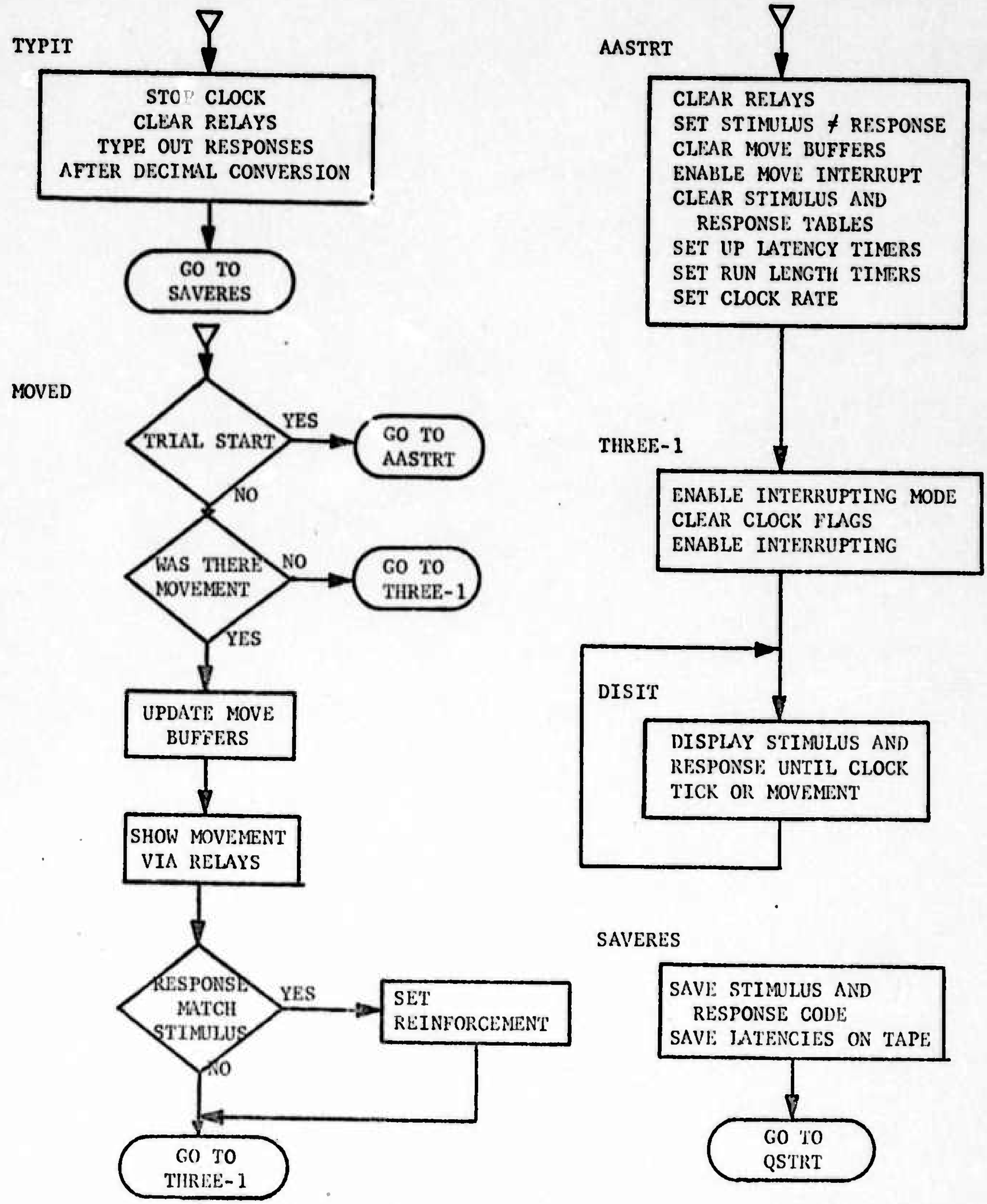
DESCRIPTION: The S code is accepted from a teletype entry, or if sense switch five is up, from external sense lines 5, 6, 7, 10, and 11. In the latter case, a zero volt level to sense line 12 indicates codification is complete and sampling may begin.

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




TYPIT
STOP CLOCK
CLEAR RELAYS
TYPE OUT RESPONSES
AFTER DECIMAL CONVERSION
GO TO SAVERES
MOVED
TRIAL START
YES
GO TO AASTRT
NO
WAS THERE MOVEMENT
NO
GO TO THREE-1
YES
UPDATE MOVE BUFFERS
SHOW MOVEMENT VIA RELAYS
RESPONSE MATCH STIMULUS
YES
SET REINFORCEMENT
NO
GO TO THREE-1
AASTRT
CLEAR RELAYS
SET STIMULUS ≠ RESPONSE
CLEAR MOVE BUFFERS
ENABLE MOVE INTERRUPT
CLEAR STIMULUS AND RESPONSE TABLES
SET UP LATENCY TIMERS
SET RUN LENGTH TIMERS
SET CLOCK RATE
THREE-1
ENABLE INTERRUPTING MODE
CLEAR CLOCK FLAGS
ENABLE INTERRUPTING
DISIT
DISPLAY STIMULUS AND RESPONSE UNTIL CLOCK TICK OR MOVEMENT
SAVERES
SAVE STIMULUS AND RESPONSE CODE
SAVE LATENCIES ON TAPE
GO TO QSTRT

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

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

```
0215  6256              JMP CONVRT
0216  1000              LDA
0217  0007              7
0220  6256              JMP CONVRT
                        /LDA
                        /10
                        /JMP CONVRT
0221  0602   TDONE,      LIF 2
0222  6101              JMP SAVRES
             /
0223  1000   BLANK,     LDA
0224  0000              0
0225  4236              STC BNKRET
0226  0062              SET I 2
0227  7771              -6
0230  1000              LDA
0231  0167              SPACE
0232  6237              JMP PUT
0233  0222              XSK I 2
0234  6230              JMP .-4
0235  6454              JMP RETBIN-2
0236  0000   BNKRET,    0
             /
             /
0237  0041   PUT,       SET I
0240  0000              0
0241  0500              IOB
0242  6041              TSF
0243  6241              JMP .-2
0244  0500              IOB
0245  6046              TLS
0246  6001              JMP 1
             /
0247  1020   CRLF,      LDA I
0250  0215              215
0251  6237              JMP PUT
0252  1020              LDA I
0253  0212              212
0254  6237              JMP PUT
0255  6163              JMP NXT
             /
0256  4301   CONVRT,    STC VAR
0257  1000              LDA
0260  0000              0
0261  4456              STC RETBIN
0262  1000              LDA
0263  0301              VAR
0264  1460              SAE I
0265  7777              7777
0266  0456              SKP
0267  6223              JMP BLANK          /TYPE BLANKS IF 4093
0270  0077              SET I 17
0271  7765              -12
0272  0076              SET I 16
0273  7765              -12
0274  0075              SET I 15
0275  7765              -12
0276  0074              SET I 14
0277  7765              -12
0300  1020              LDA I
0301  0000   VAR,       0
0302  0471              APO I
0303  6352              JMP K1024
```

```
0304  0241            ROL I
0305  0451            APO
0306  6331            JMP K3072
0307  1000            LDA
0310  0301            VAR
0311  1560            BCL I
0312  4000            4000
0313  4301            STC VAR
0314  1020            LDA I
0315  0011            11
0316  1140            ADM
0317  0017            17
0320  1020            LDA I
0321  0004            4
0322  1140            ADM
0323  0016            16
0324  1020            LDA I
0325  0002            2
0326  1140            ADM
0327  0014            14
0330  6372            JMP CONV-6
                /
0331  1020  K3072,    LDA I
0332  0002            2
0333  1157            ADM 17
0334  1020            LDA I
0335  0007            7
0336  1140            ADM
0337  0016            16
0340  1020            LDA I
0341  0003            3
0342  1140            ADM
0343  0014            14
0344  1000            LDA
0345  0301            VAR
0346  1560            BCL I
0347  4000            4000
0350  4301            STC VAR
0351  6372            JMP CONV-6
                /
0352  0241  K1024,    ROL I
0353  0471            APO I
0354  6372            JMP CONV-6
0355  1020            LDA I
0356  0004            4
0357  1140            ADM
0360  0017            17
0361  1020            LDA I
0362  0002            2
0363  1140            ADM
0364  0016            16
0365  1020            LDA I
0366  0001            1
0367  1140            ADM
0370  0014            14
0371  6372            JMP CONV-6
                /
0372  1000            LDA
0373  0301            VAR
0374  1120            ADA I
0375  0001            1
0376  0017            COM
0377  4003            STC 3
```

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

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

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

```
0663  0065            SET I 5
0664  7777            7777
0665  0066            SET I 6
0666  7777            7777
0667  0067            SET I 7
0670  7777            7777
0671  0070            SET I 10
0672  7777            7777
0673  0071            SET I 11
0674  0000            0
0675  0072            SET I 12
0676  6027  SAMTIM,   -1750
0677  1020            LDA I
0700  4100            4100            /1KC AND PRESET
0701  0500            IOB
0702  6132            CLLR
                      CLAB=6133
                      CLLR=6132
                      CLEN=6134
                      CLSA=6135
                      CLSK=6131
                      ION=6001
                      IOF=6002
0703  1020            LDA I
0704  0103  THREE,    103             /MOVEMENT OR CLOCK
0705  0500            IOB
0706  6134            CLEN            /ENABLE INPUT 3
0707  0500            IOB
0710  6135            CLSA            /CLEAR INTERUPT
0711  1020            LDA I
0712  0240            240
0713  0004            ESF             /LOCK OUT TTY
0714  0500            IOB
0715  6001            ION
0716  7020            JMP DISIT
            /
0717  1000  GETCHR,   LDA
0720  0000            0
0721  4756            STC CHRRET
0722  0072            SET I 12
0723  7776            DSCTBL-1!2000
0724  0070            SET I 10
0725  7767            -10
0726  1072            STA I 12
0727  0230            XSK I 10
0730  6726            JMP .-2
0731  0445            SNS 5
0732  6757            JMP SENSIT
0733  0500            IOB
0734  6031            KSF
0735  6731            JMP .-4
0736  0500            IOB
0737  6036            KRB
0740  1060  STRIP,    STA I
0741  0000  CHAR,     0
0742  1560            BCL I
0743  7700            7700
0744  0241            ROL 1
0745  1120            ADA I
0746  2020            CHRDIS!2000
0747  4003            STC 3
0750  1003            LDA 3
0751  1077            STA I 17
```

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

```
1050  1773              DSC I 13
1051  0223              XSK I 3
1052  7045              JMP .-5
1053  7023              JMP DISIT+3
1054  0000   DISRET,    0
             /
1055  4137   MOVED0,    STC BUFF1
1056  0204              XSK 4
1057  6000              JMP 0              /MOVED ALREADY
1060  0044              SET 4
1061  0011              11                 /MOVE REACTION
1062  6000              JMP 0
             /
1063  7727   TIMER,     -50
1064  4132   MOVED1,    STC BUFF2
1065  0205              XSK 5
1066  6000              JMP 0
1067  0045              SET 5
1070  0011              11
1071  6000              JMP 0
             /
1072  4133   MOVED2,    STC BUFF3
1073  0206              XSK 6
1074  6000              JMP 0
1075  0046              SET 6
1076  0011              11
1077  6000              JMP 0
             /
1100  4134   MOVED3,    STC BUFF4
1101  0207              XSK 7
1102  6000              JMP 0
1103  0047              SET 7
1104  0011              11
1105  6000              JMP 0
             /
1106  4135   MOVED4,    STC BUFF5
1107  0210              XSK 10
1110  6000              JMP 0
1111  0050              SET 10
1112  0011              11
1113  6000              JMP 0
             /
                        SEGMNT 2
                        *20
0020  0077              SET I 17
0021  7677              -100
0022  7000              JMP QAINIT
0023  0043              COMNT
0024  0033              ANSWER
0025  0237              XSK I 17
0026  6022              JMP .-4
0027  0067              SET I 7
0030  3777              3777
0031  0600              LIF 0
0032  6557              JMP QSTRT
0033  0000   ANSWER,    0
0034  0000              0
0035  0000              0
0036  0000              0
0037  0000              0
0040  0000              0
0041  0000              0
0042  0000              0
```

```
1164    0043  0610
1164    0044  0522
1164    0045  0540
1164    0046  2705
1164    0047  4007
1164                COMNT,  TEXT ZFHERE 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    AGAIN\Z
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 OUT\Z
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          HIT!2000
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
```

```
0131  0000  FIN4,   0
0132  0644          LDF 4
0133  1000          LDA
0134  0105          CSAV
0135  1067          STA I 7
0136  0207          XSK 7
0137  0456          SKP
0140  6224          JMP END
0141  1000          LDA
0142  0111          HSAV
0143  1067          STA I 7
0144  0207          XSK 7
0145  0456          SKP
0146  6224          JMP END
0147  1000          LDA
0150  0115          FIN1
0151  1067          STA I 7
0152  0207          XSK 7
0153  0456          SKP
0154  6224          JMP END
0155  1000          LDA
0156  0121          FIN2
0157  1067          STA I 7
0160  0207          XSK 7
0161  0456          SKP
0162  6224          JMP END
0163  1000          LDA
0164  0125          FIN3
0165  1067          STA I 7
0166  0207          XSK 7
0167  0456          SKP
0170  6224          JMP END
0171  1000          LDA
0172  0131          FIN4
0173  1067          STA I 7
0174  0207          XSK 7
0175  0456          SKP
0176  6224          JMP END
0177  0461          SNS I 1
0200  6224          JMP END
0201  0600          LIF 0
0202  6557          JMP OSTRT
                /
0203  0057  CRLF1,  SET 17
0204  0000          0
0205  1020          LDA I
0206  0215          215
0207  6214          JMP PUT1
0210  1020          LDA I
0211  0212          212
0212  6214          JMP PUT1
0213  6017          JMP 17
                /
0214  0056  PUT1,   SET 16
0215  0000          0
0216  0500          IOB
0217  6041          TSF
0220  6216          JMP .-2
0221  0500          IOB
0222  6046          TLS
0223  6016          JMP 16
                /
                /
```

```
0224  0644  END,     LDF 4
0225  6203           JMP CRLF1
0226  0061           SET I 1
0227  3777           3777
0230  0016  SETIT,   NOP
0231  0063           SET I 3
0232  7737           -40
0233  6203           JMP CRLF1
0234  6203  PUTIT,   JMP CRLF1
0235  1021           LDA I 1
0236  6214           JMP PUT1
0237  1020           LDA I
0240  0240           240
0241  6214           JMP PUT1
0242  1021           LDA I 1
0243  6214           JMP PUT1
0244  1020           LDA I
0245  0240           240
0246  6214           JMP PUT1
0247  1020           LDA I
0250  0240           240
0251  6214           JMP PUT1
0252  0062           SET I 2
0253  7773           -4
0254  1021           LDA I 1
0255  0600           LIF 0
0256  6256           JMP CONVRT
0257  0222           XSK I 2
0260  6254           JMP .-4
0261  0462           SNS I 2
0262  0000           HLT
0263  0223           XSK I 3
0264  6234           JMP PUTIT
0265  0201           XSK 1
0266  6230           JMP SETIT
0267  0000           HLT
                     NOLIST
                     SEGMNT 3
                     *0
            /
0000  0000  DSCTBL,  0
0001  0000           0
0002  0000           0
0003  0000           0
0004  0000           0
0005  0000           0
0006  0000           0
0007  0000           0
            /
0010  0000  HITTBL,  0
0011  0000           0
0012  0000           0
0013  0000           0
0014  0000           0
0015  0000           0
0016  0000           0
0017  0000           0
0020  4020  CHRDIS,  4020
0021  2055           2055        /?
0022  4477           4477
0023  7744           7744        /A
0024  5177           5177
0025  2651           2651        /B
```

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			/		

```
0122 0240  SNSCOD, 240
0123 0311          311
0124 0305          305
0125 0323          323
0126 0301          301
0127 0314          314
0130 0317          317
0131 0325          325
0132 0316          316
0133 0324          324
0134 0303          303
0135 0320          320
0136 0322          322
0137 0315          315
0140 0310          310
0141 0304          304
           /
0142 0000  TTYCOD, 0
0143 0004          4            /A
0144 0000          0            /B
0145 0012          12           /C
0146 0017          17           /D
0147 0002          2            /E
0150 0000          0            /F
0151 0000          0            /G
0152 0016          16           /H
0153 0001          1            /I
0154 0000          0            /J
0155 0000          0            /K
0156 0005          5            /L
0157 0015          15           /M
0160 0010          10           /N
0161 0006          6            /O
0162 0013          13           /P
0163 0000          0            /Q
0164 0014          14           /R
0165 0003          3            /S
0166 0011          11           /T
0167 0007          7            /U
0170 0000          0            /V
0171 0000          0            /W
0172 0000          0            /X
0173 0000          0            /Y
0174 0000          0            /Z
           /
           /
           /
           /PROGRAM ACCEPTS STIMULUS CODE FROM
           /EITHER THE TTY (IF SENSE SWITCH 5 IS UP) OR VIA A
            OCTAL CODE
           /VIA SENSE LINES 5,6,7,10, AND 11
           /(IF SNS 5 IS DOWN). A GROUND TO SXL 12
           /INDICATES THAT SENSE LINE  (SCODE) CODIFICATION IS
            COMPLETE
           /
           /DISPLAY IS MAINTAINED AS LONG AS SENSE LINE
           /12 IS GROUNDED
           /PROGRAM THEN MONITORS THE RESPONSE CODE
           /VIA SXL 0-4 FOR CORRESPONDANCE TO THE S-CODE
           /THE ALPHA EQUIVALENT OF THE S-CODE IS DISPLAYED
           /ON TOP, THE R-CODE IS DISPLAYED ON THE BOTTOM.
           /1-DISIT
           /2- UNUSED
```

```
/3-SCRATCH
/4-UNUSED
/5-UNUSED
/6-UNUSED
/7-UNUSED
/10 SUM AND MATCH POINTER
/11-MSEC TIMER
/12- NUMBER OF CHARACTERS
/13-DISIT R-CODE
/14-DISIT S-CODE
/15 NUMBER OF CHARACTERS
/16-R-CODE
/17-S-CODE
/TESTS FOR ANY R CODE, SETS TIMER
/SETS RELAYS
/SHOWS REINFORCEMENT
/
/
/WIRING CONFIGURATION
/
/
/        IN CPU ROOM
/
/RESPONSES COME TO CPU ROOM VIA COAX A-F
/THESE ARE CONNECTED VIA PATCH CORD TO
/COMPARATORS 5-10
/
/REFERENCE IS ADJUSTED TO GIVE PULSE OUT
/OF COMPARATORS WHEN THE SELECTED LEVEL IS
/EXCEEDED.
/
/COMPARATOR 5 POS OUT IS CONNECTED TO DIODE GATE A
/           6 POS OUT IS CONNECTED TO DIODE GATE B
/           7 POS OUT IS CONNECTED TO DIODE GATE C
/          10 POS OUT IS CONNECTED TO DIODE GATE D
/OUTPUT OF THESE GATES IS PATCHED TO INPUT 3
/SET SOURCE TO - AND THRESHOLD TO JUST +
/
/SENSE LINE 5 TO HUMAN 7
/           6          8
/           7          9
/          10         10
/
/HUMAN 5 TO COMPARATOR 2-    POS OUT OF 2 TO INPUT
1
/+ SOURCE, +THRESHOLD
/VERIFY
/
/K0 IS CONNECTED TO PATCH 1 AT BOTTOM OF CPU
/K1 IS CONNECTED TO PATCH 2 AT BOTTOM OF CPU
/K2 IS CONNECTED TO PATCH 5
/K3 IS CONNECTED TO PATCH 6
/K4 IS CONNECTED TO PATCH 7
/K5 IS CONNECTED TO PATCH 8
/
//
/         IN HUMAN ROOM
/
/VERIFY CONNECTIONS TO CPU INTERFACE
/GREEN TO 1 HI
/BROWN TO 5 HI
/RED TO 6 HI
/ORANGE TO 7 HI
```

```
/YELLOW TO 8 HI
/
/WHITE TO 8 LOW
/THE LOWS OF 1, 2, 5, 6, 7, AND 8 ARE
/TIED TOGETHER
/
/SOUNDPROOF ROOM CONNECTIONS
/OSCILLATOR PATCH CORD TO HEAD SET IN ROOM
/
/OPERATING INSTRUCTIONS
/
/TURN POWER STRIP TO ON
/     THIS APPLIES POWER TO ALL POWER SUPPLIES
/                          THE POLYGRAPH
/                          THE TAPE TIMER
/                          THE TAPE MARKER
/
/YOU MUST TURN ON THE TAPE MARKER WHEN READY TO RN
/
/S CODE, R CODE, AND AUDITORY R CODE PRESENTATIONS
ARE CONTROLLED
/AS FOLLOWS
/
/  TO DISABLE AUDITORY FEEDBACK, UNPLUG OSC CONT □
 PLUG
/  TO DISABLE S CODE PRESENTATION, PLACE S CODE SW
TCHES UP
/  TO DISABLE R CODE PRESENTATION, PLACE R CODE SW
TCHES UP
/
/SNS 1 DOWN FORCES PRINTOUT OF ALL PREVIOUS TRIALS
/THIS SPACE IS RESERVED FOR DANISH COMMENTS

NO ERRORS

AASTRT 0615
ANSWER 4033
BLANK  0223
BNKRET 0236
BUFF1  0137
BUFF2  0132
BUFF3  0133
BUFF4  0134
BUFF5  0135
CHAR   0741
CHRDIS 6020
CHRRET 0756
CLAB   6133
CLEN   6134
CLKSET 0576
CLLR   6132
CLSA   6135
CLSK   6131
CNVCMP 0422
COMNT  4043
CONV   3400
CONVRT 0256
CRLF   0247
CRLF1  4203
CSAV   4105
DISIT  1020
DISRET 1054
DSCTBL 6000
```

```
END     4224
ERRORS  0544
FIN1    4115
FIN2    4121
FIN3    4125
FIN4    4131
FOUR    0022
GETCHR  0717
GETKBD  5521
HIT     0630
HITTBL  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
PUT1    4214
QAB     5004
QACA    5015
QACHAR  5655
QACKLF  5621
QACNTR  5604
QAD     5026
QAE     5050
QAEXIT  5635
QAF     5516
QAG     5062
QAH     5114
QAI     5131
QAINIT  5003
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

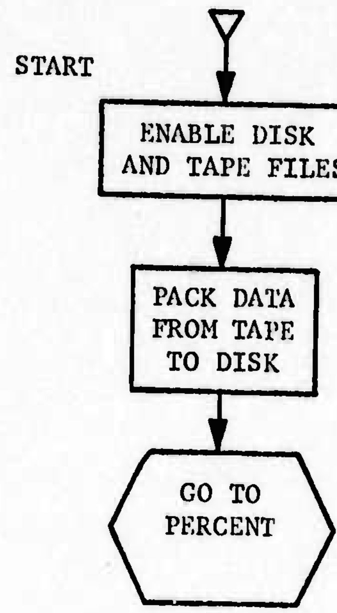
FUNCTION: Transfer S code, R code, and latency data from tape and store on disk in a packed format.

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 %4.0
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,$PERCENT,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

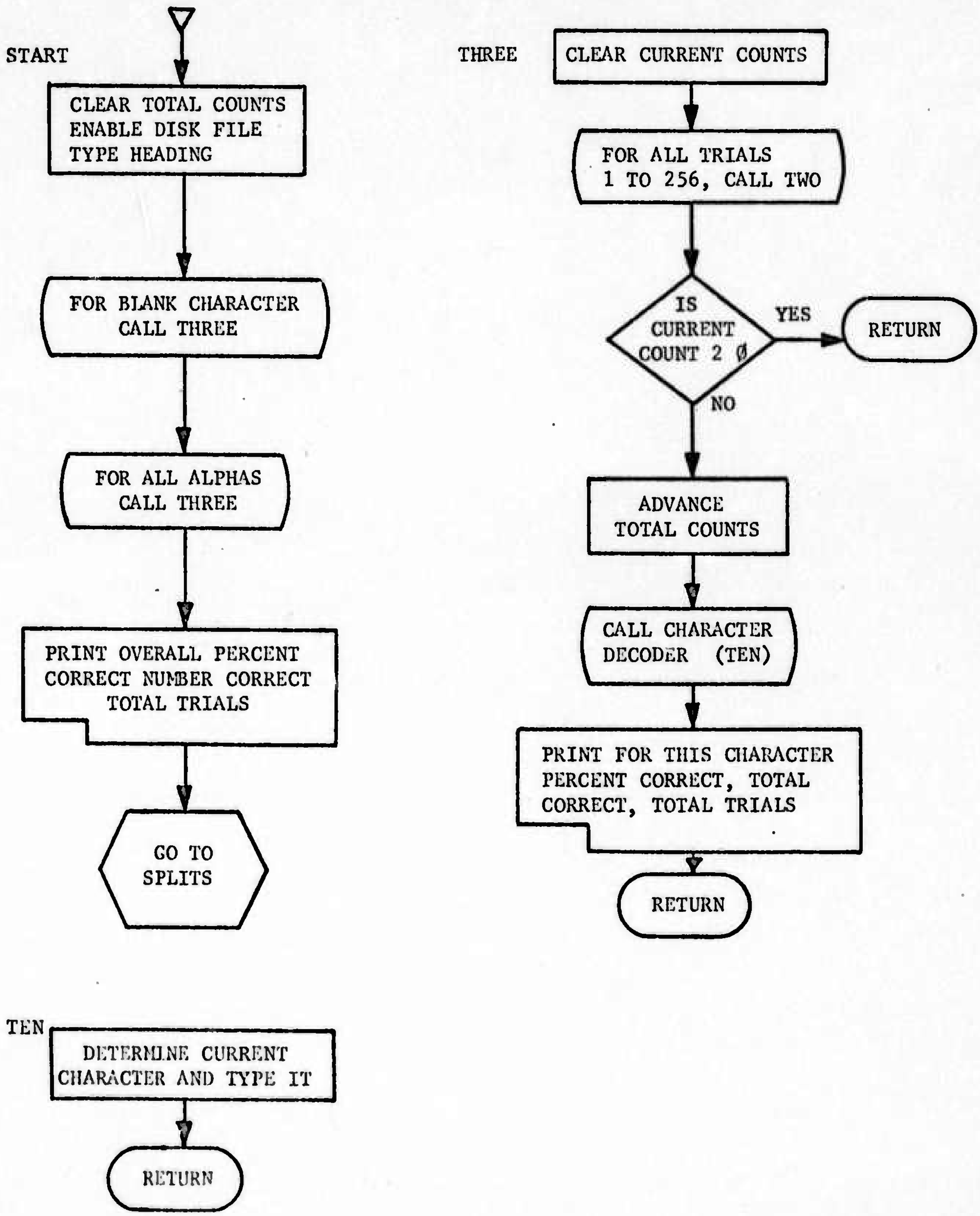
FUNCTION: Determine the percent of responses which were correct for each of 16 characters.

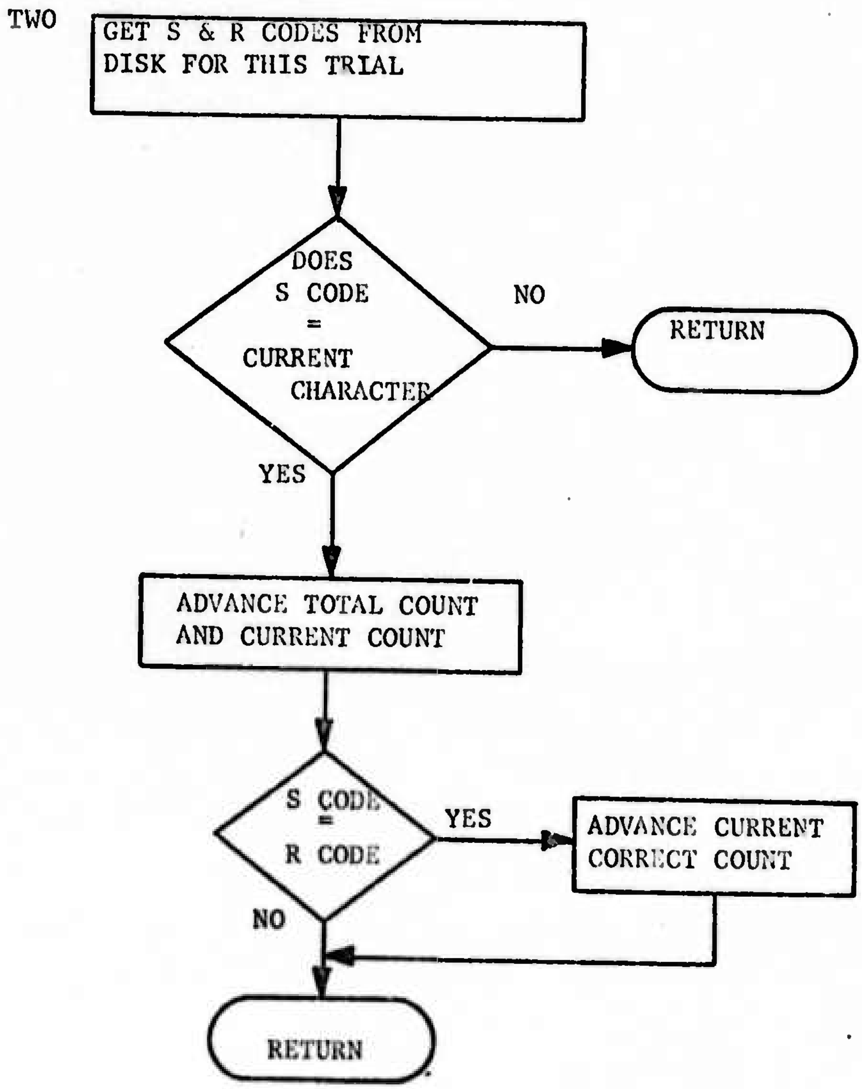
LANGUAGE: FOCAL-12

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 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: 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 %4.0
01.06 O T;S N3=0;S N4=0
01.10 L O,F1,I,#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,!;O S
01.90 L G,$SPLITS,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 %4.1,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

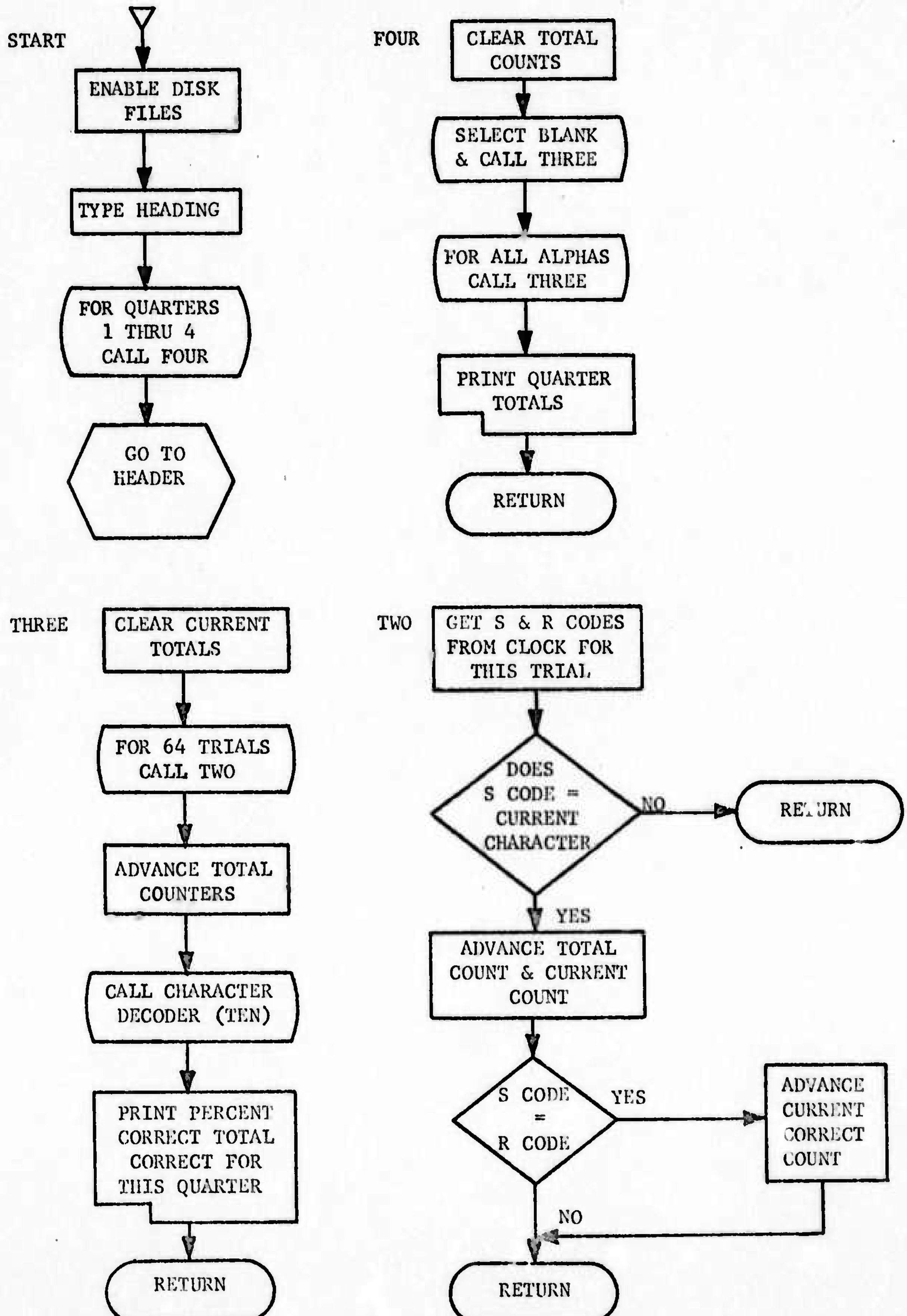
FUNCTION: Determine the percent of responses which were correct for each of 16 characters in quarters (64) of the total session.

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 %4.0
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,!;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 %4.1,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

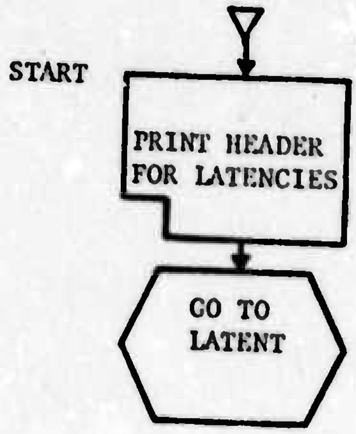
FUNCTION: Print heading for latency analysis.

LANGUAGE: FOCAL-12

DESCRIPTION: Same as function.

PROGRAM CALLED: LATENT

FLOWCHART FOR HEADER



```
C FOCAL-12

01.10 O T
01.15 T " PERCENTS                          MUSCLES",!
01.20 T "                             RL       RT"
01.21 T "    LT      LL",!
01.90 O S
01.99 L G,$LATENT,13
*
```

PROGRAM NAME: LATENT

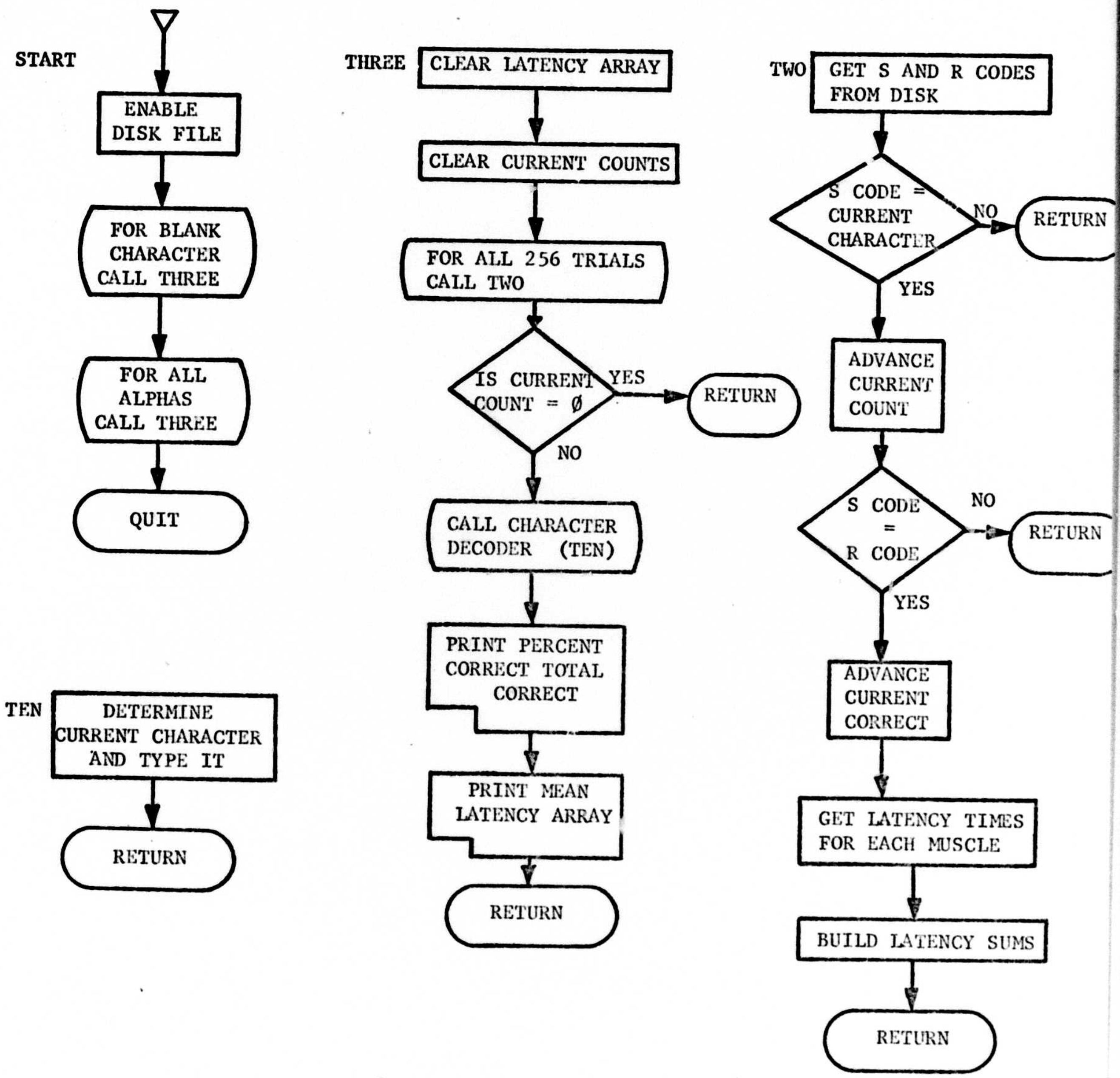
FUNCTION: Determine average latency to responsd for each muscle associated with a character.

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,#C01,14
01.20 S C=160;D 3
01.21 F C=193,215;D 3
01.85 Q

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 !,!

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)10.6;
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
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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.

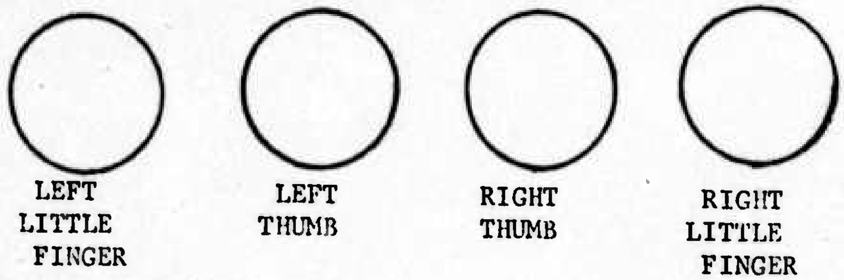
The signal will consist of a pattern of lights which are arranged in a horizontal row. There is a total of four lights, and the pattern may consist of any combination of lights from "all off" to "all on".

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.