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COMMUNICATION BY ELECTRICAL STIMULATION OF THE SKIN.(U)
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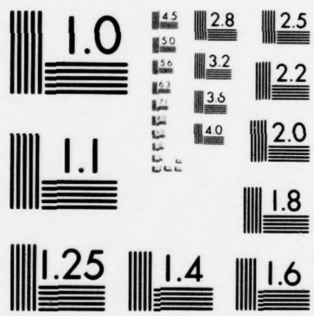
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University of Louisville

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Abstract

1. Preparing Institution: University of Louisville - Department of Psychology

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3. Principal Investigator: Emerson Foulke, Ph.D.

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For the past two years, a project has been underway to construct an electro-cutaneous code, to teach this code to a group of subjects, and to evaluate its usefulness. A code was constructed in which stimuli were varied in three stimulus dimensions. There were ten loci, the ten fingertips, two stimulus durations, and two stimulus intensities. Each signal in the code was characterized by one of the ten loci, one of the two durations, and one of the two intensities. This arrangement resulted in the stimulus alphabet of 40 signals. Twenty-six of these signals were paired with the 26 letters of the alphabet. The remaining signals were paired with punctuations and with frequently recurring letter groups such as "ing", "er", and "and".

Subjects have received training in the reception of this code for over a year. On the reception of unfamiliar prose, a few subjects have shown word rates as high as 20 words per minute. Three of these better subjects were each given fifteen random permutations of the code signals, and their performance was summarized in a stimulus - response matrix. The information analysis performed on this matrix yielded an H_t of 4.8061.

Work was also begun on another electro-cutaneous code in which signals were formed from patterns of simultaneously applied dc pulses. Although this work is still in the pilot stage, preliminary results suggest signals formed in this way may be much better than those formed by combining stimulus dimensions with respect to reaction time. Reaction times to signals in the locus pattern code appear to be two or three times as short as the reaction times to signals in the tri-dimensional code.

Note: Copies of this report are filed with the Armed Services Technical Information Agency, Arlington Hall Station, Arlington 12, Virginia, and may be obtained from that agency by qualified investigators working under Government contract.

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Communication by Electrical Stimulation

of the Skin

Report of Progress for the Period November 1, 1962 - October 31, 1963

In the research, the account of which follows, a sinusoidal electric current at 200 cps is applied to the skin of the subject. The locus, frequency, intensity and duration of this stimulus are under the control of the experimenter. Sequences of electrical stimuli, specified with respect to these dimensions, can be delivered manually, or automatically at predetermined rates. For a description of the apparatus by means of which this is accomplished, the reader is referred to the report of progress on this project covering the period November 1, 1961 to October 31, 1962.

Small stainless steel discs are used as electrodes. Electrode diameter is approximately 16 millimeters. These electrodes were cut from Nicor print paddles. A small stub was left protruding from the back side of each disc for the purpose of making electrical connection. Five electrodes were secured to each of two boards, one board for each hand. The electrodes are so located that when the hand is laid flat upon the board palm down, the fingertips rest on the electrodes while the palm of the hand makes contact with the stainless steel passive electrode, approximately 7.7 centimeters on a side. The position of each finger electrode is sufficiently adjustable to meet individual requirements. Electrode paste has not been used. The experience of Gibson and others at Carnegie Institute of Technology, (Personal Communication) suggests that when non-corrosive electrodes such as those described here are used, little or no advantage is gained by the use of electrode paste. It was judged that in the present case, its use could safely be dispensed with.

In addition, some research has been undertaken in which a d.c. pulse is used as the stimulus. A description of the apparatus by means of which this is accomplished will be given at the appropriate point in the narrative.

The Code

The major activity during this reporting period has been the training of subjects to receive electro-cutaneous three-dimensional code that requires the subject to make absolute identifications of ten loci, two durations, and two intensities.

Duration: The two stimulus durations employed in this code are 20 milliseconds and 150 milliseconds. Choice of these durations introduces an additional basis for discrimination. Over most of the stimulus duration range, the quality of the experienced sensation does not depend upon the duration of the stimulus. However, when stimulus duration is short enough, the quality of sensation changes from that of an electric shock to a sort of tapping sensation. When the stimulus is very brief, say 1 millisecond, the stimulus does not feel like an electric shock at all. The 20 millisecond stimulus used as the shorter of the two stimuli in the project is brief enough so that it is experienced more as a tap than as a shock. Use of a stimulus of still shorter duration would have made this difference in sensation more apparent, but with shorter durations there is also a shift upward in the absolute threshold for intensity, and intensity is one of the dimensions used in the code. The 20 millisecond duration was chosen as a result of informal exploration. It appeared to be a reasonable compromise affording the advantage of the change in sensation that comes with briefer stimulation, without too radical a shift in the stimulus intensity threshold. Since that time, there has been a more careful determination of the relation between stimulus duration and the absolute threshold for stimulus intensity.

The curve in Figure 1 describes this relationship. The values used in plotting this curve are averages of values obtained from three subjects.

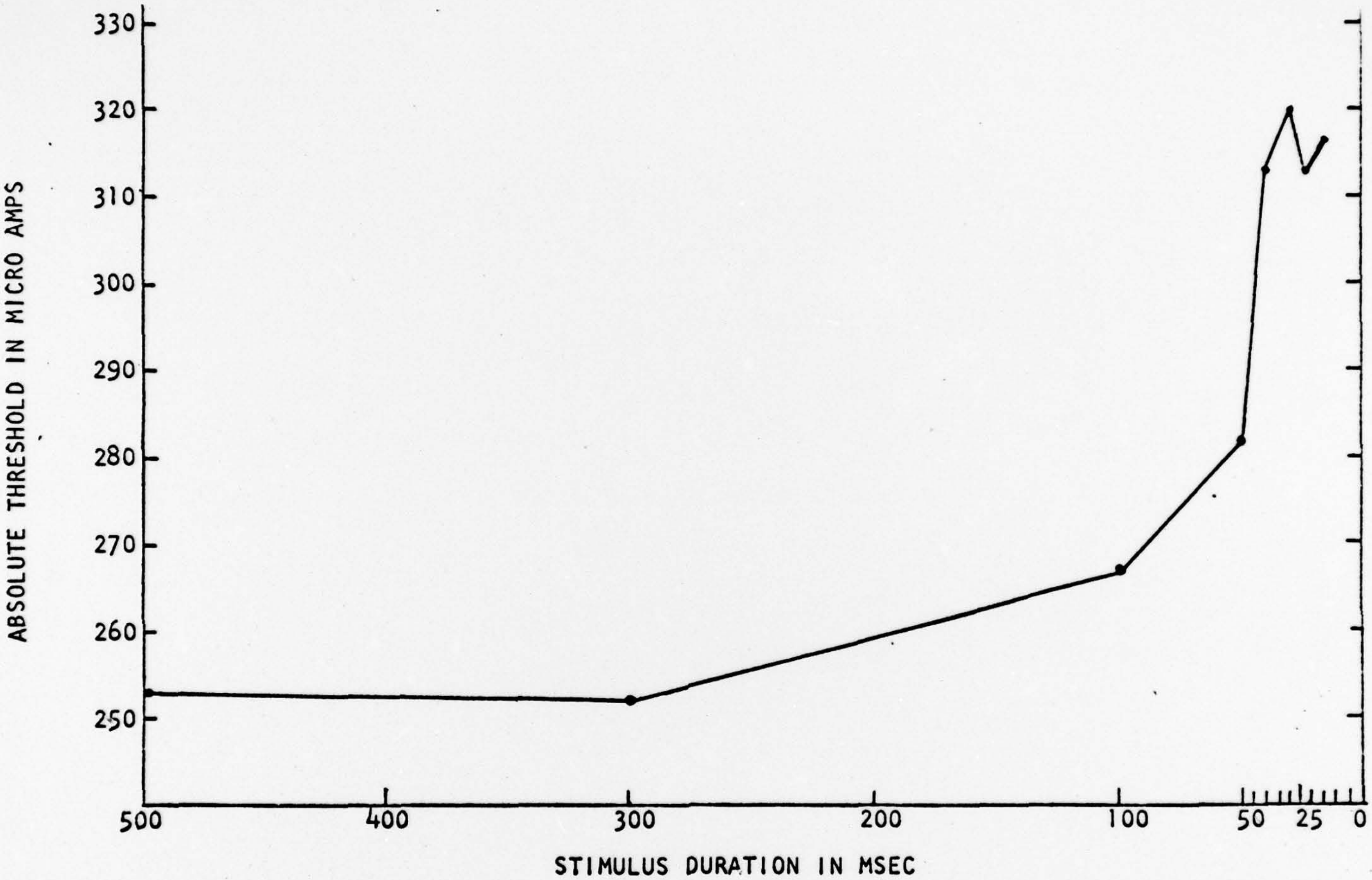

Fig. 1. Electro-Cutaneous Absolute Thresholds as a Function of Stimulus Duration

It is apparent that at stimulus durations of 20 milliseconds there has already been a considerable elevation of the absolute intensity threshold. This means that in the present code the intensities of the 20 millisecond stimuli would have to be increased considerably in order for them to be perceived as equal in intensity to the 150 millisecond stimuli. Since stimuli were not adjusted for equal apparent intensity at the two durations employed, differences in apparent intensity probably also influenced subjects' absolute identification of stimulus durations.

Intensity: Initially an effort was made to adjust the two signal intensities so that each was a given percent of the subject's absolute threshold. However, the subject's threshold varied enough from day to day so that it was necessary to make a new determination of threshold at the beginning of each training session. Also, subjects reported that a difference between two intensities which was clearly perceptible one day, was not clearly perceptible the next. The solution of these problems for the present has been to allow each subject to adjust the two intensities for himself so that they are easily discriminable and so that the stronger of the two is not uncomfortable. The explanation of the variability just mentioned may be due in part to slight differences in electrode placement and in the resistance at the junction of electrode and skin. In this project, no electrode paste has been used and electrode sites have been given no special preparation. Of course, the subject himself contributes to this variability. The problem of variability is currently under investigation by Mr. James Sheridan, a graduate student at the University of Louisville, and there will be more to report on this matter later.

Locus: The loci chosen for application of signals in a code of this sort may depend upon factors relevant to the particular situations in which the code is to be used. In some situations it may be necessary or desirable to keep the hands free to perform essential tasks. In this case, other areas of the body, such as the chest or back, might be used. In other situations, it might be desirable to imbed electrodes in the controls of apparatus that operators manipulate. In this case, the fingertips might be stimuli were not adjusted for equal apparent intensity at the two durations employed, differences in apparent intensity probably also influenced subjects' absolute identification of stimulus durations.

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Frequency: As mentioned in the previous report, it is planned to test a code that is like the one now under test except that frequency is substituted for intensity as a code dimension. In such a code, intensity could be held constant at a level that was clearly perceptible, yet well below the pain threshold. The modification in code sending apparatus required to send such a code has been completed. However, before this test can be conducted, it will be necessary to determine the relationship between frequency discrimination and stimulus duration. Plans for this research are now underway.

Code Construction: The use of ten loci, two durations, and two intensities should result in a code containing 40 characters. The code used in this project actually contains 39 characters, since one of the relays ordered for construction of the apparatus was not delivered.

Twenty-six of the 39 signals have been assigned to the 26 letters of the alphabet. A reasonable approach would be to assign the least confusing or most easily learned signals to the most frequently occurring letters. However, very little evidence was available to mediate such decisions. It was decided instead to make arbitrary assignments of signals to letters initially. When subjects have received considerable training on the present code, their confusion matrices can be analyzed and any consistencies regarding confusions that are revealed can be used in a more rational assignment of signals to characters.

The remaining signals have been used for punctuation marks and for frequently recurring letter groups such as: "er", "ing", "for". One of the signals has been used for a number sign. When this signal is presented the subject interprets all subsequent signals as numbers until there is an empty interval of the sort used to indicate separation between words. With this arrangement, it is possible to use signals that normally stand for letters or contractions as numbers. This achieves a needed symbol economy. Appendix A shows the code characters and describes the signal associated with each character.

In addition to the contractions, many abbreviations of common words have been employed. These abbreviations are the ones that have been standardized in the braille code. In most cases the abbreviations stand for most frequently occurring words. (see Appendix. B for a list of abbreviations.)

Learning the Code

Before commencing training proper, subjects are allowed to experience the electrical stimulus and are permitted to manipulate the control that regulates its intensity. In most cases, this procedure has sufficed to calm their apprehension about receiving painful shocks.

At the beginning of each session, the intensities of stimuli are adjusted so that they are of equal apparent intensity at all ten fingertips.

This is accomplished by means of variable resistance in the lead to each electrode. Then, the level of the stronger of the two stimulus intensities and the difference between stimulus intensities is set. These adjustments are made by the experimenter at the direction of the subject.

In the case of the first few people who received training, each subject was acquainted with the signals standing for the first eight letters of the alphabet. He was then given learning trials composed of these signals. When a signal was presented, the subject responded by pronouncing the letter that he believed to be appropriate. The experimenter then provided knowledge of results by pronouncing the correct letter. The time elapsing between trials was no greater than the time elapsing between signals within a trial. With this arrangement, subjects cannot structure the learning task according to trials, and hence cannot use the knowledge of letters that have already been used in a trial to alter their estimation of probabilities of signal occurences in the remainder of the trial. The order of signals in each trial was a random permutation of eight.

The subject was brought to a criterion of near - perfect performance. Then, he was introduced to the signals standing for the next eight letters and was brought to a similar criterion of performance. In this manner, the 26 letters and 13 remaining symbols were learned. Review of previously learned associations was interspersed throughout. When more than one group of letters had been mastered, review trials were composed of all letters that had been learned. The length of these review trials depended upon the number of letters learned and, near the end of this phase, they consisted of all 39 characters.

Subjects learned eight character trials so easily that it was decided to increase trial length and, thereafter, the 39 code signals were divided into three groups of thirteen signals per group. This modification has achieved the desired expedition of the acquisition phase.

Measures of Learning: Two measures of learning have been taken; errors per trial, and reaction time, or the time elapsing between the presentation of the signal and subjects' response to it. Reaction time has been determined in the following manner: pressing any key on the manual code sending keyboard also closes a microswitch connected in the clutch circuit of a Standard Timer, Type S-1. Thus, when the experimenter presses the combination of keys required for any code signal, the timer is started. The experimenter holds the keys down until he hears the subject's response. Release of the keys opens the microswitch and stops the timer. Reaction time, measured in this way, includes the associative reaction time of the subject and the simple auditory reaction time of the experimenter. The simple auditory reaction times of the two people who have served as experimenters were determined, and were found to be .14 seconds and .15 seconds. (For the tabled observations of these reaction times, see Appendix C.) One might consider correcting subjects' measured reaction times to signals by subtracting from them the experimenter's simple auditory reaction time. However, because of the apparatus used to deliver signals, there is an appreciable lag between the operation of the keyboard used to send signals and the actual occurance of a signal. Although this lag has not been measured precisely, it should cancel to a considerable extent the influence of the experimenter's simple reaction time upon the subject's measured reaction time. The reaction times that are presented in later pages are, therefore, the reaction times read directly from the face of the Standard Timer.

Results

The primary aim in this project has been to teach subjects an electrocutaneous code. Since there has been little previous relevant experience in codes of this sort, there has been considerable flexibility regarding training procedures. Modifications in procedure have been made repeatedly as indicated by experience. Since it has been necessary to involve subjects in the project for long periods of time, we have had to contend with occasional loss of subjects. Other subjects have had to rearrange their schedule of sessions from time to time. Consequently, the subjects in training at any given time cover a wide range of code proficiency. Because much of what has been done could not be carried out in accordance with the formal requirements of an experiment, it is not possible to make the comparisons or draw the conclusions that such experiments permit. Many of the relationships to be suggested are based upon the impressions conveyed by curves without the confirmation of statistical tests of significance. Many curves are presented that describe the performance of single subjects. In most cases it has not seemed advisable to develop generalized curves by averaging the performance of several subjects, since subjects often differed considerably with respect to the kind and amount of training experiences afforded them. Also many curves describing the performance of individuals have been presented in order to convey a notion of the between subject and within subject variability that has been characteristic throughout the course of training.

Code Learning as Manifested by Errors: When correct responses per trial are taken as the measure of learning, it appears that learning took place fairly rapidly. However, there was considerable variability between subjects and within the performance of individual subjects from trial to trial. Figure 2 shows the relationship between number of trials and percent of responses that were correct per trial for four subjects.

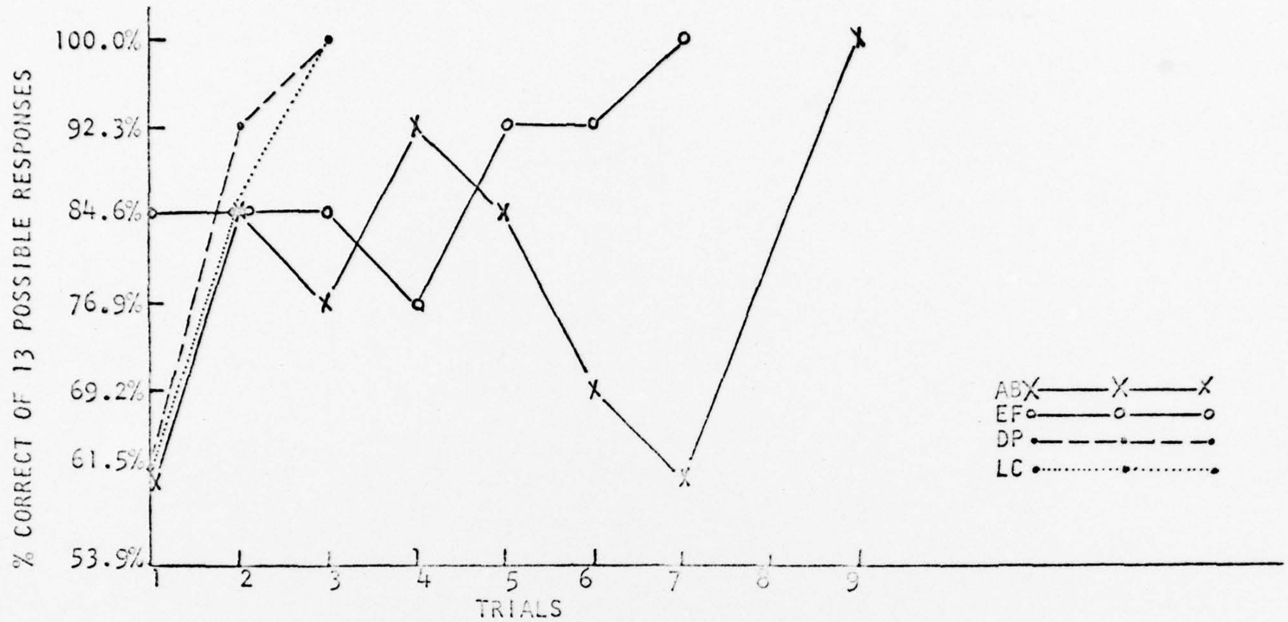


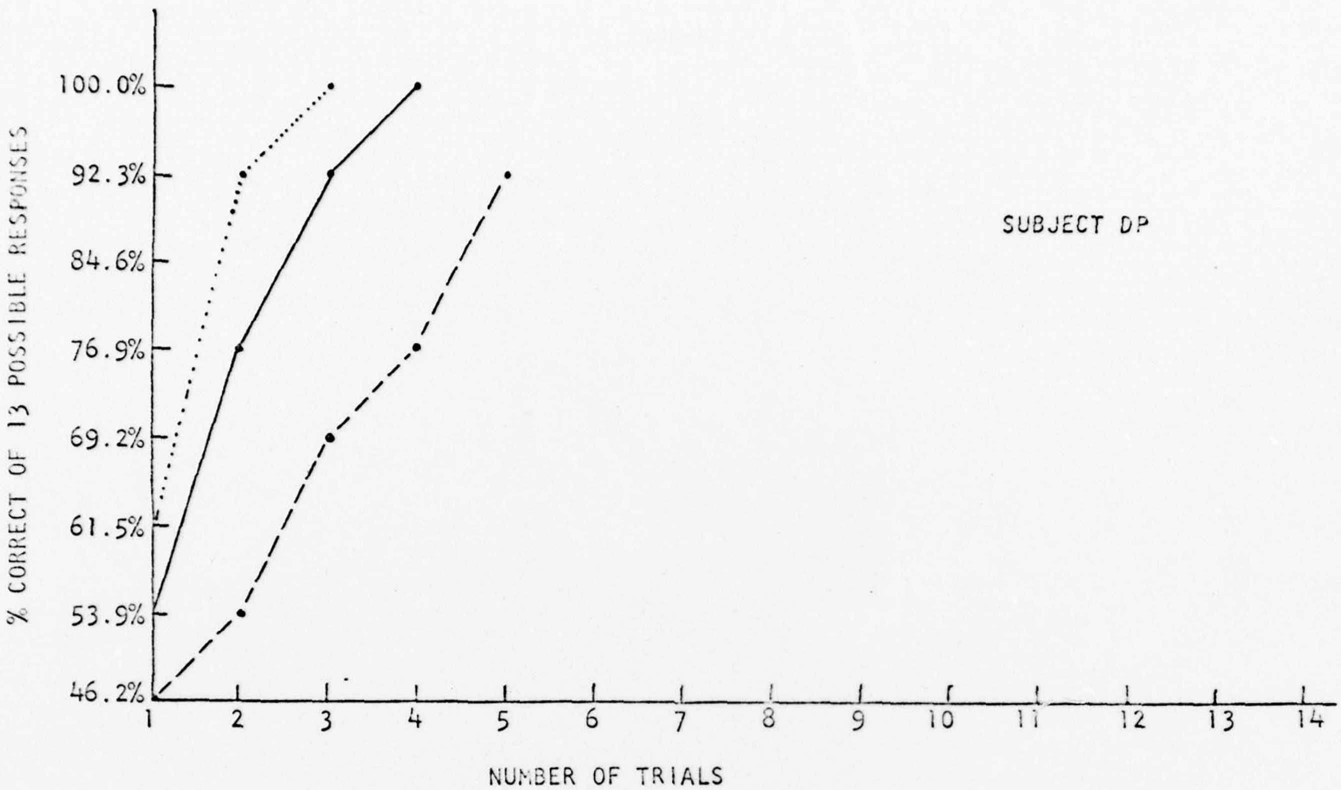
Fig. 2. Original Acquisition of "A" through "M" for Four Subjects.

The items in these trials were the letters "A" through "M". This variability is doubtless attributable to a variety of sources. One source that deserves special mention has to do with the manner in which subjects approached the task. In introducing subjects to the task, the experimenter avoided any mention of the principles according to which the code was constructed. It was hoped that this caution would promote subitization by discouraging an analytical set toward the learning task and by encouraging a more immediate association of signals and their letters. In other words, the hope was that the subjects would learn to identify a given signal as, for instance, "A", because it felt like "A", and not because "A" was the short strong signal applied to the forefinger of the right hand. However, the precaution was not adequate.

Some subjects grasped the rationale for the construction of the code during the first session and proceeded to analyze the composition of signals with respect to the three stimulus dimensions employed. The concept of subitization was explained to a few of the subjects and they were encouraged to strive for the kind of unmediated S - R association desired. However, they showed little success in their efforts to abandon an analytical approach. The inability to achieve subitization has been a persistant problem and more will be said about it later.

An impression of the variability from trial to trial may be gained from the graphs shown in Figure 3, (following two pages). Each of these graphs is a plot of the data from a different subject. The three curves express the relation between trials and percentage of responses that were correct, and refer respectively to trials composed of the letters "A" through "M", "N" through "Z", and the punctuations and contractions. Although the general trend of these curves is upward, their direction is reversed in many instances. It is also clear that in many cases, even after errorless performance has been achieved, there has been considerable subsequent variability and decrement in performance.

Another outcome shown in these graphs is deserving of mention. In three of the four cases shown in Figure 3, the letters "A" through "M" and "N" through "Z" were learned more rapidly than were the punctuations and contractions. This is probably because letters constitute a much more familiar response language for the subject than do the punctuations and contractions. The contractions have remained troublesome for the subjects throughout the course of training. This problem will be referred to again under subsequent headings.



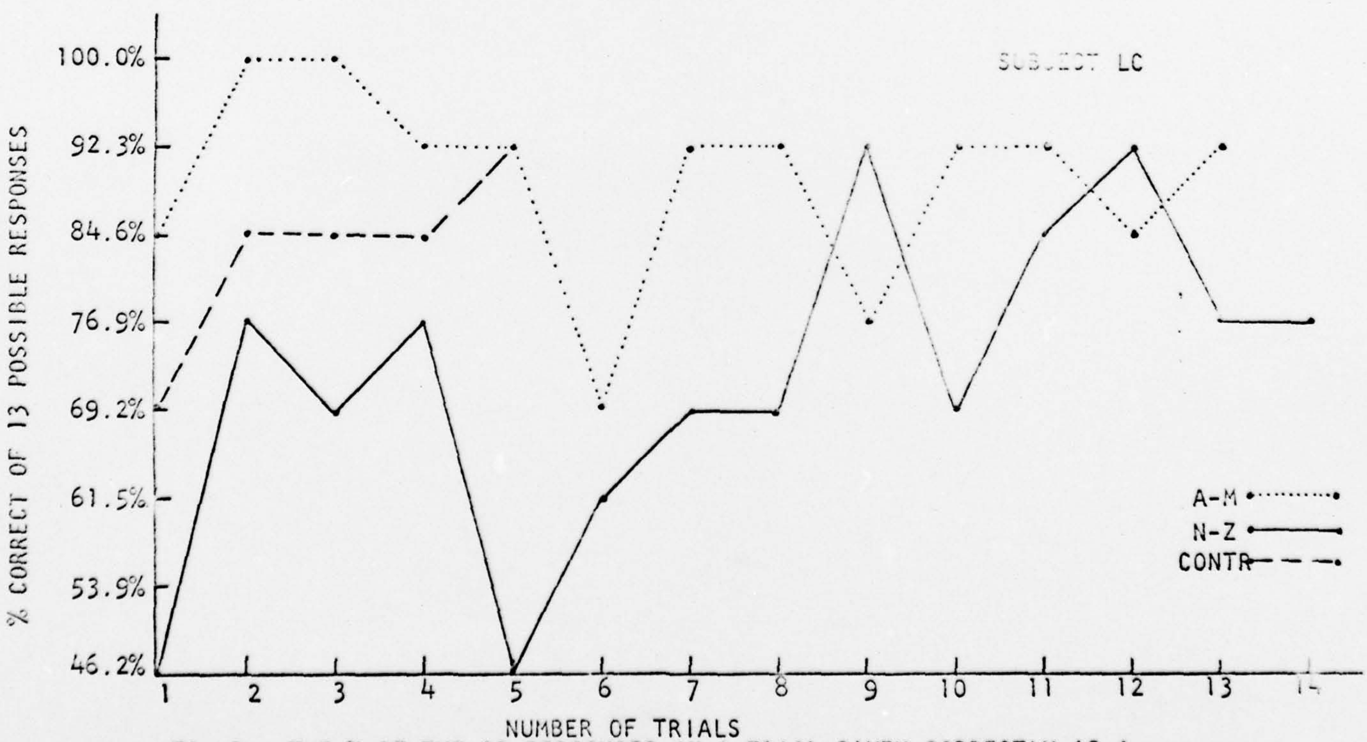
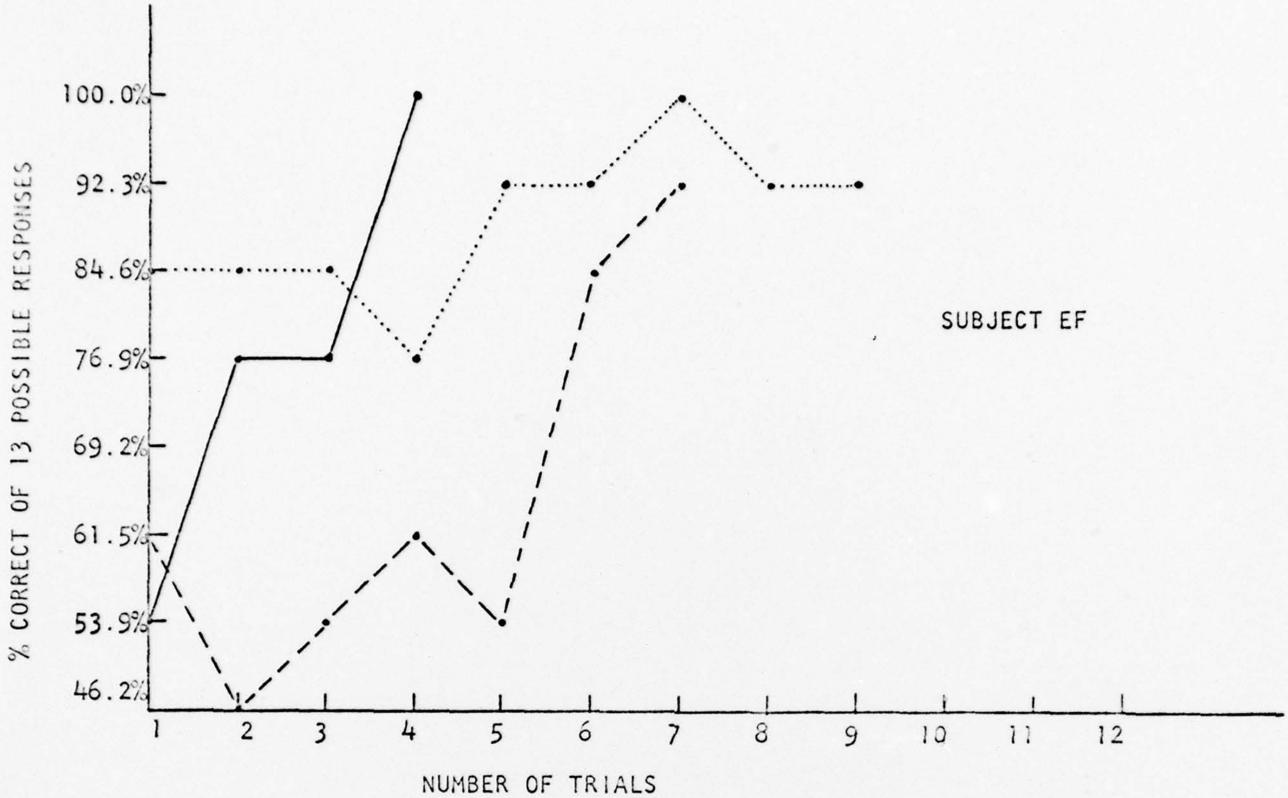


Fig.3a. THE % OF THE 13 RESPONSES IN A TRIAL GIVEN CORRECTLY AS A FUNCTION OF NUMBER OF TRIALS FOR LETTERS A-M, LETTERS N-Z, AND THE 13 CONTRACTIONS AND PUNCTUATIONS



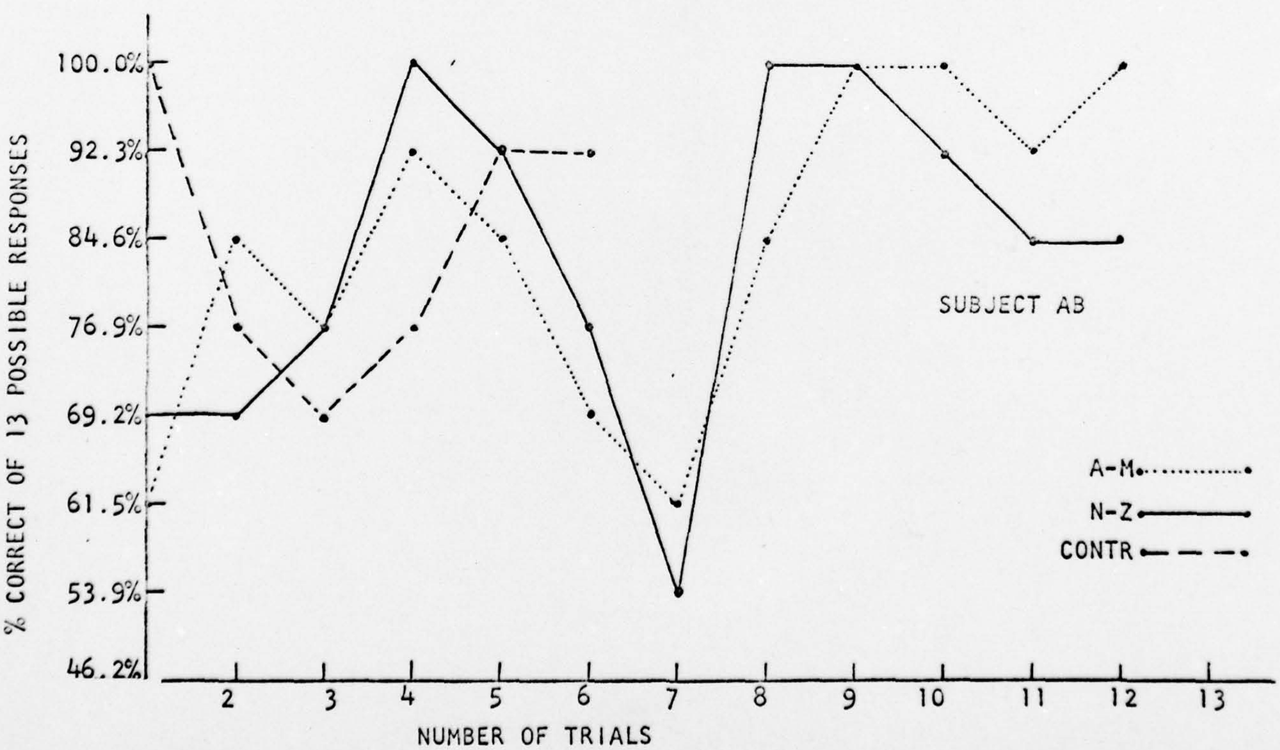


Fig.3b. THE % OF THE 13 RESPONSES IN A TRIAL GIVEN CORRECTLY AS A FUNCTION OF NUMBER OF TRIALS FOR LETTERS A-M, LETTERS N-Z, AND THE 13 CONTRACTIONS AND PUNCTUATIONS

When a subject has learned the three groups of characters separately, they are combined to form trials with 39 items. These trials are then administered to subjects for several sessions until a dependably high percent of signal identification is achieved. At this point, subjects begin to receive practice on the reception of words and then prose. The reception of prose passages will receive specific attention later. When subjects have reached the point in training at which they are receiving prose, they commence each training session with a single 39 item trial. These trials were provided in order to make a continuing check upon the elimination of errors and decrease in reaction time. Such a check is not possible when prose is sent, because subjects do not respond to individual letters, but only to whole words.

Thirty-nine item trials have been administered once per session until subjects have received a good deal of practice in the reception of prose. However, their administration consumes a large amount of training time. In order to make more time available for practice in receiving prose, the daily administration of 39 item trials has been discontinued. At the present time, a single 39 item trial is administered at the beginning of every fourth training session to those subjects whose practice consists primarily in the reception of prose.

Performance on these trials indicates an initial rapid improvement, followed by a number of trials in which performance appears fairly level. In Figure 4, curves are presented for four subjects whose performance was characteristic. These curves show correct responses per trial as a function of trials. Since large fluctuations in performance from day to day have continued to be typical of subjects, running averages have been used in order to make trends in performance more apparent. Therefore, the points in terms of which a subject's curve is plotted is an average.

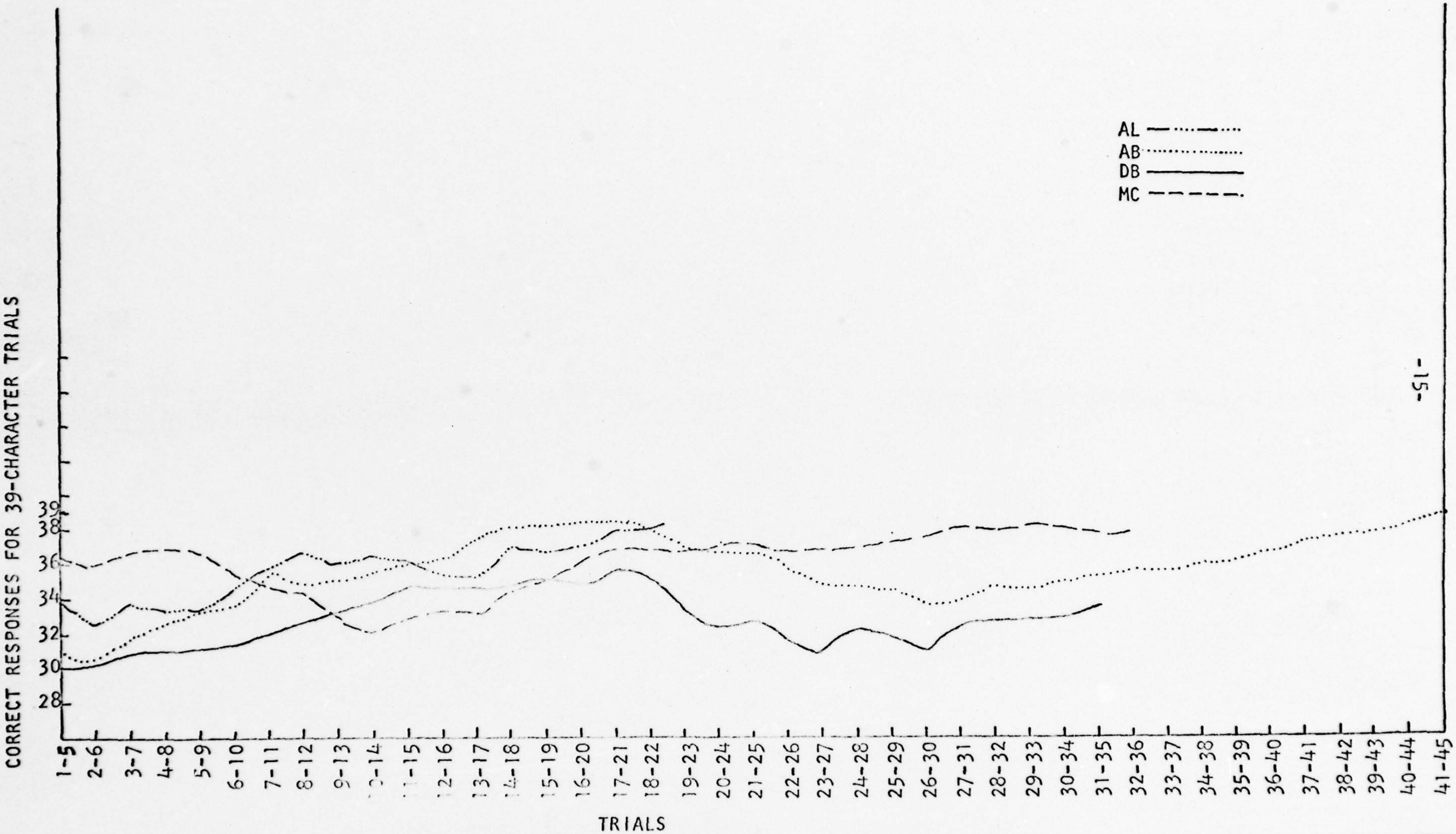


Fig. 4. CORRECT RESPONSES FOR 39 CHARACTER TRIALS AS A FUNCTION OF TRIALS FOR FOUR SUBJECTS (The data points in terms of which the curves are plotted are running averages based on the mean of correct responses for trials 1-5, 2-6, 3-7, etc.)

The first point is the mean number of correct responses for the first five in the series of trials on which the curve is based. The second point is the mean value of trials two through six, the third represents trials three through seven, and so on. The irregularity of these curves even when plotted in this manner is still striking. One reason for this variability in performance may have been the environment in which training has been conducted. The training apparatus was set up in a room that is not soundproof and conversations and movement in the adjacent hall can be heard clearly. Performance records and subjective reports suggest that distraction is a serious problem in a task of this sort. For these reasons, it is now planned to install a soundproof testing room for further training.

In all of the trials composed of randomly ordered signals, a complete record has been kept of the subject's responses. This has made it possible to gauge the kind and amount of confusions that occur. Such information may be used to provide a rational basis for the pairing of signals in the stimulus alphabet with letters and other symbols in the response alphabet. In such a scheme, seldom confused signals would be paired with frequently occurring letters, while often confused signals would be paired with infrequent letters. In certain situations, where only a small number of code signals are required, it might be desirable to eliminate altogether those signals most frequently involved in confusions. In order to reveal the pattern of confusions that have taken place, each subject's responses to the 39 signals in the trials administered at the beginning of each training session have been entered in confusion matrices. Each of these matrices contains the subject's responses from as many such trials as were available at the time the matrices were constructed. The entries along the left-hand margin of each matrix refer to signals sent. The row of entries at the top of each matrix refer to signals received. The spread of entries in such a matrix affords a picture of the confusions that have taken place. Two such matrices are shown in Tables 1 and 2, (following two pages). Table 1 is based upon the performance of the subject who has shown the fewest confusions. Table 2 is based upon the subject who has shown the greatest number of confusions. Matrices for other subjects can be found in Appendix D. Table 3, (page 20), is a summary of the information displayed in eight matrices.

As practice continues, one may reasonably expect to find a decrease in confusions, and an increase in the information transferred. Table 4, (page 21), is a summary matrix based upon the matrices constructed from the most recent fifteen trials of three subjects. Comparison of this table with Table 3 reveals a definite decrease in the number of confusions.

Subjects are still receiving training, and their performance continues to improve. A complete information analysis will be made of their performance on the last few training sessions. However, the amount of information transferred and the subject's present state of proficiency may also be of interest. To answer this question, the confusion matrices summarized in Table 4 have been analyzed. The results of this analysis are shown in Table 5, (pages 22 - 24).

Initial Acquisition as Indicated by Reaction Time: In the case of the first few subjects who received training, provisions were not yet made for the collection of reaction times to signals. They were well along in training before this could be accomplished. However, some subjects have had their reaction times measured from the beginning or near beginning of their training. It is therefore possible to use reaction times of these subjects as another measure of learning. Figure 5, (page 25) shows the mean reaction time in seconds to all signals in a trial as a function of the number of trials for four subjects. The trials upon which this figure is based are the 39-item trials administered to subjects after they have

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	&	BLE	TH	ER	EN	IN	ING	,	?	AR	ED	OF	FOR	no rsp	# crt
A	36																																						1		36
B		36																																						1	36
C			37																																						37
D				33					1						2																									1	33
E					35																													2							35
F						33																														2				2	33
G						2	34																						1												34
H								30	3						1																				3						30
I									37																																37
J										31	4			2																											31
K											35																													2	35
L			1									33						1										1												1	33
M													36																							1					36
N														37																											37
O															37																										37
P																37																									37
Q																1	35				1																				35
R												1						35																		1					35
S	1	1																	35																						35
T																				37																					37
U									1								2				34																				34
V																						32	4						1												32
W																						1	36																		36
X						2																		32												3					32
Y																									35														2		35
Z					1																					35					1										35
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AR																																				37					37
ED																												5									32				32
OF									3		6																											27		1	27
FOR	1	2																																					34		34

Table 1. Confusion Matrix for Subject Showing Least Confusions, Based on 37 trials. Subject M.C.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	&	BLE	TH	ER	EN	IN	ING	,	?	AR	ED	OF	FOR	no rsp	# crt	
A	31																																						3		31	A
B	1	27																	6																						27	B
C			30						1					1											2																30	C
D				30					2		2																														30	D
E					33																												1								33	E
F						24	8																	1												1					24	F
G						6	28																																		28	G
H								32							1																		1								32	H
I									34																																34	I
J										28				3												1												1		1	28	J
K											31														2													1			31	K
L												29						2										3													29	L
M													30									1	1													2					30	M
N			1							2	1			28											1			1													28	N
O								2							29				3																						29	O
P																27				6	1																				27	P
Q																1	28				4																1				28	Q
R			2															31																			1				31	R
S	1																		33																						33	S
T																1		1	1	31																					31	T
U												1					3			1	29																				29	U
V																	1	1				24	6						2												24	V
W																						2	32																		32	W
X																								27					2							4	1				27	X
Y			1							1				1											31																31	Y
Z																										29				2	3										29	Z
AND														1													28					3	1						1		28	AND
BLE							1			2		2											2					22							1		4				22	BLE
TH													6										1						25							2					25	TH
ER																										2				30	2										30	ER
EN																										2				5	27										27	EN
IN																											1					33									33	IN
ING								1							1													1					29	1			1				29	ING
,					1																						3					1		29							29	,
?								6																									2		21		1	3	1		21	?
AR													4											3					1							26					26	AR
ED																		2							1			3									28				28	ED
OF									2																													32			32	OF
FOR	5	6				1		1											1													1							19		19	FOR

Table 2. Confusion Matrix for Subject Showing Most Confusions - Subject D.B. based on 34 trials.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	&	BLE	TH	ER	EN	IN	ING	,	?	AR	ED	OF	FOR	NO RSP
A	196	2																																					8	
B	3	193																	6																				3	1
C			195	1					1					2				1							6															
D			2	194					3	1	3				2																									1
E					197																											3		6						
F						184	13																	2												4			1	2
G						11	189																	5					1											
H								184	3						4																		2	3	8					2
I				2					192																													7		5
J										176	4			12			1							1	6	1												1		4
K				7					1		191														2												1	1		3
L			1								1	175						4										14									8			3
M													195									1	2	1		1			3							3				
N			2							8	1			191											1			3												
O								4				1			195			1	3														2							
P																188	3			1.2	3																			
Q																3	185				14	1																1		2
R			2									4						190																		2	5			3
S	2	2																	202																					
T													1			5		1	2	197																				
U									1			1				2	11			2	189																			
V																	1	1			2	179	20						3											
W																						14	191						1											
X						5	1																	181		1		1	2							12	2			1
Y			5							6				1											189	1													2	2
Z					1																					187				8	9			1						
AND														1													184					12		7					2	
BLE							1			3		8						1					2					173		1					1		15			1
TH												1	21										5	1	1		1		174						2					
ER								1														1				4				188	8	1							1	
EN					2																					14				5	184	1								
IN					3																						8			1	1	185		6						2
ING								8							6											1		1					186	1	1		1			1
,					2									1													13			3	1	8		173			1			4
?								14	1																							1	15	1	166	1	3	3		1
AR													4											9	1				1							141				
ED												8						7						1	1			9		1							178			1
OF								22			10																											170	1	3
FOR	16	24				1		1											1								1						1					1	166	

Table 3. Summary of the Confusions Shown in Eight Confusion Matrices

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	&	BLE	TH	ER	EN	IN	ING	,	?	AR	ED	OF	FOR	no rsp	
A	43	1																																					1		43 A
B	1	40																	3																					1	40 B
C			42						1					1											1																42 C
D			1	42					1		1																														42 D
E					45																																				45 E
F						39	2																	1															1	2	39 F
G						2	43																																		43 G
H								44																											1						44 H
I									44																														1		43 I
J										43																												1		1	43 J
K											42														1													1		1	42 K
L												45																													45 L
M													41										1													3					41 M
N											1			43											1																43 N
O								1							41				3																						41 O
P																44				1																					44 P
Q																1	42				1																1				42 Q
R			2															43																							43 R
S	1	1																	43																						43 S
T																		1	1	43																					43 T
U												1					2				42																				42 U
V																						43	2																		43 V
W																						4	41																		41 W
X																								38		1			2							3	1				38 X
Y			2							1	1														41																41 Y
Z																										40				3	2										40 Z
&																											38					4		1					1	1	38 &
BLE							1			3		1											1					35							2		2				35 BLE
TH													2										2						39							2					39 TH
ER								1																						42	2										42 ER
EN																														3	42										42 EN
IN																											1					44									44 IN
ING								2							1																		40				2				40 ING
,																														1		4		39						1	39 ,
?								4																									3		33		1	3	1		33 ?
AR													4											1					1							39					39 AR
ED												1													1												43				43 ED
OF									4																													40		1	40 OF
FOR	4	3						1																							1		1						36		36 FOR

Table 4. Summary Confusion Matrix for the Most Recent 15 Trials of 3 Subjects.

Table 5

Information Analysis for the Last Fifteen Trials from Three Subjects

Notes on Table

1. Signals have been ranked according to response ambiguity. "E", the first signal in the table shows the least response ambiguity.

2. The entries in column 2 are coded descriptions of the signals. The first symbol specifies the hand stimulated: R = right; L = left. The second symbol specifies the finger stimulated: 1 = thumb; 2 = index finger, etc. The third symbol specifies stimulus duration: B = brief; L = long. The fourth signal specifies signal intensity: W = weak; S = strong.

3. The symbols in each entry in column 6 refer to the dimensions in which confusions occurred. No symbols are entered for those dimensions in which no confusions occurred.

4. Hs(r) = Response Ambiguity H_t = Information Transmitted

Signal	Description of Signal	Hs(r)	Substituted Response	Frequency of Confusion	Description of Confusion
E	R1LS	.00000	——	——	——
L	R4BS	.00000	——	——	——
H	L2BS	.00393	?	1	- - - W
I	L3BS	.00393	FOR	1	R 2 - W
P	L4LW	.00393	T	1	- - - S
IN	R1BS	.00393	AND	1	- - - W
G	R5BW	.00671	F	2	- - - S
R	R4LS	.00671	C	2	- 3 - -
V	L5BW	.00671	W	2	- - - S
A	R2BS	.00785	B	1	- - L W
			FOR	1	- - - W
J	R3BW	.00785	OF	1	L - - -
			NR	1	——
N	R3BS	.00785	K	1	L - L W
			Y	1	- - L W
S	R2LS	.00785	A	1	- - B -
			B	1	- - - W
T	L4LS	.00785	R	1	R - - -
			S	1	R 2 - -
ED	R4LW	.00785	L	1	- - B S
			Y	1	- 3 - -
EN	L1LS	.00905	ER	3	- - B -
U	L4BS	.01061	L	1	R - - -
			Q	2	- - - W
ER	L1BS	.01061	H	1	- 2 - -
			EN	2	- - L -

Table 5 (Cont'd)

Signal	Description of Signal	Hs(r)	Substituted Response	Frequency of Confusion	Description of Confusion
W	L5BS	.01108	V	4	- - - W
C	R3LS	.01174	I	1	L - B -
			N	1	- - B -
			Y	1	- - - W
D	L3LS	.01174	C	1	R - - -
			I	1	- - B -
			K	1	- - - W
K	L3LW	.01174	Y	1	R - - -
			OF	1	- - B -
			NR	1	
Q	L4BW	.01174	P	1	- - B -
			U	1	- - - S
			ED	1	R - L -
B	R2LW	.01293	S	3	- - - S
			NR	1	
M	L5LS	.01293	W	1	- - B -
			AR	3	R - - -
O	L2LS	.01293	H	1	- - B -
			S	3	R - - -
Y	R3LW	.01448	C	2	- - - S
			J	1	- - B -
			K	1	L - - -
OF	L3BW	.01493	I	4	- - - S
			NR	1	
Z	L1LW	.01564	ER	3	- - B S
			EN	2	- - - S
ING	L2LW	.01720	H	2	- - B S
			O	1	- - - S
			ED	2	R 4 - -
,	R1LW	.01877	ER	1	L - B S
			IN	4	- - B S
			NR	1	
AR	R5LS	.01877	M	4	L - - -
			X	1	- - - W
			BLE	1	- 4 B W
TH	L5LW	.01990	M	2	- - - S
			W	2	- - B S
			AR	2	R - - S
F	R5BS	.02104	G	2	- - - W
			X	1	- - L W
			FOR	1	- 2 - W
			NR	2	
AND	R1BW	.02258	ING	4	L 2 L -
			,	1	- - L -
			FOR	1	- 2 - -
			NR	1	
X	R5LW	.02329	Z	1	L 1 - -
			TH	2	L - - -
			AR	3	- - - S
			ED	1	- 4 - -

Table 5 (Cont'd)

Signal	Description of Signal	Hs(r)	Substituted Response	Frequency of Confusion	Description of Confusion
FOR	R2BW	.02745	A	4	- - - S
			B	3	- - L -
			H	1	L - - S
			ING	1	L - L -
BLE	R4BW	.03347	G	1	- 5 - -
			J	3	- 3 - -
			L	1	- - - S
			W	1	L 5 - S
			?	2	L 2 - -
			ED	2	- - L -
?	L2BW	.03749	H	4	- - - S
			ER	1	- 1 - S
			ING	2	- - L -
			ED	1	R 4 L -
			OF	3	- 3 - -
			FOR	1	R - - -

$H_t = 4.8061$

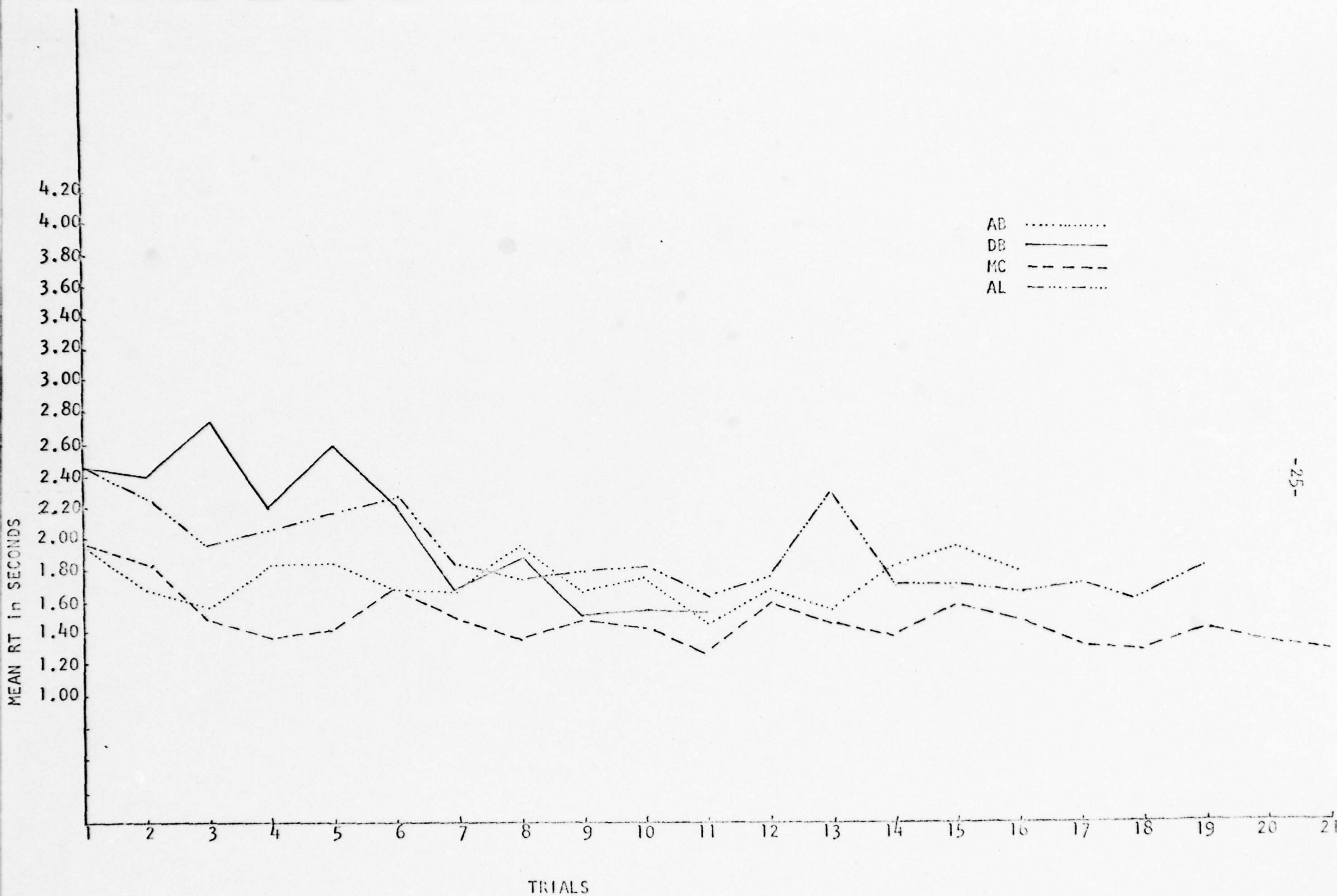

Fig. 5. Mean RT vs. Trials (Mean based on RT s of all 39 Signals in a trial)

reached criterion on the 13-item trials, (see page 7). Figure 5 should be compared with Figure 4, which is based upon performance of the same subjects and differs only in that the number of correct responses has been used as the evidence of learning instead of reaction time. Figure 4 suggests that there is little improvement as a function of practice. Figure 5, on the other hand, suggests a continued improvement with practice.

The Reduction of Reaction Times: Reaction times to individual signals remained quite long even after considerable amounts of training. When receiving meaningful sentences, subjects get many cues from spelling conventions and anticipated sentence meanings that assist them in identifying letters and whole words. When letters are organized into such words and sentences, the subject can receive them at a much faster rate than would be suggested by summing reaction times to these same letters when presented singly. Nevertheless, the reaction time to individual signals does place a definite upper limit upon the rate at which meaningful communication can proceed. It is therefore desirable to examine more closely the reaction times to the various signals. Table 6, (page 27), presents mean reaction times to each of the 39 signals for three subjects on the last ten trials before the administration of paced drill. Paced drill will be discussed in a moment. The mean reaction times of the subjects to each of the 39 signals have been averaged again to obtain column five of this table. The entry in the next to the last row of each column is an average of the reaction times for letters in that column. The last row of each column presents average reaction times for punctuations and contractions.

Inspection of this table suggests several observations. When the table is read by rows, the marked variability in performance from subject to subject that has been seen elsewhere is again apparent. Reading the table by columns

Table 6

Mean* Reaction Times to Each of the Thirty-nine Signals

Signal	AB	DB	MC	Mean of 3 Ss
A	1.08	1.92	.86	1.29
B	1.91	1.32	1.14	1.46
C	1.17	1.22	1.12	1.17
D	1.38	1.29	1.20	1.29
E	1.32	.98	.91	1.07
F	1.37	2.97	1.61	1.98
G	1.55	1.75	1.84	1.71
H	1.44	1.62	2.11	1.72
I	1.56	1.12	1.39	1.36
J	2.05	1.97	1.61	1.88
K	1.61	1.63	1.64	1.63
L	1.59	1.06	1.39	1.35
M	1.43	1.58	1.51	1.51
N	1.48	2.35	1.30	1.71
O	1.39	1.80	1.20	1.46
P	1.66	2.12	1.41	1.73
Q	1.71	2.46	1.77	1.98
R	1.60	1.31	1.04	1.32
S	1.34	1.49	1.05	1.29
T	1.40	1.81	1.36	1.52
U	1.75	2.88	1.34	1.99
V	1.84	2.10	1.43	1.79
W	1.95	1.94	1.28	1.72
X	1.77	2.32	2.20	2.10
Y	2.42	1.32	1.15	1.63
Z	1.85	1.88	1.66	1.80
and	2.17	1.99	2.21	2.16
ble	2.62	7.17	1.35	3.71
th	1.81	3.83	1.17	2.27
er	2.07	1.89	1.38	1.78
en	1.44	2.33	1.27	1.68
in	1.71	1.86	1.29	1.62
ing	2.99	2.44	1.44	2.29
,	3.08	2.24	1.58	2.30
?	2.45	6.30	1.60	3.45
ar	1.47	3.36	1.58	2.14
ed	2.25	2.16	1.49	1.97
of	2.07	2.33	1.83	2.08
for	2.02	2.52	1.30	1.95
Average for letters	1.60	1.78	1.40	1.59
Average for punctuation and contractions	2.17	3.11	1.50	2.26

*mean based on last 10 correct responses to each of the signals before administration of paced drill reveals considerable variation in the reaction time to the various signals. Furthermore, even the shortest of the reaction times is disturbingly long. An effort has been made to reduce reaction times by the administration of paced trials. The results of the effort will be presented in a moment. Comparison of reaction times to letters with reaction times to contractions indicates that reaction times to contractions are considerably longer. This slowness of reaction times to contractions is emphasized by the differences between the pairs of mean reaction times at the foot of each column. "t" tests reveal that the differences between means in each of these columns is significant at the .05 level.

Pursuing this point further, we may examine the course of learning for letters and for contractions separately. Figure 6, (following two pages), presents two curves for each of two typical subjects. The solid line curve shows the means of the reaction times to letters as a function of the number of trials. The dotted line curve shows the means of the reaction times to the remaining signals as a function of the number of trials. The graph suggests that reaction times to letters are shorter than those to contractions, and that this difference is appreciable.

Contractions were used in the code in an effort to increase communication rate by reducing the number of signals required to state those words in which contractions occur. However, this advantage was counteracted to an extent by the longer reaction times to contractions. If reaction times to contractions were enough longer, there would, of course, be no advantage in using them. This does not appear to be the case. Reaction times to contractions are rarely twice as long as reaction times to letters, and each contraction replaces at least two and often three or more letters. More evidence will be presented on this point when the reception of connected prose is discussed.

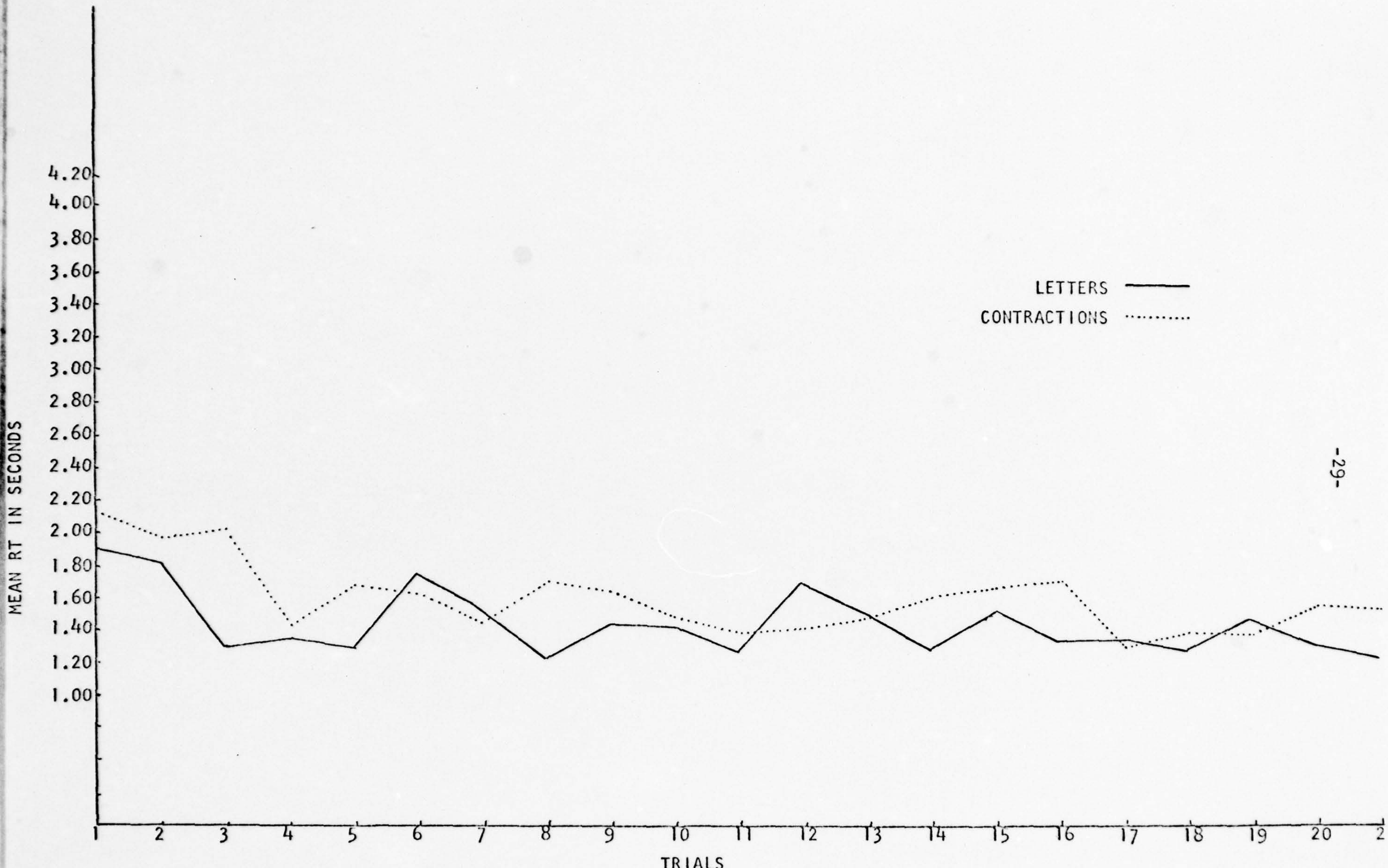

Fig. 6A. (Subject MC) Comparison of Mean RTs for Letters with Mean RTs for Contractions (Fig. 6 is based on the same data as that used to plot the curves for subjects MC and AB in Fig. 5.)

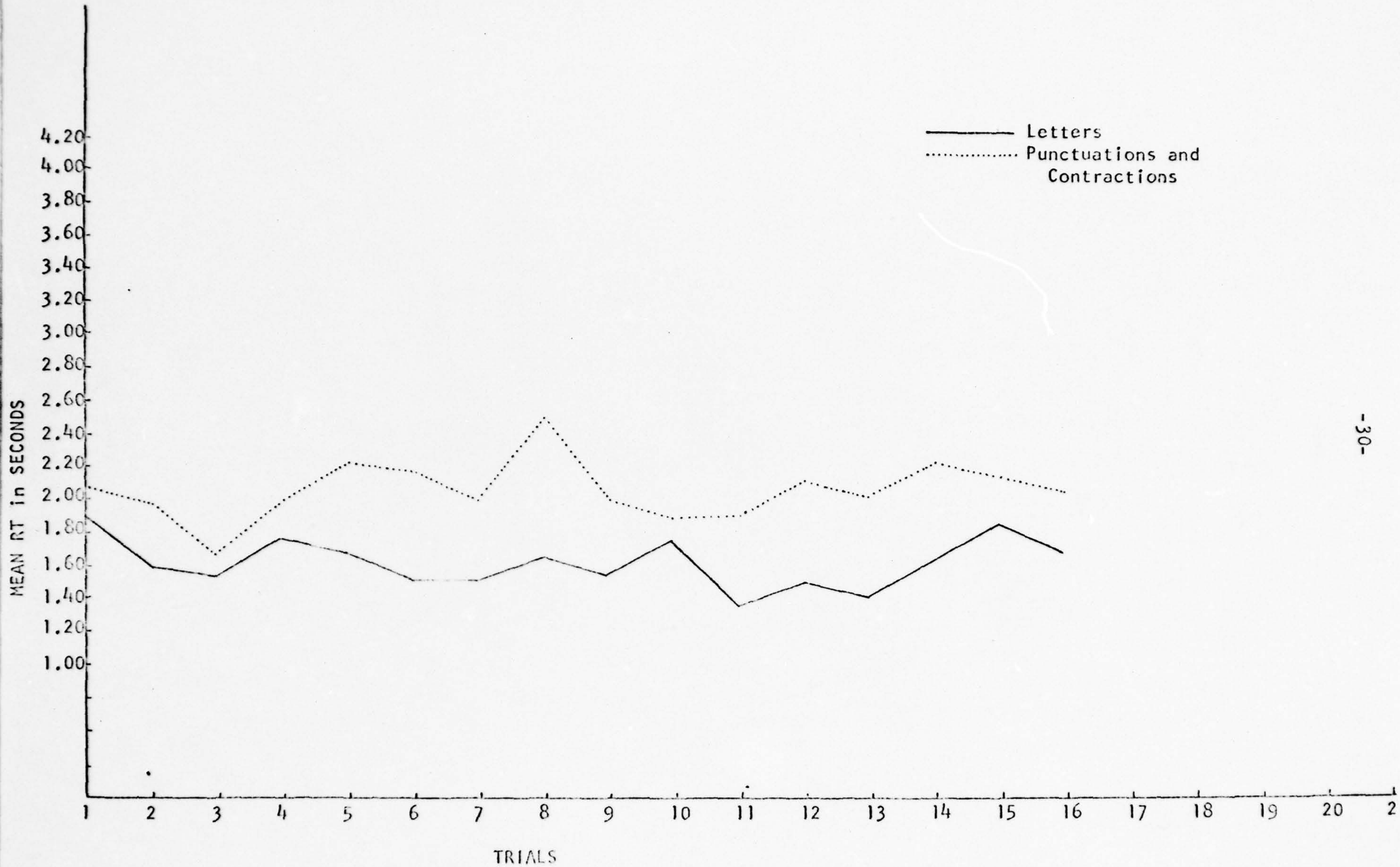

Fig. 6B (Subject AB) Comparison of Mean RTs for Letters with Mean RTs for Contractions (Fig. 6 is based on same data as that used to plot the curves for subjects MC and AB in Fig. 5)

<u>Forced Pacing</u>: With the kind of practice described so far, reaction times have remained too long for rapid communication. Therefore, an effort has been made to reduce reaction times by the forced pacing of subjects. This has been accomplished by the automatic operation of the code sending apparatus with a tape reader. A tape is punched so that it will send random permutations of the 39 signals to the subject. The tape reader is stepped automatically by means of a Hunter Timer. The stepping rate is adjusted so that the subject identifies many signals but makes many errors, too. The subject is presented signals at this rate until his error score improves. The stepping rate is then increased slightly and drill is continued. Because of the manner in which the apparatus is constructed, it has not been possible to determine reaction times to signals during paced drill. Furthermore, during paced drill, subjects' responses often lag signals by two or three steps, much as in the case of Morse Code reception. When the subject is responding in this manner, the determination of reaction times to individual signals is not possible.

The practice so far has been to interrupt forced pacing drill from time to time, approximately once a week or every third training session, and to administer a trial manually in the manner described previously, so that reaction time can be recorded. Each of the curves in Figure 7 describes the performance of one subject. The figure shows mean reaction time to all 39 signals as a function of the amount of forced pacing. No curve expressing average performance has been plotted since subjects were not at the same point in their training when paced drill was commenced, and since subjects were not treated alike during this drill. That is, the rate at which each subject was paced depended upon his current performance. Each of the curves clearly suggests that paced drill has been effective in reducing reaction times to signals.

The initial point for each of the curves is the mean reaction time to the 39 signals in the trial administered just before the subjects commenced paced

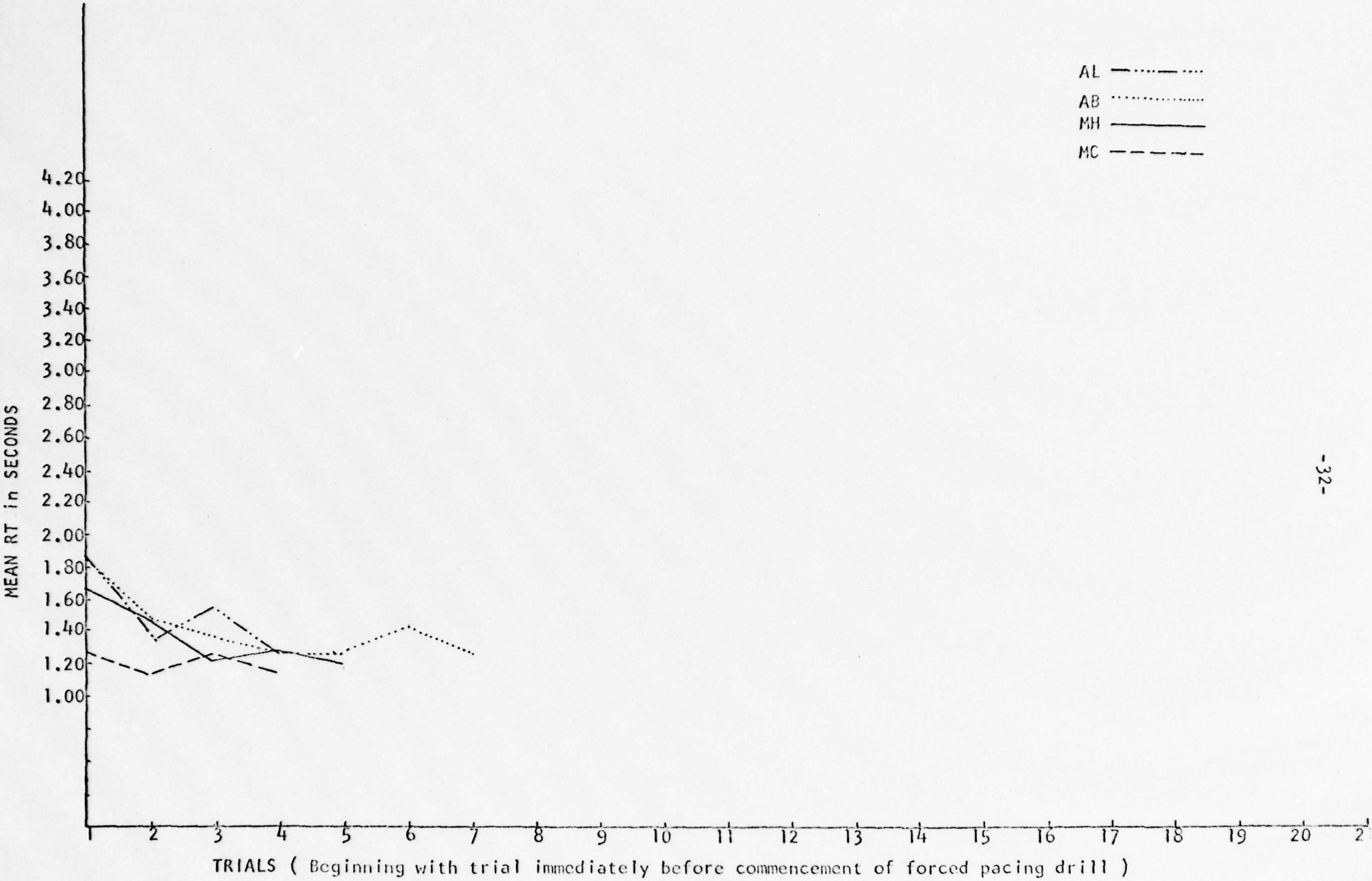

Fig. 7. MEAN RT TO ALL 39 SIGNALS IN A TRIAL AS A FUNCTION OF FORCED PACING

drill. Thus, a comparison of the ordinate value for this point with the ordinate value for the final point through which the curve passes will give an idea of the advantage gained by the amount of paced drill that has taken place so far. Each curve indicates that as forced pacing continues, reaction time decreases. For instance, the mean reaction time for subject "A B" was 1.81 immediately before forced pacing, and 1.30 on the final trial shown in the figure.

Informal observation of the performance of subjects suggested that paced drill brought about an improvement in performance during a single session. To test this impression, subjects commenced a recent session with a trial in which errors and reaction times for each of the 39 signals were determined. Next, they were given one trial of paced drill consisting of eight random permutations of the 39 signals presented at a rate ranging from .80 second per signal to 1.50 second per signal, depending upon the skill of the subject. Following this they received another trial in which reaction times were recorded. The results are shown in Table 7. Each column in this table presents the data for one subject. Each row presents the reaction times for one signal across subjects. The first entry in each cell is the pre-drill reaction time for a signal. The second entry in each cell is the post-drill reaction time for the same signal. The row at the bottom of the table contains the means for column entries. The data in this table might have been treated by an analysis of variance with pre- and post-drill reaction time, subjects, and signals as sources of variation. However, subjects were not equally trained in code reception at the outset of the experiment. Thus, between subjects variation was confounded with variation attributable to differences in the amount of original training. Therefore, the data for each subject have been evaluated separately with "t" tests. These results are shown in Table 8.

Table 7

Decrease in Reaction Time (RT) as a Consequence of the Paced Drill Administered During A Single Session

Signals	AB Pre-Drill RT	AB Post-Drill RT	MC Pre-Drill RT	MC Post-Drill RT	MH Pre-Drill RT	MH Post-Drill RT
A	.85	.87	1.08	.66	.81	.64
B	1.19	..92	.92	1.20	.98	.88
C	1.71	1.14	1.75	1.23	1.00	1.03
D	1.38	1.24	1.20	1.14	.95	1.40
E	.94	.95	.94	.99	.80	1.01
F	1.16	1.16	1.21	1.08	1.28	1.15
G	1.44	1.30	1.45	1.27	.96	1.00
H	1.27	.98	.94	.93	.91	1.03
I	1.65	1.78	.96	1.28	1.60	2.01
J	1.27	1.37	1.10	1.16	1.69	1.11
K	1.31	1.47	1.45	1.18	1.09	.94
L	1.18	1.18	.95	.96	.67	1.54
M	1.95	1.11	1.15	1.01	1.23	1.05
N	1.17	.98	1.23	1.14	1.10	1.19
O	1.03	1.07	1.04	.93	1.03	1.09
P	1.67	1.18	1.30	1.53	1.31	1.01
Q	1.28	1.62	1.08	1.11	1.28	1.37
R	1.33	1.12	1.98	1.30	1.12	1.31
S	1.25	.88	1.27	.77	1.00	.87
T	1.52	1.04	1.00	1.12	1.00	.93
U	1.42	2.14	1.12	1.19	1.54	1.54
V	1.40	1.37	1.20	1.12	1.50	1.26
W	1.28	1.15	1.02	1.12	.75	1.20
X	1.65	1.28	1.34	1.23	1.56	1.03
Y	1.02	1.22	2.46	1.21	1.29	1.47
Z	1.19	1.20	1.22	1.39	1.23	.65
and	1.40	1.50	1.69	1.06	2.15	1.02
ble	2.50	1.64	1.19	1.22	1.58	1.28
th	1.56	1.90	1.11	.87	1.14	1.53
er	1.45	1.40	1.00	1.00	1.64	1.19
en	1.20	1.12	.96	1.19	1.05	1.12
in	1.80	1.35	1.49	1.21	1.20	1.75
ing	1.42	1.12	.96	1.27	1.73	1.44
,	1.51	1.25	1.72	1.44	3.20	1.22
?	1.76	1.75	2.04	1.45	1.90	1.49
ar	1.73	1.45	1.64	1.75	1.19	1.03
ed	2.70	1.75	1.10	1.06	2.10	1.71
of	1.36	1.48	1.35	1.35	1.92	1.75
for	1.37	1.40	.84	1.01	1.60	1.75
Mean Reaction Time	1.44	1.30	1.27	1.16	1.33	1.23

Table 7 (Cont'd)

Decrease in Reaction Time (RT) as a Consequence of the Paced Drill Administered During A Single Session

Signals	AL Pre-Drill RT	AL Post-Drill RT	MM Pre-Drill RT	MM Post-Drill RT
A	.70	.66	.85	.92
B	1.02	.84	.98	1.31
C	1.60	1.25	1.47	1.50
D	1.94	1.41	1.65	1.12
E	.89	1.01	2.17	2.27
F	1.49	1.13	1.18	1.04
G	1.04	1.40	.93	1.05
H	3.09	.98	1.43	1.36
I	1.65	1.11	1.57	1.61
J	1.55	1.48	1.20	1.90
K	.99	1.00	1.23	1.22
L	1.18	1.67	1.30	1.25
M	1.74	1.16	1.83	1.09
N	1.86	1.37	1.97	1.56
O	1.28	1.07	1.10	.90
P	.87	1.32	1.06	1.15
Q	1.50	1.51	1.65	1.86
R	1.35	1.42	1.75	1.07
S	1.70	1.10	2.39	1.90
T	1.80	1.22	1.06	1.11
U	1.33	1.33	2.29	1.78
V	1.80	1.50	1.91	1.67
W	2.02	1.34	1.27	1.13
X	1.35	1.05	1.50	1.25
Y	1.76	1.51	1.49	1.05
Z	1.24	1.13	1.92	1.34
and	1.10	1.90	1.07	.91
ble	1.52	1.57	1.49	1.55
th	1.35	1.21	1.85	1.14
er	1.81	1.39	1.73	2.12
en	1.70	2.07	2.20	1.77
in	1.88	1.40	1.40	1.52
ing	1.42	1.07	3.06	1.37
,	1.05	1.02	1.24	1.57
?	1.49	1.73	1.69	1.56
ar	1.88	1.24	1.47	1.16
ed	3.03	1.75	1.83	1.60
of	.87	1.98	.72	1.00
for	1.30	1.27	2.30	1.26
Mean RT	1.52	1.32	1.57	1.38

Table 8

Comparison of Pre and Post-Drill Mean Reaction Times

of Five Subjects

Subjects	M_1	M_2	$M_1 - M_2$	S_{m_d}	$\frac{(M_1-M_2)}{S_{m_d}}$
"A B"	1.44	1.30	.1497	.0175	8.554
"M C"	1.27	1.17	.0995	.0164	6.070
"M H"	1.33	1.23	.0972	.0796	1.221
"A L"	1.52	1.32	.1946	.0469	4.149
"M M"	1.57	1.38	.2068	.0304	6.808

.05 = 2.021
.01 = 2.704

M_1 = mean of the pre-drill reaction times to all 39 signals

M_2 = mean of the post-drill reaction times to all 39 signals

The Reception of Prose: After subjects have shown sufficient mastery of trials composed of 39 signals, they are given brief experience in the reception of short familiar words. Shortly thereafter, they begin to receive training in the reception of prose passages. Passages have been chosen from a book that contains fiction, biography, information, etc.

When this training was commenced, the tape equipment used for automatic code sending had not yet been installed. It was therefore necessary to send signals manually. With this arrangement, it was not possible to determine subjects' word rate accurately, since the word rate of the sender could not be regulated with precision. Therefore, it was not possible to keep a very meaningful record of improvement during this stage of training.

When the tape reader became operational, the experimenter gained good control over the sending rate and this afforded a better assessment of the receiving rate.

Several methods of sending signals by means of the tape reader have been tried. Initially, subjects were presented signals at a rate determined by the setting of the Hunter Timer associated with the tape reader. However, when the tape reader was stepped at a fast enough rate to force-pace the subject, he would begin to miss signals. While he stopped to ponder a missed signal, the following signals continued to be sent. He soon became confused, lost the thread of the narrative, and had difficulty in picking it up again.

An arrangement that permitted self-pacing was also tried. The subject was given two foot pedals to operate. When he pressed the right pedal, the tape reader was stepped and a signal was presented. When he pressed the left pedal, the last signal sent was repeated. Thus, the subject had complete control over the rate at which signals were sent. This approach seemed to yield promising results at first. However, as the subject who was used to evaluate this method gained proficiency, he began to complain that he could not operate the pedal with enough agility to send signals as fast as he could receive them. In support of this impression, his word rate, which had previously shown improvement with practice, leveled off.

The method now in use is intermediate to the methods just described. The subject controls the tape reader by means of foot pedals. However, when he presses the right pedal, he does not receive just one signal. As long as he holds the pedal down, the tape reader is stepped at a rate determined by the setting of the associated Hunter Timer. When this pedal is released, the tape reader is stopped. Pressing the left pedal repeats the last signal sent, the same as before. As the subject shows improvement, the stepping rate of the tape reader is gradually increased.

Word rates attained by subjects are determined in the following way. The amount of time required by a subject to receive all the words punched into a particular tape is measured by means of a Standard Timer that is started when the subject receives the first signal on the tape, and stopped when he responds to the last signal. The number of words on the tape is then divided by the measured time. The obtained quotient is the number of words sent per minute, and, if the subject has missed no words, it is also the number of words received per minute. However, in spite of the fact that subjects can repeat missed signals, they do miss words and a record of their misses is kept by the experimenter. When a word is missed, the subject is told what it is. The number of words received per minute is determined by subtracting words missed from words sent, and then dividing as before.

Subjects began to receive training on the reception of prose before the tape reading equipment was installed. The time required for the transmission of prose passages was measured, but, since the code was sent manually, and since missed words were repeated, it was not possible to distinguish clearly between words sent and words received. Nevertheless, curves based upon the data taken at this time do suggest an improvement with practice. Figure 8 presents curves for three subjects. The number of training sessions is shown on the "X" axis, and words per minute on the "Y" axis. Performance from day to day was again quite variable. In order to smooth curves somewhat so that their direction is more apparent, the points through which they pass are running averages. It can be seen that, even when the curves have been based upon these averages, variability is still quite apparent. It is also clear that in general, word rate increases as training proceeds.

Figure 9 is based upon data collected since the installation of the tape reading equipment. This figure describes the performance of two typical subjects. The solid line curve refers to words sent. The dotted line curve refers to words received. It can be seen that, although the two curves for each subject are roughly parallel , they each show considerable fluctuation. The variability in sending rate is due to the fact that the subject has control over this rate. The upper limit on sending is determined by the setting of the Hunter Timer that steps the tape reader automatically when the subject's right foot pedal is pressed, and it has been the practice to send signals fast enough so that the subject cannot achieve errorless performance. When he approaches errorless performance, the rate is increased. The actual sending rate depends not only upon the rate at which the tape reader is stepped, but also upon the amount of time during the sending of a passage that the tape reader is stopped by the subject for the purpose of repeating missed signals or thinking about recently experienced signals.

The overall impression conveyed by the curve that describes words received per minute is one of improvement with practice, although there are frequent reversals in the direction of the curve.

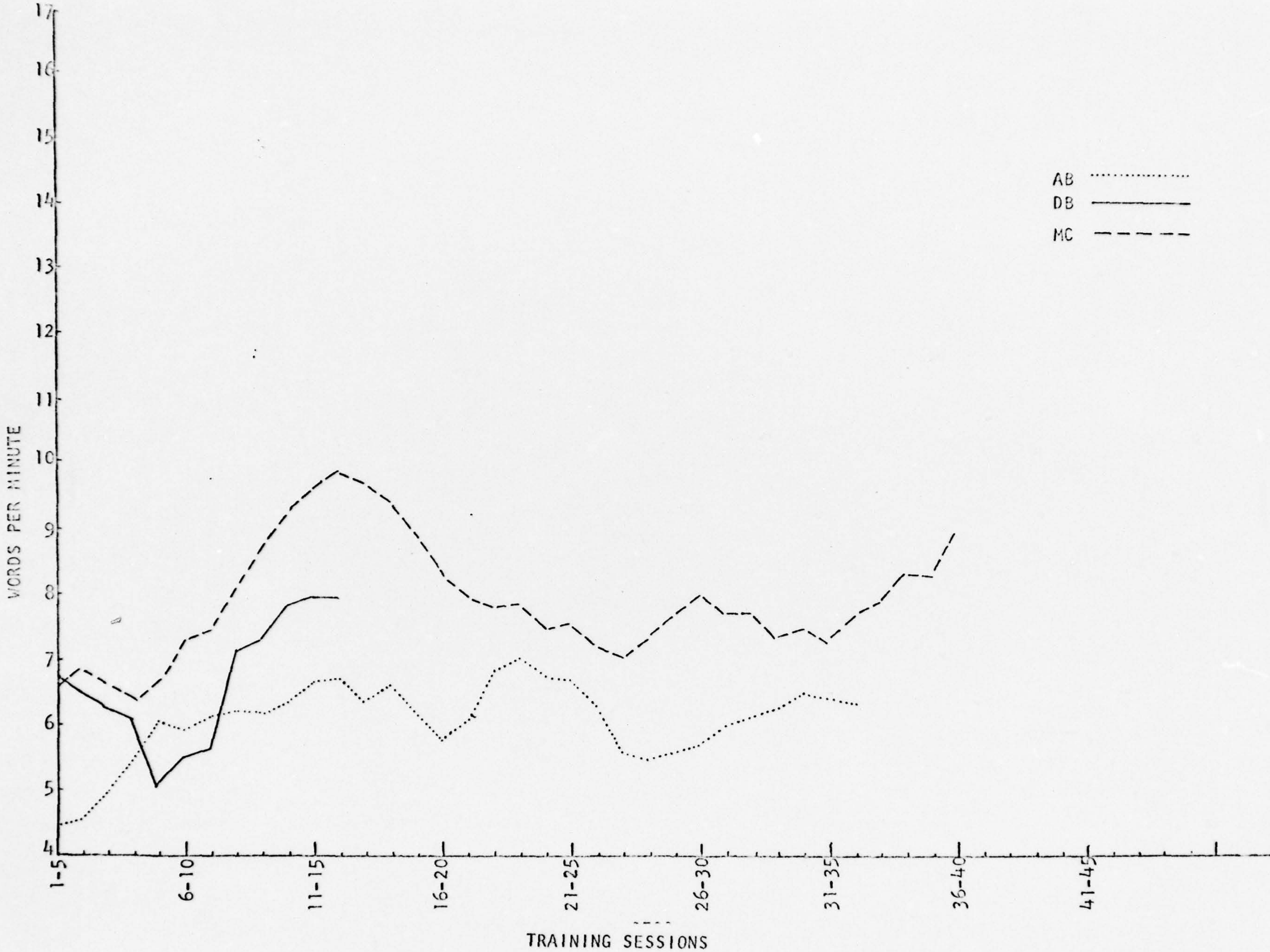

Fig. 8. Number of words per minute as a function of manually sent trials (The data points in terms of which the curves are plotted are running averages based on the means of word rates (wpm) for training sessions 1-5, 2-6, 3-7, etc.)

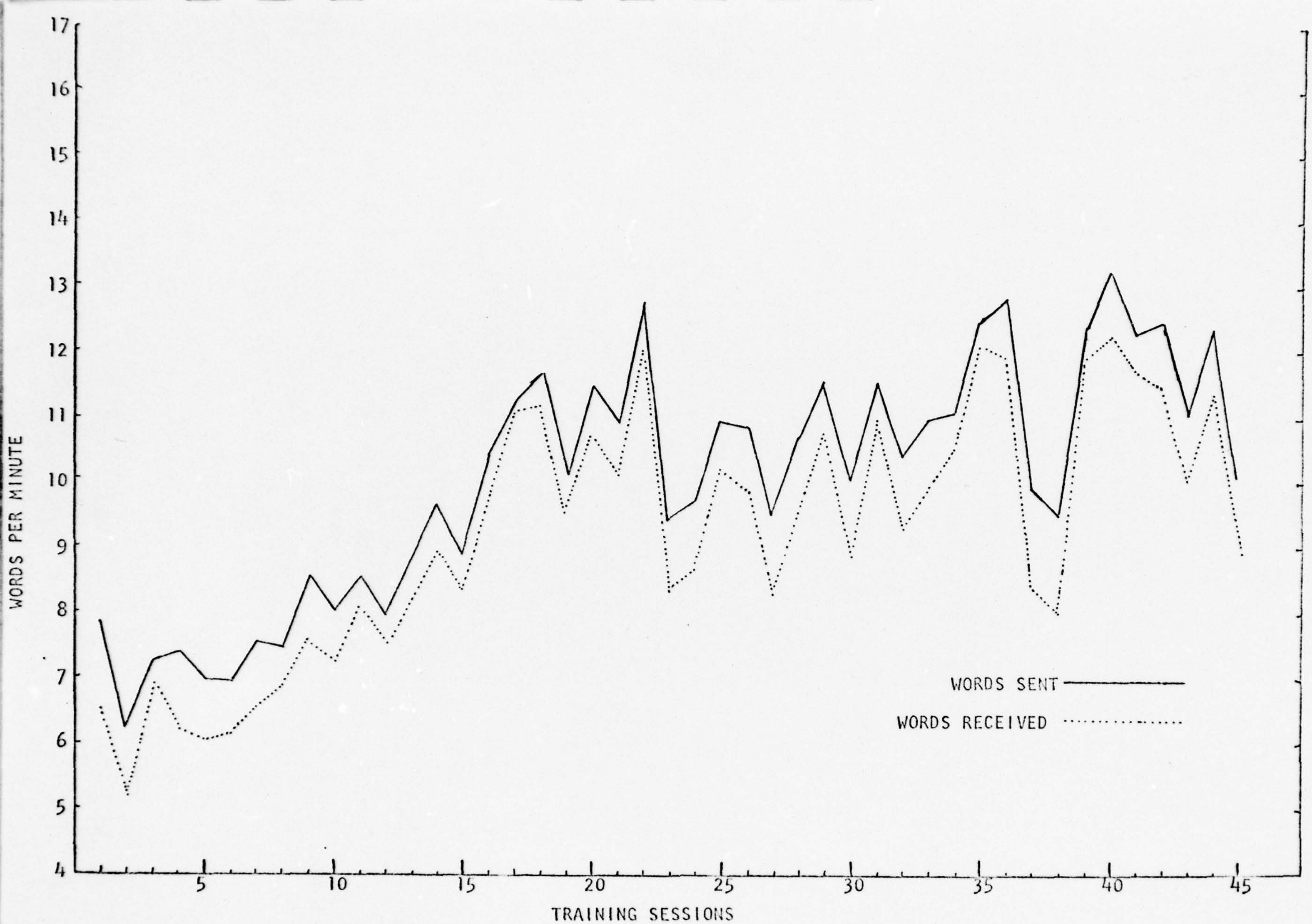

Fig. 9A (Subject AB) Number of words per minute as a function of the number of modified self pacing trials

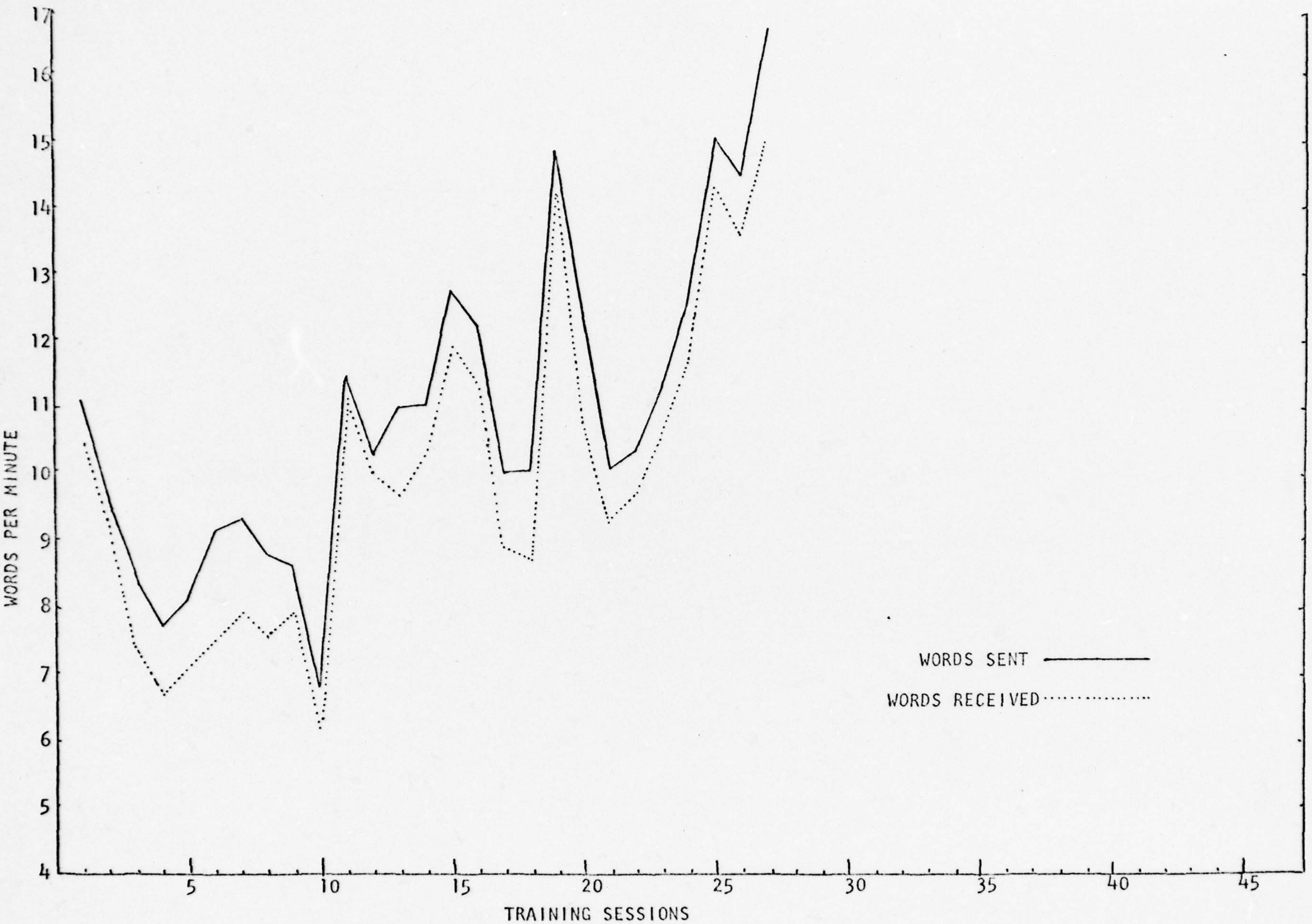

Fig. 9B (Subject MC) Number of words per minute as a function of the number of modified self pacing trials

Table 9 shows words sent and words received for seven subjects. Each column presents data for a single subject and each row for a single session. The first entry in each cell of the table refers to words sent, the second to words received. This table gives a good picture of the progress made by subjects in learning to receive prose, and the last few rows of the table can be regarded as a fairly accurate statement of the subjects' skill at the present stage of training.

As indicated earlier in this report, the advantage gained by the use of contractions and abbreviations is not as apparent as was hoped. In fact, informal observation has suggested that subjects often seem to perform better when receiving uncontracted unabbreviated prose. In order to determine the influence of contractions and abbreviations upon the reception of prose, a prose selection was divided into twenty passages of approximately one hundred words in length. A passage was terminated only at the end of a sentence, and therefore it contained fewer or more than one hundred words depending upon the direction of the nearest sentence break from the point in the sentence at which the one hundredth word fell. All passages were transcribed onto punched tape. Half of the tapes contained contractions and abbreviations. The remaining tapes were uncontracted. Subjects received two passages per training session for the course of the experiment, one contracted and one uncontracted. To control for the effects of fatigue and practice, the order in which contracted and uncontracted passages were encountered was alternated from session to session. Because of difficulties encountered during the course of the experiment, subjects did not all receive the same number of trials. However, each subject did receive enough trials to permit comparison of his performance on the reception of uncontracted prose with his performance on the reception of contracted prose.

The results are shown in Table 10. Each column in this table presents the data for one subject. Each row presents the data for one session. The first

Table 9

Number of Words Sent and Words Received Per Minute
By Seven Subjects Using a Modified
Self Pacing Method

Session	Subj. "AB"		Subj. "MC"		Subj. "DB"		Subj. "MH"		Subj. "AL"		Subj. "MM"		Subj. "EF"	
Words:	Sent	R'd	Sent	R'd	Sent	R'd	Sent	R'd	Sent	R'd	Sent	R'd	Sent	R'd
1	7.81	6.59	11.10	10.50	7.86	7.42	3.58	3.09	2.97	2.07	5.13	4.81	6.98	6.32
2.	6.28	5.25	9.60	9.11	10.29	9.99	4.64	3.97	4.21	3.95	6.56	5.65	6.78	6.26
3.	7.33	6.92	8.51	7.53	9.61	9.25	7.80	7.49	5.23	5.23	8.40	7.98	7.87	7.60
4.	7.51	6.26	7.70	6.67	8.47	7.57	7.21	6.95	3.83	3.11	7.59	6.51	6.76	6.64
5.	7.00	6.10	8.08	7.05	10.87	10.47	7.34	6.80	5.14	4.54	6.59	5.82	6.19	6.02
6.	6.99	6.13	9.14	7.47	9.35	8.37	7.72	7.09	6.80	6.57	6.97	6.56	6.33	5.88
7.	7.62	6.57	9.31	7.92	11.40	11.04	7.16	6.45	7.80	7.63	7.26	6.39	6.00	5.68
8.	7.49	6.93	8.81	7.56	10.34	9.59	7.46	7.09	7.27	7.00	6.75	6.08	5.87	5.35
9.	8.60	7.58	8.65	7.89	10.25	9.57	7.50	6.83	6.24	6.00	6.70	5.81	6.79	6.55
10.	8.10	7.33	6.80	6.06	13.17	13.03	7.43	6.84	7.23	7.00	6.76	6.34	6.17	6.08
11.	8.60	8.04	11.39	11.10	11.98	11.35			8.17	7.91	8.00	7.66	6.98	6.88
12.	8.00	7.58	10.28	9.99	10.20	10.09			8.61	8.52	8.92	8.57	7.73	7.57
13.	8.90	8.18	11.00	9.68	10.68	10.46			8.53	8.18	9.45	8.72	7.63	7.63
14.	9.70	8.98	11.10	10.24	14.84	14.53			8.88	8.80	9.68	9.17	7.12	7.12
15.	8.98	8.39	12.70	11.87	10.68	9.94			9.05	8.97	9.44	7.71		
16.	10.49	9.86	12.20	11.43	11.99	11.61			9.40	8.93	8.84	8.10		
17.	11.31	11.07	10.00	8.89	14.19	13.91			12.89	12.76	8.14	7.78		
18.	11.67	11.22	10.04	8.70	11.33	10.90			10.87	10.36				
19.	10.14	9.63	14.80	14.20	12.15	12.15			12.51	12.38				
20.	11.54	10.76	12.10	10.70	11.29	10.31			14.04	13.60				
21.	10.90	10.14	10.05	9.25	10.79	10.14			13.81	13.20				
22.	12.80	12.00	10.33	9.67	10.97	10.37			11.61	11.15				
23.	9.43	8.37	11.24	10.53	11.21	11.10			14.44	14.28				
24.	9.76	8.66	12.50	11.57	12.07	11.55								
25.	10.96	10.21	15.00	14.30	14.63	14.31								
26.	10.85	9.84	14.40	13.60	11.72	10.97								
27.	9.54	8.31	16.73	14.96	11.06	10.13								
28.	10.68	9.67	12.20	10.37	11.93	11.29								
29.	11.54	10.77			11.83	11.33								
30.	10.09	8.88			12.69	12.29								
31.	11.59	10.98			12.77	12.65								
32.	10.44	9.29			8.98	7.50								
33.	11.00	10.00			10.65	10.37								
34.	11.10	10.56			9.86	8.96								
35.	12.48	12.12			15.31	15.00								
36.	12.89	11.95			10.21	10.20								
37.	9.95	8.49			11.57	10.87								
38.	9.49	8.05			12.57	11.89								
39.	12.39	11.84			9.96	8.66								
40.	13.20	12.31			11.42	10.39								

Table 9 (Cont'd)

Session	Subj. "AB"		Subj. "MC"		Subj. "DB"		Subj. "MH"		Subj. "AL"		Subj. "MM"		Subj. "EF"	
Words:	Sent	R'd	Sent	R'd	Sent	R'd	Sent	R'd	Sent	R'd	Sent	R'd	Sent	R'd
41.	12.34	11.77			13.77	13.04								
42.	12.53	11.49			14.58	14.17								
43.	11.10	10.11			13.89	13.48								
44.	12.40	11.40			12.47	11.77								
45.	10.20	9.00			13.71	13.14								
46.					16.11	15.11								
47.					13.28	12.53								
48.					16.27	15.90								
49.					13.99	12.77								
50.					15.53	14.76								
51.					12.79	11.14								
52.					14.31	14.16								
53.					15.28	14.70								
54.					13.01	12.17								
55.					15.32	14.84								
56.					11.99	11.15								
57.					14.86	13.96								
58.					15.08	14.79								
59.					17.98	17.45								
60.					22.70	21.99								
61.					15.60	14.87								
62.					14.09	13.08								
63.					15.72	14.31								
64.					16.45	15.97								
65.					15.99	15.32								
66.					17.69	17.53								
67.					13.13	11.63								
68.					13.57	12.57								
69.					12.49	11.15								
70.					16.27	15.42								
71.					13.49	12.34								
72.					18.93	18.04								
73.					14.87	14.23								

Table 10

Words Per Minute for Contracted vs. Uncontracted Prose

Session	Subject "A B"		Subject "D B"		Subject "M C"		Subject "M H"	
	Uncontracted	Contracted	Uncon'd	Con'd	Uncon'd	Cont'd	Uncon'd	Cont'd
1	4.56	5.80	10.87	9.35	7.10	7.43	6.53	8.03
2	5.97	6.30	11.40	10.34	6.65	7.85	8.49	8.06
3	7.13	6.32	13.17	10.25	6.43	7.24	8.52	7.51
4	8.52	6.77	11.98	10.20	8.73	8.35	10.96	9.97
5	5.60	5.16	14.84	10.68	5.85	9.07	11.59	12.00
6	4.97	5.65	10.68	11.99	6.51	6.83		
7	6.20	5.62	11.33	14.19	7.99	9.10		
8	7.13	6.01	12.15	11.29				
9	5.42	6.96						
10	5.69	6.78						
Means of Columns	6.12	6.14	12.05	11.04	7.04	7.98	9.22	9.11

entry in each cell is the receiving rate in words per minute for uncontracted passages, and the second entry in each cell is the corresponding figure for contracted passages. The row at the bottom of the table gives the means for uncontracted words and for contracted words. Since there were large differences in the amount of training received by each of the subjects at the onset of the experiment, no test was made for between - subjects variance. "t" tests show that the difference between the means for subjects are not significant at the .05 level.

A Locus Code

The investigation of another approach to electro-cutaneous communication is now in progress. This is a code in which subjects are required to identify patterns of simultaneously applied d.c. pulses. The patterns are analogous to those formed from dots in the Braille code. Braille is by far the most succesful means of cutaneous communication that has been tried. Braille reading rates of over 100 words per minute are common, and rates up to 200 words per minute are possible. The reading of Braille requires the reader to recognize patterns of dots. Each of these patterns is formed in a cell in which six dot positions are available. Any number of dots from one to six may be used, and for any given number of dots, all possible combinations of positions can be used. Therefore, the total number of possible dot arrangements is $2^6 = 64$. One of these arrangements is that of no dots. This leaves 63 dot patterns for use in the Braille code.

Absolute tactual identification of all 63 patterns is a relatively easy task for humans. Since this is true, it may also be the case that similar patterns formed from electro-cutaneous stimuli can be identified easily.

Apparatus: To explore this possibility, two pieces of apparatus have been developed. Each can deliver a combination of from one to six d.c. pulses to the skin.

One device makes use of a separate 107 volt battery for each of the six possible stimuli. Battery current is switched on and off from a keyboard composed of six microswitches. Stimulus pulse length is determined by a Hunter Timer connected in the common lead. To be painless, d.c. stimulation must be brief. With the timer used, it has been possible to form pulses of approximately two msecs. in duration. A variable resistance is connected in each of the six electrode leads so that the six d.c. pulses can be adjusted for comfort and for equal apparent intensity.

The other device makes use of the pulse that is developed when a circuit is broken in which an inductance is connected. For each of the six stimuli there is a 6.2 volt filament transformer. A 1.5 volt battery is connected across the 6.2 volt winding. The subject is connected across the 117 volt winding. A microswitch is connected, in its normally closed mode, in series with the battery. When this switch is open, a pulse is generated, and this pulse serves as the stimulus. A variable, limiting resistance is also connected in series with the battery. The pulse generated in this way has a duration of approximately one-half msec. Without limiting resistance, it rises to a peak of approximately 1,000 volts. A picture of its oscilloscope trace was taken and is shown in Figure 10. The "X" axis in this figure is scaled in microseconds, and the "Y" axis is scaled in volts.

Both devices can be operated manually from a keyboard or automatically by means of the tape reader.

<u>Subjects</u>: So far, only the principal investigator and an assistant have served as subjects. The principal investigator is an experienced Braille reader and is therefore quite familiar with the patterns used in the code. For him, learning the code should be primarily a matter of substituting patterns of d.c. pulses for patterns of dots. This should make possible a fairly rapid evaluation

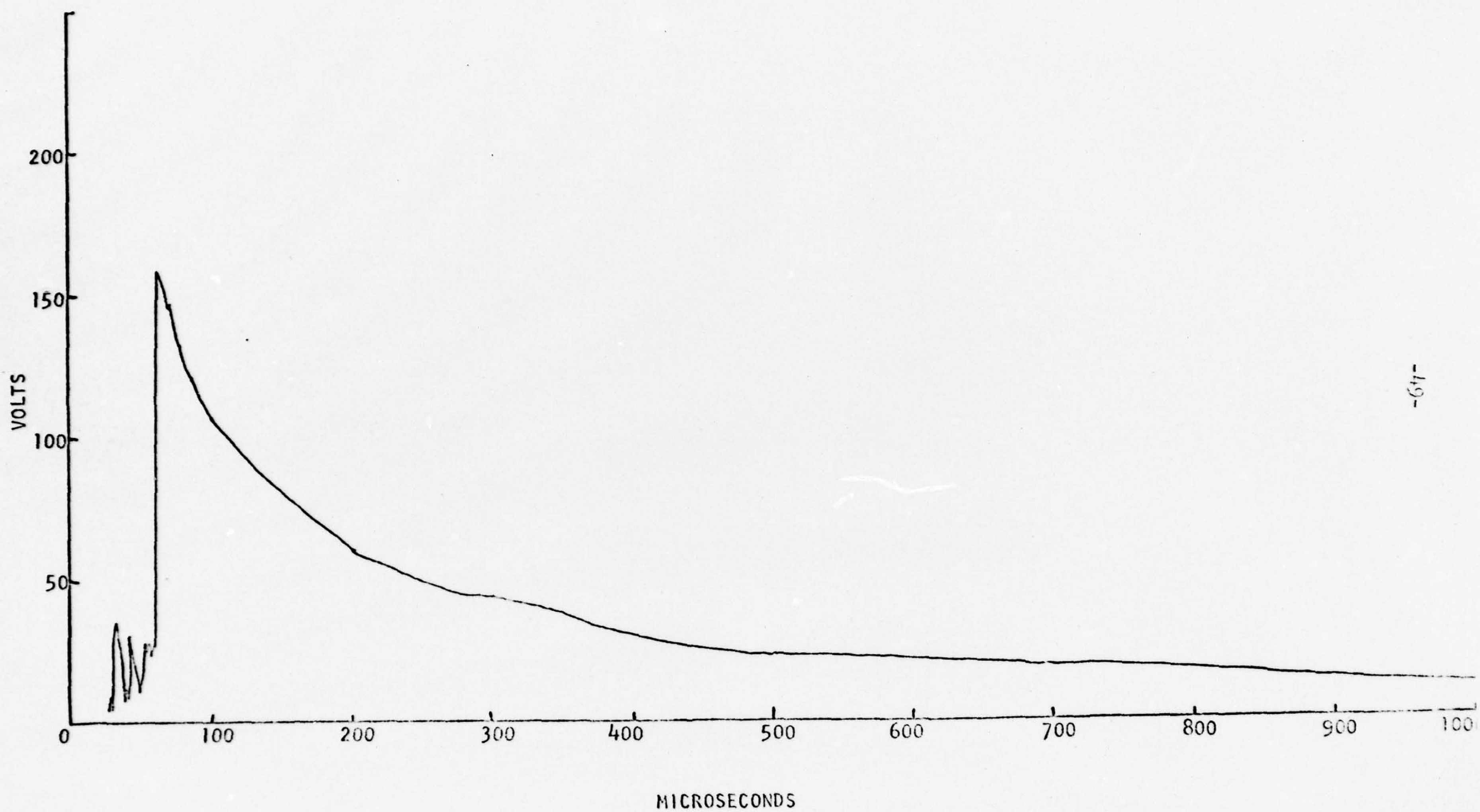

Fig. 10. STIMULUS VOLTAGE AS A FUNCTION OF TIME (Measurement taken with 20,000 ohm load across transformer primary)

of the feasibility of such a code. Plans are now being made for formal experiments in which both experienced Braille readers and naive subjects will participate.

Preliminary Results:

The Choice of Stimuli

The .5 msec. stimuli produced by the inductive stimulator described above appear to be more satisfactory. They are experienced as light taps on the surface of the skin and there is no sting associated with them. The stimuli produced by the direct application of battery current to the skin do occasionally result in a stinging sensation. This problem could be avoided by using shorter stimulus durations. However, this is not possible with the timers to which we have access. The inductive stimulator requires no timing device.

Locus

So far, two sets of loci have been tried. One set includes the forefinger, middle finger and ring finger on each hand. Starting with the forefinger, the fingers on the left hand correspond to positions 1, 2, and 3 in the Braille cell, while the fingers on the right hand correspond to positions 4, 5 and 6. These fingers are the ones used to activate the keys on a Braille writer. There are six keys on a Braille writer and each key, when pressed, produces one of the six dots in the Braille cell. Thus, for one experienced in the use of a Braille writer, there is already a learned correspondence between these six fingers and the six positions in the Braille cell.

The six loci in the other set that has been evaluated so far are the wrists, elbows and shoulders. Starting with the wrist, the loci on the left side of the body correspond to Braille cell positions 1, 2 and 3, while the loci on the right side of the body correspond to positions 4, 5 and 6. Informal and limited experience with these two sets of loci does not indicate any clear cut advantage for one set over the other. This matter will be explored more carefully and, in addition, other sets of loci will be tested in the future.

Reaction Time

One preliminary finding that may prove to be of considerable importance has to do with reaction time. The reaction times to signals composed of patterns of simultaneously applied stimuli appear to be running much shorter than the reaction times to the tri-dimensional stimuli used in the other code. The principal investigator's reaction times to all 63 signals in the locus code were determined. At the time of this determination, he had had practically no experience with this code. The mean of these reaction times was one second. The mean of the same subject's reaction times to the 39 signals in the tri-dimensional code, after many training sessions, was three seconds.

Though the finding regarding reaction times is based upon insufficient data, it suggests a difference in favor of the locus code that may turn out to be crucial. An experiment is now in progress in which groups of subjects are taught three simple codes that are the same in all respects except for the number of stimulus dimensions involved. One code uses only locus cues. The second code uses either locus and duration cues or locus and intensity cues. The third code uses locus, duration and intensity cues. The results of this experiment will be presented in a subsequent report.

Accuracy of Identification

So far, the one subject who has received locus code training, has been administered 40 trials. Each trial consists of a single presentation of each of the 63 stimulus combinations available in this code. There have been from two to eight errors per trial. The same subject, on the 39 element tri-dimensional code, had a much higher error score at the same stage in training.

A short passage of unfamiliar prose was sent to the subject by means of the locus code. Without prior experience in receiving connected prose presented in this manner, he achieved a word rate of 11.53 wpm. This figure should be compared with 7.64 wpm, the best word rate achieved by this subject on the tri-dimensional code after 16 training sessions.

At the writing of this report, only the pilot work on the locus code that is preliminary to the conduct of more formal research has been accomplished. However, enough has now been learned to permit the planning of several experiments. The results of these experiments will be presented in subsequent reports. The pilot work accomplished so far suggests that, as far as the stimulus alphabet is concerned, a code based on locus cues alone may be perceptually superior to a code in which the subject is required to make an absolute identification in each of three dimensions for every signal.

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Appendices

Appendix | Page

Appendix A

In the chart below, each symbol is followed by a group of characters that describe the stimulus associated with that symbol. The first character in the group designates the hand to which the stimulus is applied. R=right, L = left. The second character specifies the finger to which the stimulus is applied. The fingers are numbered 1 through 5, starting with the thumb. The third character in the group specifies the duration of the stimulus, S = short, L = long. The fourth character specifies the intensity of the stimulus, W = weak, S = strong.

		Numbers
A = R2SS	U = L4SS	1 = L5LS
B = R2LW	V = L5SW	2 = L4LS
C = R3LS	W = L5SS	3 = L3LS
D = L3LS	X = R5LW	4 = L2LS
E = R1LS	Y = R3LW	5 = L1LS
F = R5SS	Z = L1LW	6 = R1LS
G = R5SW	Th = L5LW	7 = R2LS
H = L2SS	ing - L2LW	8 = R3LS
I = L3SS	en = L1LS	9 = R4LS
J = R3SW	in = R1SS	0 = R5LS
K = L3LW	of = L3SW	
L = R4SS	er = L1SS	
M = L5LS	and = R1SW	
N = R3SS	for = R2SW	
O = L2LS	ed = R4LW	
P = L4LW	ar = R5LS	
Q = R4SW	ea (& comma)=R1LW	
R = R4LS	? = L2SW	
S = R2LS	ble(&# sign)=R4SW	
T = L4LS		

APPENDIX B

CHART OF SHORT WORD FORMS

ab - about
abv - above
ac - according
acr - across
af - after
afn - afternoon
afw - afterward
ag - again
agst - against
al - also
alm - almost
alr - already
alt - altogether
alth - although
alw - always
b - but
bec - because
bef - before
beh - behind
bel - below
ben - beneath
bes - beside
bet - between
bey - beyond
bl - blind
brl - braille
c - can

chn - children
concv - conceive
concvg - conceiving
d - do
dcl - declare
dclg - declaring
dcv - deceive
dcvg - deceiving
e - every
ei - either
f - from
fr - friend
fst - first
g - go
gd - good
grt - great
h - have
herf - herself
hm - him
hmf - himself
imm - immediate
immly - immediately
j - just
k - knowledge
l - like
ll - little
lr - letter

mch - much
mst - must
myf - myself
n - not
nec - necessary
nei - neither
o'c - o'clock
onef - oneself
ourvs - ourselves
p - people
pd - paid
percv - perceive
percvg - perceiving
perh - perhaps
q - quite
qk - quick
r - rather
rcv - receive
rcvg - receiving
rjc - rejoice
rjcg - rejoicing
s - so
sch - such
sd - said
shd - should
t - that
td - today

APPENDIX B(cont'd)

cd - could

m - more

tgr - together

th - this

themvs - themselves

thyf - thyself

tm - tomorrow

tn - tonight

u - us

v - very

w - will

wd - would

x - it

xf - itself

xs - its

y - you

yr - your

yrf - yourself

yrvs - yourselves

z - as

APPENDIX C

SIMPLE AUDITORY REACTION TIME OF EXPERIMENTERS

Experimenter:	MM	EF
	.14	.16
	.20	.14
	.14	.13
	.12	.15
	.15	.12
	.16	.12
	.12	.15
Simple Reaction Times	.12	.15
	.21	.16
	.13	.12
	.12	.11
	.13	.15
	.17	.13
	.15	.14
	.16	.12
Mean	.148	.137
S. D.	.0273	.0157

APPENDIX D

Confusion Matrix

Signals Received (columns) / Signals Sent (rows)

Signals Sent	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	&	BLE	TH	ER	EN	IN	ING	,	?	AR	ED	OF	FOR	No rsp	# crt
A	44	2																																							
B		45																																							
C			47																																						
D			1	46																																					
E					46																																				
F						44	1																																		
G							42																																		
H								43																																	
I				1					46																																
J										43																															
K				4							43																														
L												42																													
M													47																												
N			:							3				43																											
O								1							46																										
P																42	1			3	1																				
Q																	42				5																				
R																		46																							
S																			47																						
T																				47																					
U																	3			1	42		1																		
V																						47																			
W																						5	42																		
X						1	1																	42		1															
Y			2																						45																
Z																										44															
&																											40														
BLE												1																43													
TH													6										3						38												
ER								1																		1				42	3										
EN																										7					46										
IN																															1	43		3							
ING								3							2																		42								
,					1																									1	1	6		35			1			1	36
?								4																								1	2		40						40
AR																																				47					47
ED												6																									41				41
OF									7		2																											38			38
FOR	2	9																																					36		36

Subject A. B. based on 47 trials

Confusion Matrix

Signals Received (columns) / Signals Sent (rows)

Sent	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z
A	11																									
B		11																								
C			10																						1	
D				10							1															
E					11																					
F						10	1																			
G							11																			
H								7																		
I				1					5																	
J										7				1											1	
K				1							9															
L											1	2														
M													11													
N														11												
O															11											
P																10					1					
Q																1	10									
R																		8								
S																			11							
T																				11						
U																					11					
V																						11				
W																						1	9			
X																								9		
Y										4															5	1
Z																										10
AND																										
BLE																										
TH																										
ER																										
EN					1																					
IN																										
ING								1							2											
,																										
?																										
AR																										
ED																								1		
OF									1		1															
FOR		2																								

Sent	&	BLE	TH	ER	EN	IN	ING	,	?	AR	ED	OF	FOR	no rsp	# crt
A															11
B															11
C															10
D															10
E															11
F															10
G															11
H									2					2	7
I												1		4	5
J														2	7
K												1			9
L		5									1			2	2
M															11
N															11
O															11
P															10
Q															10
R														3	8
S															11
T															11
U															11
V															11
W			1												9
X		1												1	9
Y														1	5
Z					1										10
AND	11														11
BLE		9									2				9
TH			11												11
ER				9	1									1	9
EN					9	1									9
IN	2			1		8									8
ING							8								8
,	4			1				6							6
?				1			4		6						6
AR										11					11
ED											10				10
OF												8		1	8
FOR	1												8		8

Subject E. F. - based on 11 trials

Confusion Matrix

Signals Received (columns) / Signals Sent (rows)

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	&	BLE	TH	ER	EN	IN	ING	,	?	AR	ED	OF	FOR	no rsp	# crt
A	9																																								9
B		8																																					1		8
C			9																																						9
D				9																																					9
E					9																																				9
F						9																																			9
G							9																																		9
H								9																																	9
I									9																																9
J										9																															9
K											9																														9
L												9																													9
M													9																												9
N														9																											9
O															9																										9
P																9																									9
Q																	8				1																				8
R																		9																							9
S																			9																						9
T																				9																					9
U																					9																				9
V																						9																			9
W																						1	8																		8
X																								9																	9
Y																									8															1	8
Z																										9															9
and																											7							2							7
ble																												9													9
the													1																8												8
er																														9											9
en																															9										9
in																																9									9
ing																																	8		1						8
,																																		9							9
?																																			9						9
ar																								1												8					8
ed																																					9				9
of																																						9			9
for		2																																					7		7

Subject M. H. - based on 9 trials

Confusion Matrix

Signals Received (columns) / Signals Sent (rows)

Sent	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	&	BLE	TH	ER	EN	IN	ING	,	?	AR	ED	OF	FOR	no rsp	# crt
A	22																																								22
B		22																																							22
C			21																						1																21
D			1	21																																					21
E					22																																				22
F						22																																			22
G						2	20																																		20
H								20																											2						20
I									22																																22
J										21																														1	21
K											22																														22
L												22																													22
M													21																1												21
N										2				20																											20
O															21																	1									21
P																22																									22
Q																	22																								22
R																		20																		1	1				20
S																			22																						22
T													1			4				17																					17
U																1	1				20																				20
V																						21	1																		21
W																						2	20																		20
X																								20												2					20
Y			1																						21																21
Z																										21					1										21
and																											22														22
ble												4						1										17													17
th																													22												22
er																														22											22
en					1																					[illegible]					18										18
in																											[illegible]					19		1							19
ing								1																									20							1	20
,																																1		19						2	19
?																																	2		19					1	19
ar																								2												20					20
ed																		4																			17			1	17
of									6																												1	15			15
for	2																																					1	18	1	18

Subject A.L .-based on 22 trials

Confusion Matrix

signals received

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	&	BLE	TH	ER	EN	IN	ING	,	?	AR	ED	OF	FOR	no rsp	# crt
A	14																																									14
B		14																																						14
C			12	1																					1																	12
D				14																																					14
E					13																													1							13
F						14																																			14
G							14																																		14
H								14																																	14
I									12																													1		1	12
J										14																															14
K											14																														14
L												13																									1				13
M													14																												14
N														14																											14
O															13			1																								14
P																13				1																					13
Q																	13				1																				13
R												1						13																								13
S																			14																						14
T																				14																					14
U																	1				13																				13
V																					2	10	2																		10
W																							14																		14
X																								14																	14
Y																									14																14
Z																										13								1							13
and																											14														14
ble																												11									3				11
th													1																	13												13
er																														11	2	1									11
en																										1					13										13
in																																13								1	13
ing																																	14								14
,																																		14							14
?								1																									1		12						12
ar																								1													13					13
ed																												1									13				13
of									2		1																											11			11
for	2																																					12		12

Subject M. M. - based on 14 trials

Confusion Matrix

Signals Received (columns) / Signals Sent (rows)

Sent	A	B	C	D	E	F	G	H	I	J	K	L	M
A	29												
B	2	30											
C			29										
D				31						1			
E					28								
F						28	3						
G						1	31						
H								28					
I									27				
J										21			
K				2					1		28		
L												25	
M													26
N										1			
O								1				1	
P													
Q													
R												2	
S		1											
T													
U													
V													
W													
X						2							
Y			1										
Z													
and													
ble												1	
th													6
er													
en													
in					2								
ing								1					
,													
?								2					
ar													
ed												2	
of									1				
for	4	3											

Sent	N	O	P	Q	R	S	T	U	V	W	X	Y	Z
A													
B													
C	1				1							1	
D													
E													
F											1		
G													
H		1											
I													
J	5			1								3	
K													
L													
M										1	1		1
N	30												
O		29											
P			28	2			2						
Q				26				2	1				
R					28								
S						31							
T						1	31						
U				2				30					
V									25	7			
W									2	30			
X											28		
Y												31	
Z													26
and													
ble													
th										1		1	
er									1				1
en													
in													
ing		1											
,	1												
?													
ar											3		
ed					1								
of													
for													

Sent	&	BLE	TH	ER	EN	IN	ING	,	?	AR	ED	OF	FOR	no rsp	# crt.	
A													3		29	A
B															30	B
C															29	C
D															31	D
E						2		2							28	E
F															28	F
G															31	G
H							1		1					1	28	H
I												5			27	I
J														2	21	J
K														1	28	K
L		4									3				25	L
M			3												26	M
N		1													30	N
O							1								29	O
P															28	P
Q												1		2	26	Q
R											2				28	R
S															31	S
T															31	T
U															30	U
V															25	V
W															30	W
X										2					28	X
Y															31	Y
Z				4	2										26	Z
and	28					3								1	28	and
ble		27		1							3				27	ble
th	1		23												23	th
er				29									1		29	er
en					32										32	en
in	2					25		2						1	25	in
ing							30								30	ing
,	6			1				25							25	,
?									30						30	?
ar										29					29	ar
ed				1							28				28	ed
of												29	1	1	29	of
for												1	24		24	for

Subject D. P. - 32 trials