XIX. SENSORY AIDS RESEARCH*

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A. STUDIES OF TEMPLATE-MATCHING CHARACTER RECOGNITION

In connection with research[1] directed toward establishing the feasibility of a single-sensor optical comparator technique for character recognition for use in a reading machine for the blind, experiments were performed in an attempt to establish some measure of the static and dynamic performance of such a system for the various template-character pairs. In particular, for the purpose of preliminary evaluation, data have been acquired to determine the character-discrimination potential and registration tolerances of the technique by using specially designed template characters in conjunction with IBM Executive typewriter test capitals. Each selected template character was projected onto each of the test characters one by one, and a table of relative

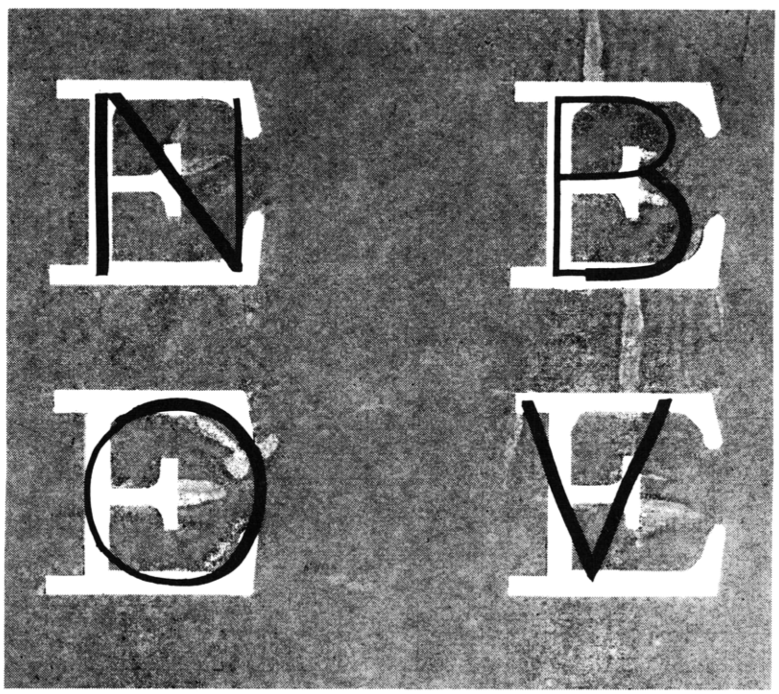

Fig. XIX-1. Typical character overlays. (Template characters on test characters.)

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amplitudes corresponding to all of these combinations was made, as well as a table showing the effects of various mismatchings. (See Figs. XIX-1 and XIX-2 and Table XIX-1.) These data were verified by sample calculations based on the overlays in Fig. XIX-1 as tabulated in Table XIX-2.

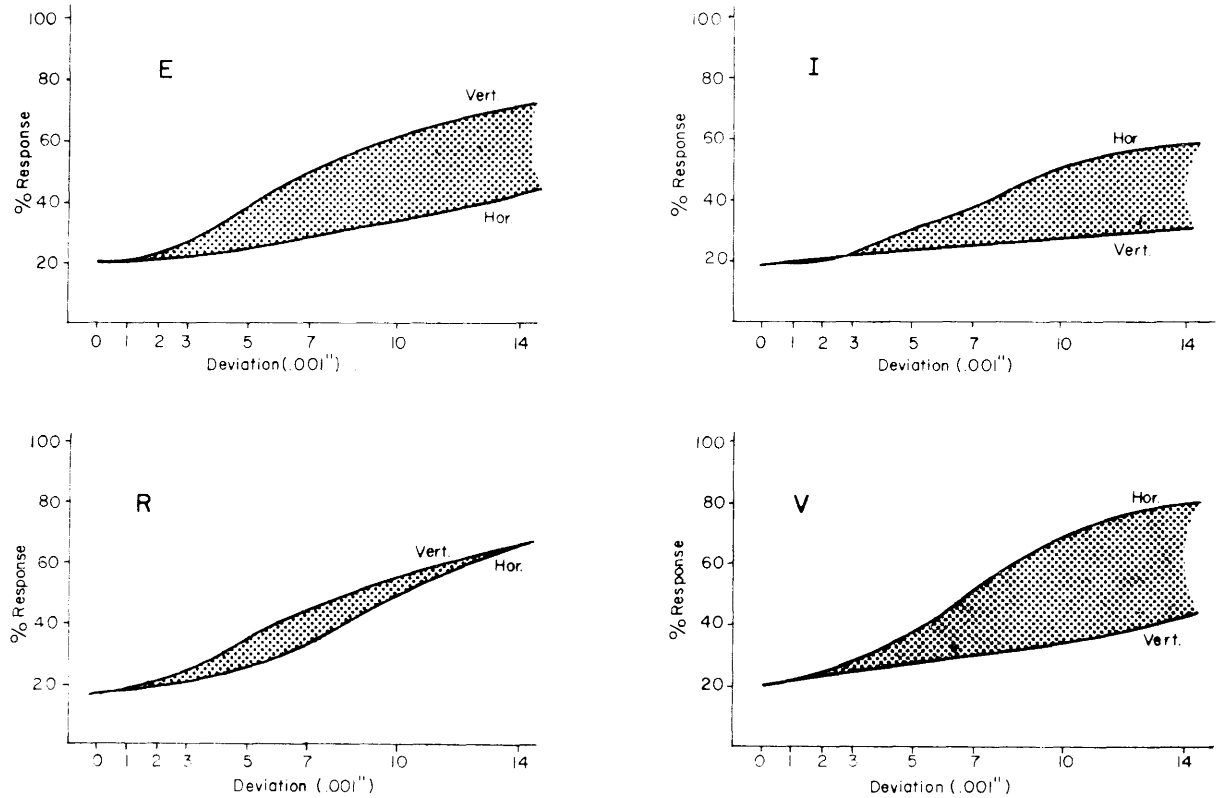


Fig. XIX-2. Deviation from registration vs per cent response for characters E, I, R, V.

The functional components of the model, as detailed in Fig. XIX-3, are mounted on an optical bench as illustrated in Fig. XIX-4. In this fashion a selected template character may have its image projected through a light chopper and focusing lens onto the reading surface. A measure of its reflected light is picked up by a photo transistor, amplified, filtered, and read out by means of an oscilloscope.

The chart relating to the response of the registration of template characters on the typewritten capitals was then used to plot an incidence versus response chart for the entire matrix (Fig. XIX-5), and another for each character (Fig. XIX-6). Examination of these charts yields the salient features illustrated in Table XIX-3. We see from this tabulation that a large measure of discrimination between characters is possible.

Table XIX-1. Photo response to the reflection of projected template characters from IBM Executive typewriter capitals.

REFLECTED LIGHT RATIO PER PROJECTED TEMPLATE CHARACTER

	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	20	46	72	57	55	66	72	60	86	72	46	64	49	58	73	64	68	50	56	72	78	76	58	60	76	64
B	53	22	62	46	52	54	52	44	74	58	44	58	56	72	52	70	56	53	26	56	56	64	54	52	52	58
C	62	32	20	26	30	52	26	50	77	46	52	54	48	68	23	66	22	46	28	62	36	78	62	53	62	44
D	66	33	48	16	38	64	48	36	70	60	52	42	50	50	37	54	35	52	44	70	34	68	50	64	70	52
E	50	32	50	36	21	40	56	44	56	58	35	42	46	56	54	40	56	37	35	46	45	62	59	50	47	42
F	45	26	50	41	22	23	60	28	57	54	26	57	48	56	56	28	58	22	48	52	52	62	50	48	58	58
G	54	34	36	38	39	78	22	42	94	50	78	58	44	50	36	66	34	46	33	40	48	84	58	54	44	46
H	38	32	52	40	50	66	67	20	86	65	43	50	51	59	58	42	48	42	40	56	54	66	58	58	64	58
I	60	20	43	17	21	28	49	21	22	34	19	21	31	36	50	23	44	20	53	27	35	64	55	51	43	54
J	52	34	58	35	40	54	46	47	31	22	58	72	26	45	42	56	37	48	40	38	36	60	54	58	58	58
K	49	58	62	68	56	56	68	58	89	64	18	66	50	46	64	60	58	39	50	62	70	64	44	34	63	52
L	46	26	33	23	18	53	46	31	56	52	33	20	39	58	34	32	30	40	42	52	32	64	42	44	57	38
M	70	54	75	52	72	78	78	64	92	68	55	76	18	68	70	66	50	72	60	74	59	48	54	58	56	61
N	66	60	76	56	54	72	74	44	90	70	38	64	46	22	64	58	58	51	55	66	58	52	52	54	54	74
O	56	32	28	24	32	60	29	48	90	56	57	71	56	58	22	47	21	38	34	57	48	74	58	65	70	49
P	47	36	68	46	48	56	68	34	92	58	52	52	50	62	58	23	58	30	50	64	52	68	54	54	66	58
Q	60	40	36	27	40	64	42	55	93	62	61	68	57	66	25	54	21	48	47	62	54	79	62	71	74	60
R	46	44	64	56	47	48	53	62	74	60	44	76	58	68	68	54	60	18	38	49	69	66	52	55	58	58
S	52	41	56	54	57	52	58	56	64	80	68	60	60	63	63	57	66	36	19	54	60	66	59	54	61	61
T	62	24	46	22	23	30	58	30	32	29	52	28	28	38	45	26	43	30	56	25	39	61	49	58	51	54
U	54	32	52	22	50	55	42	28	80	40	58	59	52	52	36	41	34	56	34	49	20	56	51	64	58	65
V	43	52	72	51	56	58	57	50	58	50	53	62	39	60	48	71	52	46	58	56	58	25	30	50	52	64
W	49	62	74	76	63	80	80	66	82	74	54	67	48	66	77	62	70	56	57	69	70	46	19	52	60	72
X	52	54	72	59	60	62	60	62	68	70	56	61	48	47	65	59	40	30	58	66	62	64	47	20	62	50
Y	53	42	38	40	46	50	46	50	57	48	58	47	50	70	48	46	52	59	64	54	47	43	36	58	24	49
Z	62	50	63	58	48	60	72	58	70	64	44	64	52	78	74	60	70	55	50	56	63	60	55	32	45	23

Reflected Light Ratio
(Template Projection on Printed Character/Projection on White)

Table XIX-2. Calculated response to the reflection of projected template characters from IBM Executive typewriter capitals.

Template Character	Test Character — Exposed area Calculated/Measured Response							
Total Area	E		F		L		I	
N 72	36	50/54	40	56/72	42	58/64	46	64/90
B 66	29	44/52	39	59/54	45	68/58	55	83/74
O 66	23	35/32	37	56/60	45	69/71	54	82/90
V 56	32	57/56	33	59/58	38	68/62	38	68/58

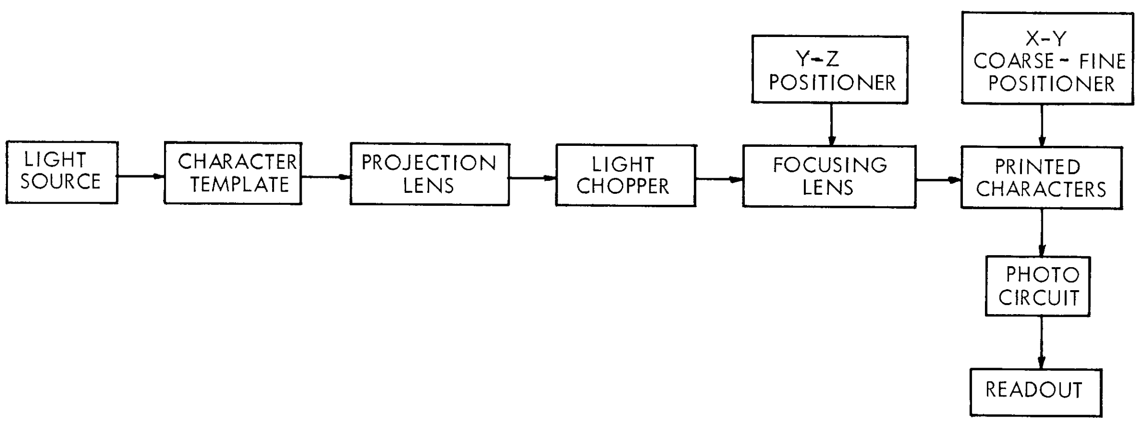


Fig. XIX-3. Block diagram of experimental arrangement.

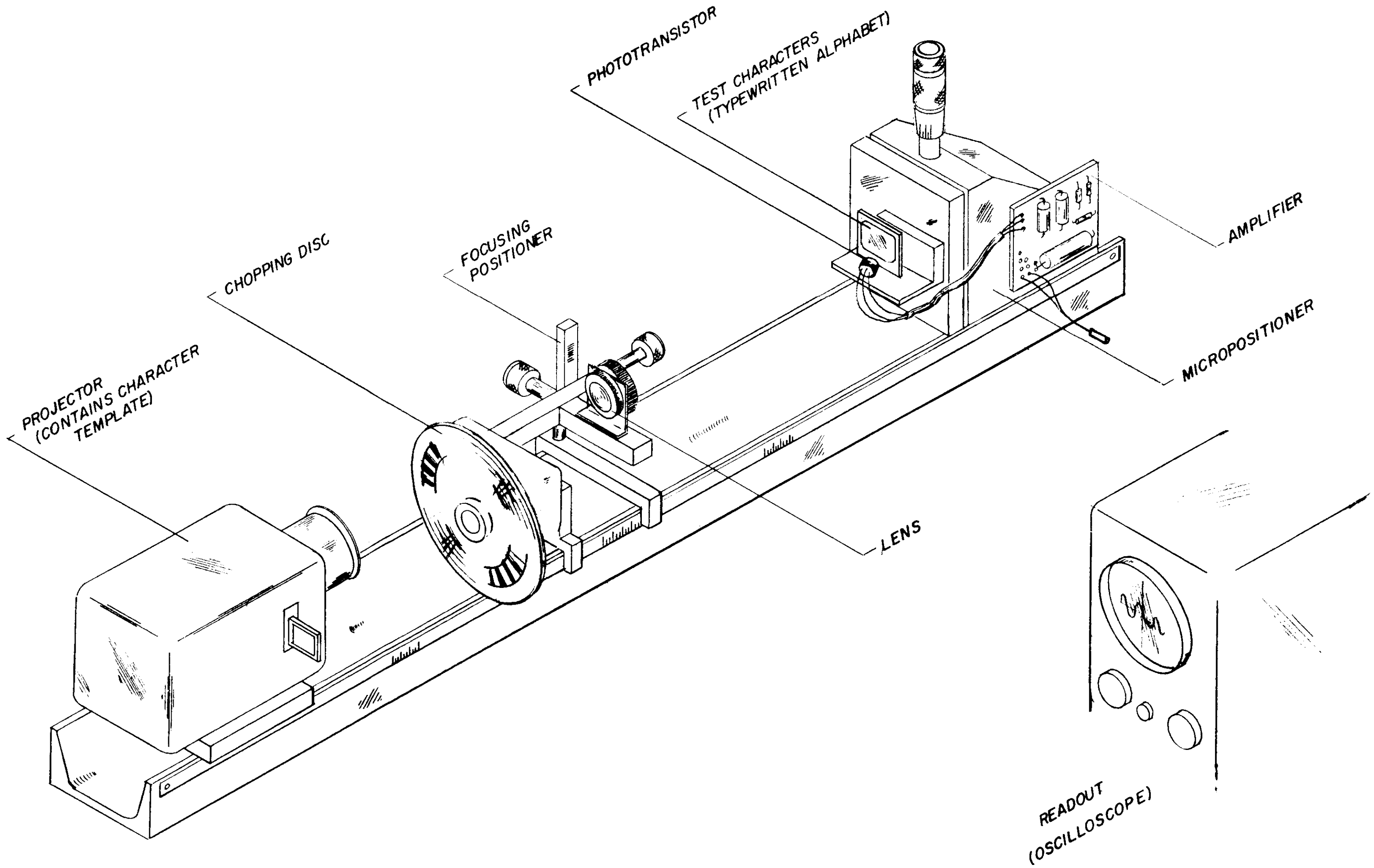


Fig. XIX-4. Optical bench experimental arrangement for evaluation of projected template character comparison technique.

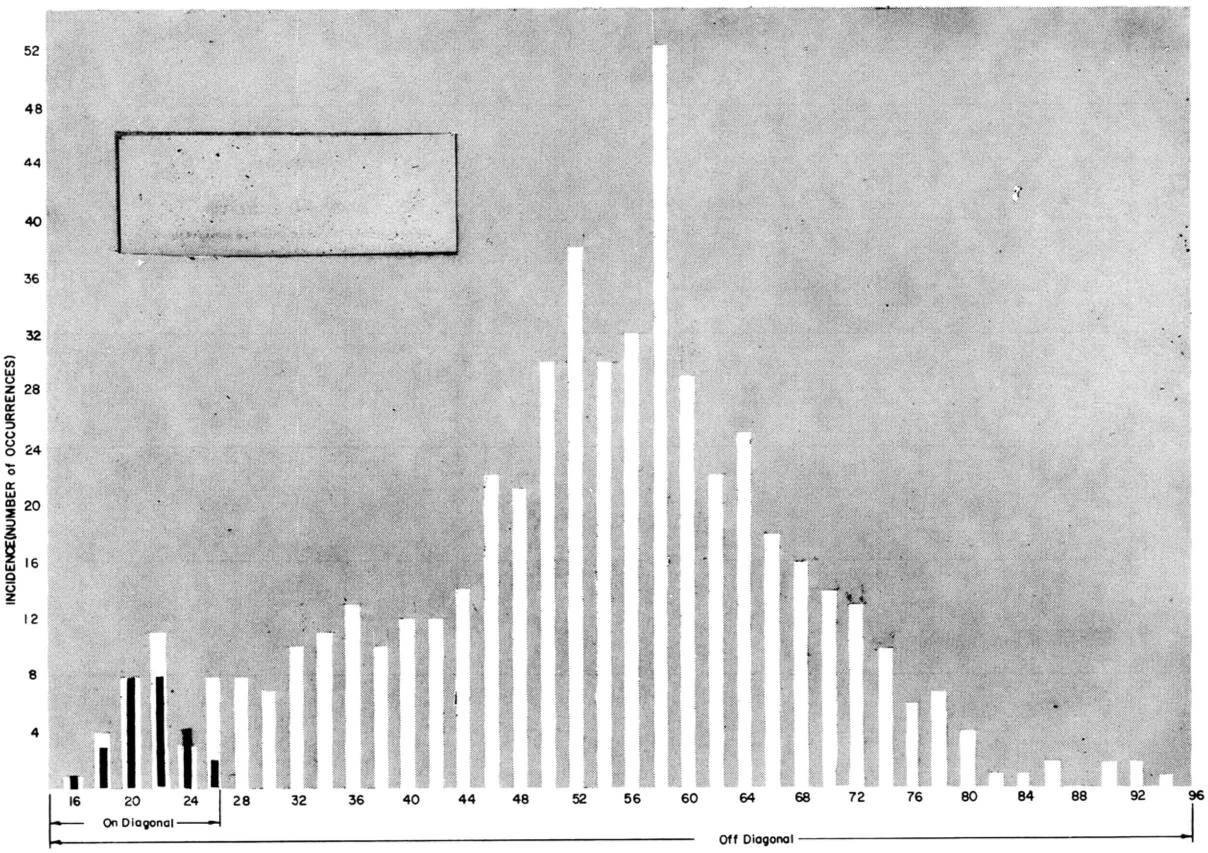
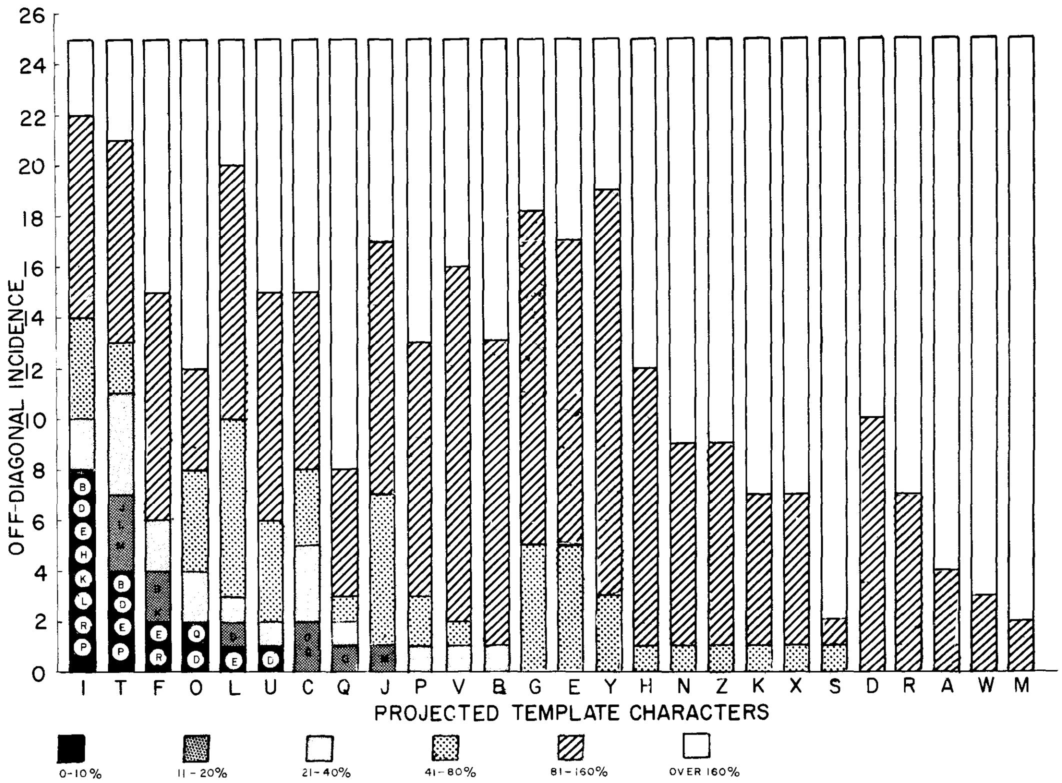


Fig. XIX-5. Incidence vs reflected light ratio (template projection on printed character/projection on white).



Ratio of off-diagonal response /on-diagonal response

Note The off-diagonal characters whose responses are within 20% of the on-diagonals are identified. Their respective template characters must precede the template character on which they are indicated in order to avoid ambiguity.

Fig. XIX-6. Incidence per projected character vs response ranges.

Table XIX-3. Summary of the results of measurements of photo response to the reflection of projected template characters from IBM Executive typewriter capitals.

	Incident	No. of	Mean	Relative Response = $\frac{R_{ij}}{R_w}$ Average Deviation	Standard Deviation
1.	On-diagonals	26	21%	2.0%	2.43%
2.	Off-diagonals	650	57%	11.6%	15.1 %

3.	85% of off-diagonals have response	twice the mean on-diagonal
4.	95% of off-diagonals have response	any on-diagonal
5.	98% of off-diagonals have response	the mean on-diagonal
6.	98.5% of off-diagonals have response	80% of R_w

where R_w = Response to template projection on white
R_{ij} = Response to template projection on character

Characters No.	Characters Name	$X = \frac{\text{Off-diagonal Response}}{\text{On diagonal Response}}$	Incidence No. $<X$	Incidence No $>X$
6	I, T, F, O, L, U	X = 10%	2.8%	97.2%
9	above + C, J, Q	20%	4.3%	95.7%
12	above + P, V, S	40%	7.4%	92.6%
26	(all)	160 %	45. %	55. %

The mismatch data were obtained by projecting each template character onto its mating test character for a best match. Then, for each measured deviation from registration, a response ratio was tabulated. Typical deviation charts have been plotted for several of the characters as shown. For the most part, a shift of 0.003 inch (±3 per cent) causes less than a 15 per cent response change. This effect, in conjunction with horizontal registration requirements, appears to support the feasibility of producing a device by using this technique, which would meet one of the objectives in a reading machine for the blind, namely, the attainment of reading speeds in excess of 90 words per minute.

M. M. Schiffman

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B. A SYSTEM ENABLING TACTUAL PERCEPTION OF VISIBLE PATTERNS

1. Introduction

The study of sensory aids for the blind is the study of devices and techniques for aiding a person who lacks the advantage of sight to perceive those things in his environment which otherwise would be perceived visually. Most often, this is accomplished by conversion of information that is normally available visually to forms that are easily perceived through the tactual or auditory senses. Much of the contact that a sighted person has with the world around him is through the medium of print, such as newspapers, books, and magazines.

Some of this material has been converted to braille, but only a small fraction of it, because of the time and expense involved. More rapid and less expensive conversion to braille and similar codes is one approach to the problem of making a wider variety of printed matter available to blind persons.[1] Direct skin communication with active stimulators is another approach.[2] Codes such as braille are still required for skin communication. A reading machine to convert printed matter directly to spoken letters or words might eliminate the need for a code but would be limited by the ability to recognize only a restricted variety of patterns.[3] Another approach is to enable the sightless person to feel the outlines or shapes of printed characters. The advantage of this approach is that a limitless variety of material may be used, for neither is it translated into a code nor is a machine called upon to identify it.

The size of type in most printed matter is so small that the ability to feel the edges of the printed characters would be of little value without magnification. Newsprint is only approximately 1/8 inch high. One of the simplest means of magnifying printed matter to enable tactual perception is to view the printed matter with a television system. A television camera with a suitable lens can easily magnify newsprint that is 1/8 inch high to a height of 3-5 inches on a 21-inch television screen. A significant advantage of the television system over an optical system is that the television system converts the image from one of reflected light to one of radiant light. The radiant-light image is more easily sensed by conventional light-sensing devices.

Thus, one means of enabling a sightless person to observe printed matter directly, without conversion to intermediate codes and without pattern restrictions, would be to convert the presence of light on the television screen to stimuli applied to the fingers when they are placed over the light area of the screen. The subject would be free to move his hand over the face of the television screen and would receive stimuli when the fingers passed over the pattern or reached an edge of the pattern.

There are many possible ways in which stimuli may be applied to the fingers. Some may be more advantageous than others. The question of relative advantages and disadvantages can only be answered through experiments with subjects, and thus a system to sense the presence of light on the screen and convert it to an electric signal that is capable of driving electromechanical transducers is required. It is our purpose to design such a system to enable further tests and research with various types of transducers. A transducer that applies to the finger a force that is proportional to the light intensity and lies in a plane that is parallel to the television screen has been selected to complete the system.

2. System Considerations

The essential elements of a tactual perception system are shown in Fig. XIX-7. A closed-circult television system enlarges the image and converts it to one of radiant light. A light sensor provides an electrical signal corresponding to light intensity. A feedback system converts the light signal to a force applied to the finger. The feedback system includes a summing junction and amplifier, a force-producing transducer, and a force-measuring transducer.

Selection of the transducer system was based upon the manner in which one normally grasps an object with the hand. If one places his palm down on a flat surface, fingers extended, and then draws in the fingers with no lateral motion of the palm, the directions in which the fingertips travel are approximately as shown in Fig. XIX-8. This is the

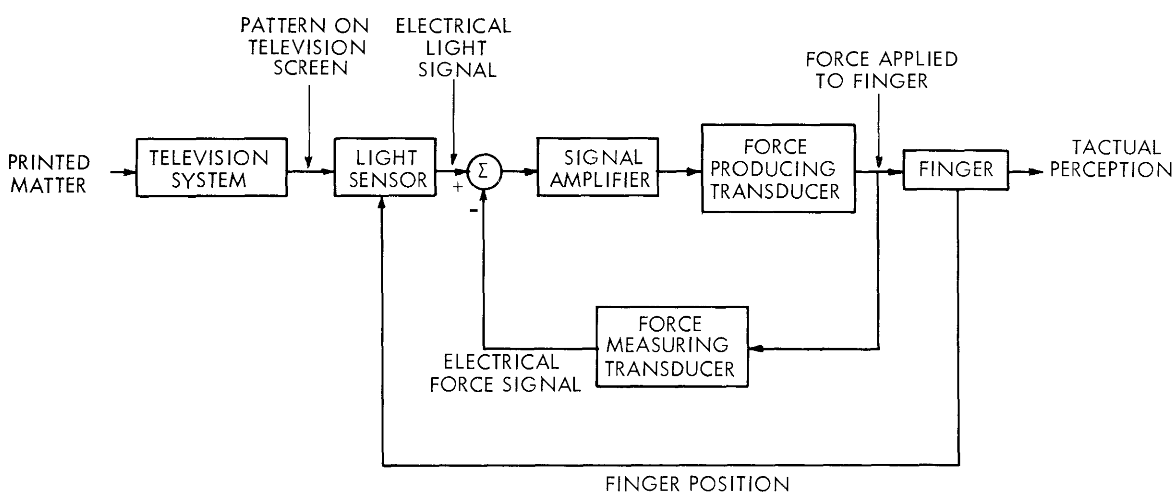

Fig. XIX-7. A tactual perception system.

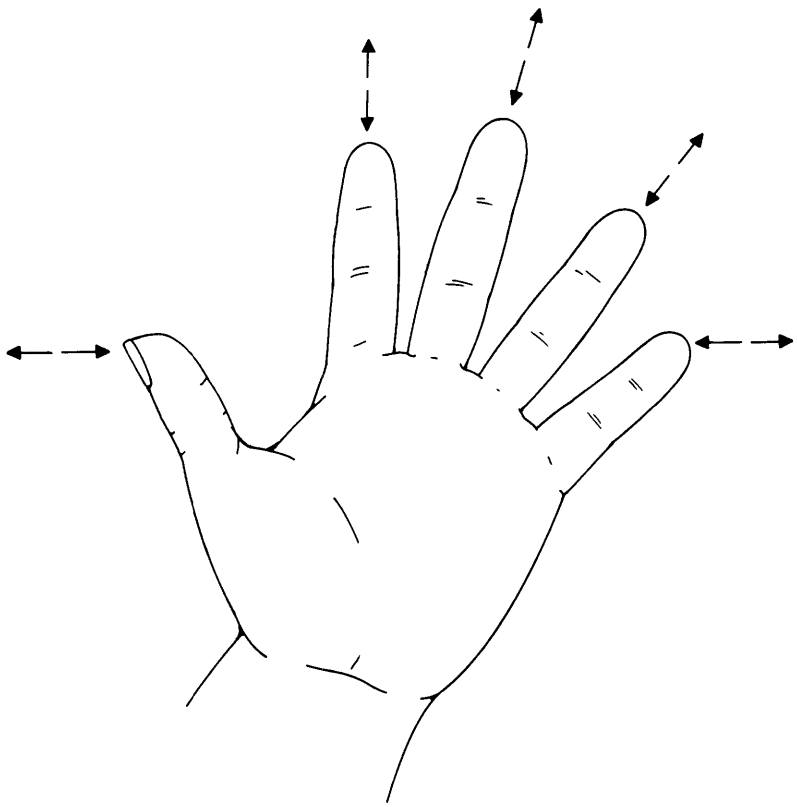

Fig. XIX-8. Illustrating finger travel and force directions.

way in which one naturally grasps a solid object not more than 2-3 inches across. By applying forces to the fingers in the opposite directions, a tactual stimulation similar to that of grasping a soft object should be achieved. The transducers may be a set of strings oriented as indicated in Fig. XIX-8 in a plane that is parallel to the television screen and driven by torque motors or magnetic clutches.

The light sensor is attached to the finger so that the position of the finger is guided by the light on the screen. The force applied to the finger should be small enough so that the subject has control of the position of his finger, but large enough to help guide his finger along the edge of the pattern by holding his finger at the edge (if the finger is partially relaxed) rather than allowing his finger to slide over the pattern. The effect produced should be that of feeling or grasping the outer edge of the pattern. With only one light sensor and string attached to the finger there will be an instability on an inner edge of the pattern which tends to pull the finger into the pattern rather than provide a stiff edge. This effect may be overcome when five fingers are used, with the forces oriented as shown in Fig. XIX-8, by feeling from different directions with different fingers. Another possibility is the use of more than one light sensor and force direction per finger.

The transducers used to produce the forces applied to the fingers and the amplifiers driving the transducers are likely to have an inconstant transformation of light intensity to force. A force-measuring transducer is used to provide feedback to help stabilize this ratio. For a system with strings to the fingers, a cantilever with strain gauges may serve as a force-measuring transducer.

To facilitate the use of five fingers simultaneously, either five separate systems must be used or five channels must be multiplexed in one system. Multiplexing may reduce the number of components required for five channels. Multiplexing may be achieved by sequential switching of the signal channels and a reference channel. The reference channel must be included to re-establish the dc level of the signals at the output of the system. The signal for a single channel thus becomes a series of rectangular pulses, with similar pulse trains for the other channels filling the time between

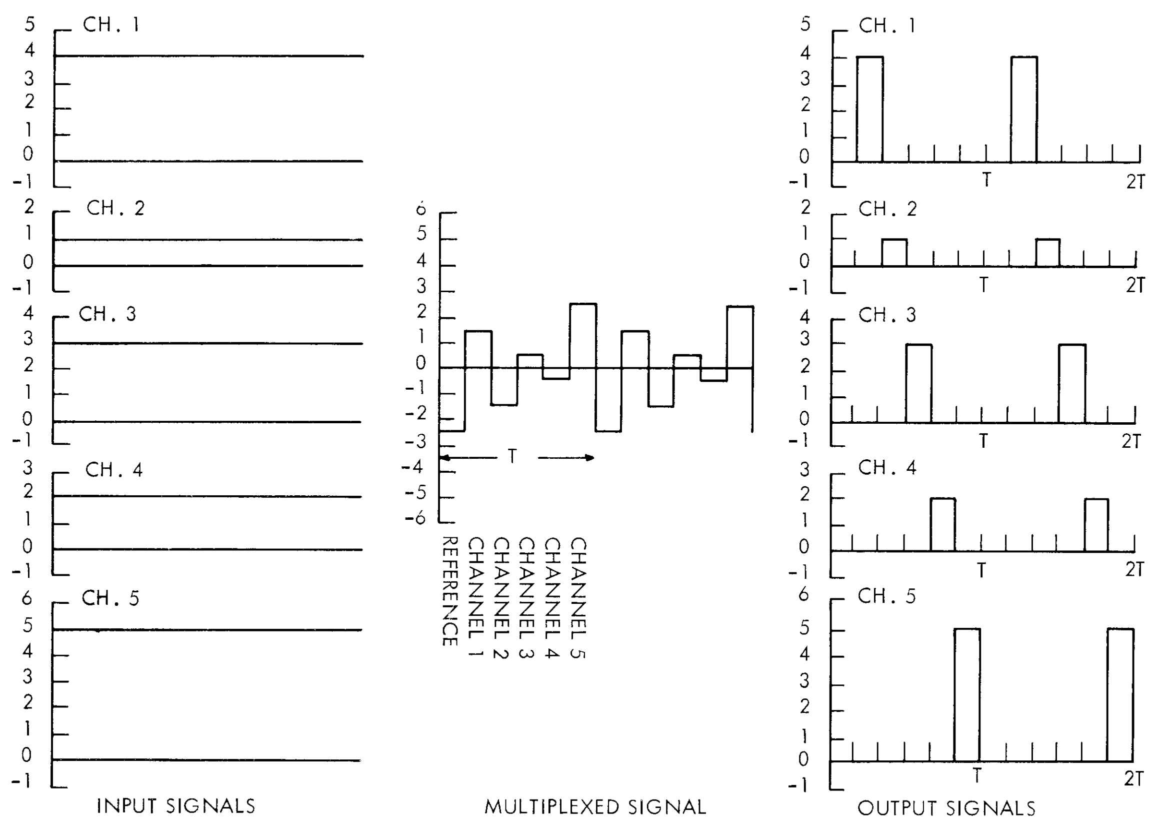

Fig. XIX-9. Multiplex system.

pulses. Fig. XIX-9 illustrates multiplexing for a five-channel system. The multiplexed signal has zero average level; this indicates capacitive coupling, which may be used to simplify signal amplifier design. The separated output signals may be peak-detected to give an output signal that is nearly identical with the input signal. If the multiplexing period is short enough, the error from sampling and interpolation is very small. For an output of force to the fingers, the maximum frequencies of interest will lie below 20-40 cps. A sampling frequency of 1000 cps should keep errors low. The pulse width for a five-channel system is approximately 170 μsec, which is long enough so that conventional switching times of a fraction of a microsecond are negligible.

3. Input and Multiplexing Circuits

The light-input circuits convert the signals from the light sensors to a multiplexed signal that goes to the summing junction. The design of the input circuits is influenced significantly by the signals that may be obtained from the light sensors.

The light sensor selected is a Texas Instrument IN2175 photodiode. This is an NPN silicon device mounted in a slender cylindrical hard-glass case (0.600 inch long by 0.082 inch in diameter) with a prefocused lens in the end. The chief advantages of this device are the small physical size and the low dark current. The prefocused lens provides a cone of light sensitivity only a few degrees wide. With a 10-megohm load on the photodiode (Tektronix oscilloscope probe) and a 10-volt dc bias, a voltage output of approximately 0.5 volt peak may be obtained from a medium brilliance trace on the television screen (or 2.5 volts peak from a bright trace). The waveform is essentially a sharp rise (0.5 msec rise time) every 16.7 msec followed by a nearly exponential decay with a 4-5 msec time constant.

Since the photodiode output is a current, the most desirable input circuit would be one with a very high input impedance. An ideal device for this application is the field-effect transistor. The input characteristics of the field-effect transistor are essentially those of a reverse-biased silicon diode, including a leakage current of a few nanoamperes and a junction capacitance of a few picofarads. A high-input impedance amplifier with conventional low-leakage transistors may be used with slight degradation of performance when economy of parts' cost is required.

The strain-gauge input circuits provide a multiplexed signal representing the force levels in all channels. The arrangement of strain-gauge preamplifiers and gates is identical with the arrangement of light preamplifiers and gates in the light-input circuits. Multiplexing is also identical with that in the light-input circuits.

The summing junction, signal amplifier, and clamp compose the central portion of the electronic system. This portion of the system forms the error signal, amplifies it, and establishes a dc reference. The summing junction consists of two low-gain dc coupled amplifiers with a common load. Differences in summing amplifier gains provide proper balance between the force and light signals. Separation of the multiplexed signal is accomplished in the transducer-driving amplifiers.

4. Transducer and Force Sensor

The transducer is required to convert the electrical output of the system to a force that may be applied to the finger. Experiments have shown that the maximum force required will not exceed 5 or 6 ounces. The force-measuring transducer should be capable of measuring the force applied to the finger with precision.

A motor and magnetic-clutch unit with an aluminum spool was available. This unit was selected to be the first transducer for the system. The motor is run continuously to rotate the center of the magnetic clutch. When current is applied to the clutch coil, a clutch plate is drawn against the rotating section and transmits torque to the 2-inch diameter spool. The string is wound around the spool. A sketch of the clutch and spool assembly is shown in Fig. XIX-10.

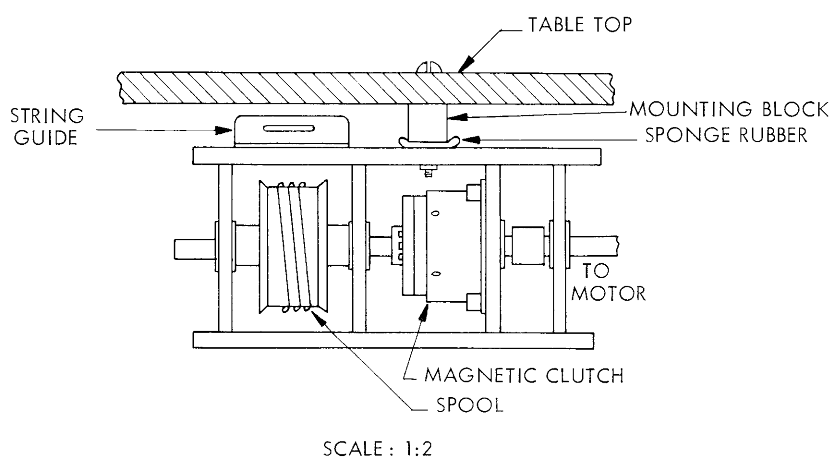

Fig. XIX-10. Clutch assembly (cantilever removed).

Figure XIX-11 shows the cantilever used as a force-measuring transducer. String from the spool passes through a slot in a cover plate and around a 0.75-inch aluminum pulley mounted on the end of the cantilever.

The 0.125-inch thick aluminum cantilever is clamped between two mounting blocks at the lower end. Strain gauges are mounted on each side of the cantilever near the mounting blocks. Short leads from the strain gauges connect to terminals on an insulating board attached to the mounting blocks. A string guide is mounted on the top of the clutch assembly to prevent the string from slipping off the pulley.

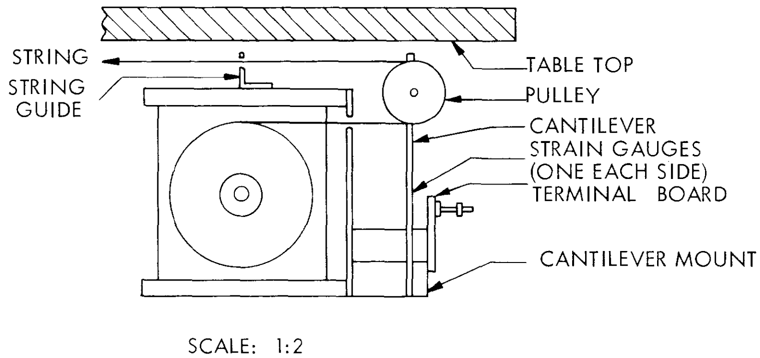

Fig. XIX-11. Cantilever assembly (cross section).

From the clutch and cantilever assembly, the string passes through a space between the table top and the picture-tube mounting plate to attach to the finger and light sensor

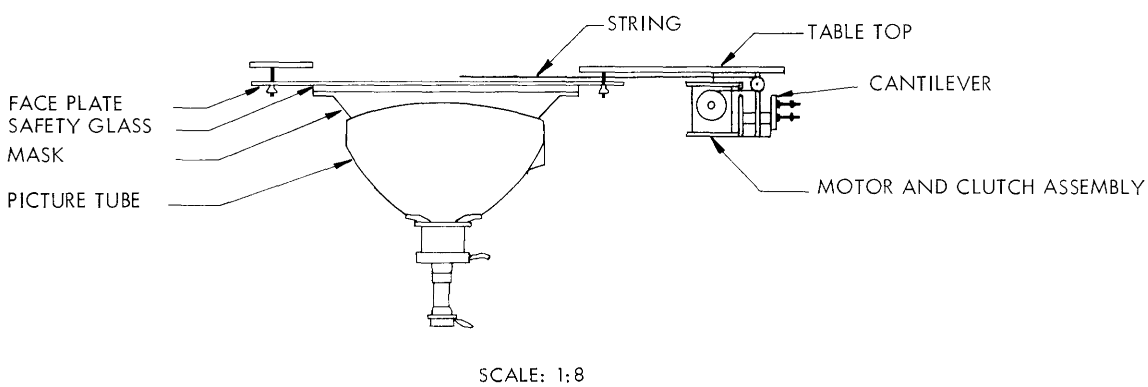

Fig. XIX-12. Picture-tube mounting and transducer.

above the picture tube. A sketch of the transducer and picture-tube mounting is shown in Fig. XIX-12.

5. Preliminary Operation of the System

The tactual perception system that was constructed was complete for only one channel. The clock system provided timing pulses to multiplex the signal of the one complete channel with a reference signal and a dummy channel signal. The length and spacing of the reference and active channel pulses were identical with those of a five-channel system. The dummy channel filled the other four portions of the multiplexing period. Light-input and strain-gauge input circuits each contained an active channel, an identical channel used for reference levels, and a dummy channel. The summing junction, signal amplifier, and clamp circuits were identical with those of a complete five-channel system. A single transducer-driver amplifier and transducer were included.

The cantilever that was used when the system was first completed was approximately 0.04 inch thick. The spring constant of the cantilever and the inertia of the 2-inch diameter spool provided a resonance between 7 cps and 10 cps when the feedback loop was closed. To permit operation of the system with feedback, the cantilever thickness was changed to 0.125 inch (thus the strain-gauge output was reduced by a factor of 1/8 and deflection of the cantilever by 1/23). The inertia of the 1-inch thick, 2-inch diameter spool was reduced by drilling ten 0.3125-inch holes through it. Operation was greatly improved, resulting in smooth response with feedback. A chief consideration in the design of future transducers should be reduction of mass and inertia to a minimum.

Reduction in strain-gauge output was overcome by increasing gain in the strain-gauge input circuits and the summing junction. The dc drift of the strain-gauge differential circuit is now a problem with reduced strain-gauge signal. Future work should include investigation of the drift problem. Placing the differential transistors on a common heat sink and matching the transistors may help.

Another problem in the mechanical system was vibration. The original mounting of the clutch and motor system was rigid. Sponge pads were inserted to prevent the table top from acting as a sounding board. With the sponge pads, the vibration appeared as noise in the strain-gauge signal. The amplitude of the noise was sufficient to make normal system waveforms almost unrecognizable. A torque motor or other force-producing transducer should eliminate this problem.

Operation of the light-input circuits, clock, signal amplifier, clamp, and transducer-driver circuits seemed quite satisfactory, except for a small problem caused by switching spikes. Phase inversion of the strain-gauge signal was accomplished in the strain-gauge buffer amplifier rather than in the summing junction. Thus the small switching spikes in the multiplexed signal were inverted. These spikes appeared as positive spikes at the output of the clamp circuit and were sufficient to alter the residual force levels. This problem was eliminated by reversing the strain-gauge leads, and operating the buffer amplifier without phase inversion.

The photodiode was mounted in a small block of wood to keep it perpendicular to the television screen. The string was attached to the wooden block. The block was grasped by the thumb and first two fingers. Future work should include design of a photodiode mounting that easily attaches to the string and finger.

Curve-following with the one-channel system was quite easy over the center portion of the television screen. The curvature of the picture tube reduced the light intensity at the photodiode toward the edges of the screen. Removal of the mask would allow the safety glass to be placed closer to the screen. Use of a phosphor more closely matched to the photodiode sensitivity characteristics, or use of additional video amplification with clipping, may be helpful but probably not necessary.

Transducer configurations other than those indicated in Fig. XIX-8 may be of interest in future work. Systems with two or three force directions and a single hand-held probe may allow curve tracing without the instability problem encountered with a single force direction. For only two or three sensors and transducers, single-channel, unmultiplexed systems may prove less complicated and equally economical.

This report has been based on the author's thesis.[4] Further details of the system described here will be found there.

E. S. Davis

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4. E. S. Davis, A System Enabling Tactual Perception of Visible Patterns, S. M. Thesis, Department of Electrical Engineering, M. I. T., September 1962.

C. COMPARISON OF TACTILE AND VISUAL READING RATES

Essentially all tactile reading devices restrict the reader to a sequential letter-by-letter presentation of English text. In this report we compare visual reading rates attained for two modes of presentation, letter by letter and word by word, with tactile reading rates obtained with a particular tactile stimulator system.

1. Tactile Stimulator System

The main building block of the tactile stimulator system is a compressed-air actuated poke probe. Compressed air has been chosen as the primary power source for the poke probes because it affords a convenient, practical way of achieving large extensions at low force levels. The primary advantages of compressed-air-operated probes over solenoid-actuated probes are: (a) small size, which permits a large degree of flexibility in possible stimulus patterns; (b) coolness of operation; (c) the ease with which large extensions can be obtained at low force levels; and (d) greater preference on the part of the user. This last advantage is the most important.

A schematic drawing of an individual poke probe is shown in Fig. XIX-13. The size of the leakage hole in conjunction with the spring constant of the bellows is the dominant factor in determining the relaxation time. The retaining washer limits the extension and allows the use of higher pressures which yields a faster rise time. The mass of

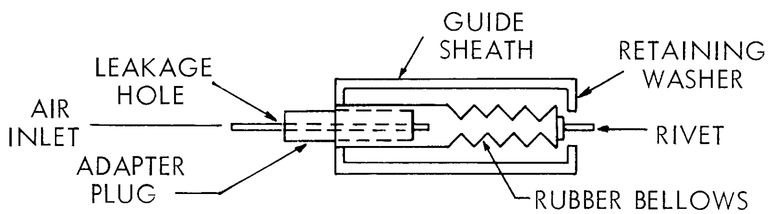

Fig. XIX-13. Poke-probe assembly.

the moving part of the bellows and the rivet naturally impose a lower limit on the rise and relaxation times. This mass is quite low compared with that of any conceivable poke probe and is a significant factor that influences the choice of compressed air as a prime power source.

The over-all dimensions of the poke-probe assembly have been limited by the difficulties that rubber companies faced in manufacturing the rubber bellows. The first model measured 0.5625 inch in diameter and 1.25 inches in length, but for the second version the dimensions were reduced to 0.375 inch in diameter and 0.75 inch in length. This change represents an approximate minimum size if we use the following technique in making the rubber bellows. A mandrel is dipped in liquid latex and the rubber is partially cured at room temperature. The bellows are then stripped from the mandrel, compressed to a normally closed position, and given a high-temperature cure. The use of an injection-molding technique may result in reducing the diameter of the poke-probe assembly to 0.1875 inch.

It is extremely difficult to measure the rise and fall times of the poke probe when it is placed in contact with the skin. Accordingly, a probe was used to operate a microswitch by pushing against a spring steel lever that approximated the loading of the skin. The rise and fall times and their sum (cycle time) are shown in Fig. XIX-14 as a function of air pressure. The normal air pressure used throughout the experiments was 2-3 psig. The maximum repetition rate for the poke probes is, then, greater than 10 cps. This is approximately the maximum frequency at which humans can distinguish individual pokes. At higher rates a smooth vibration is perceived.

The supply of compressed air to the individual poke probes was controlled by a valve consisting of punched paper tape that is drawn between two brass plates having holes

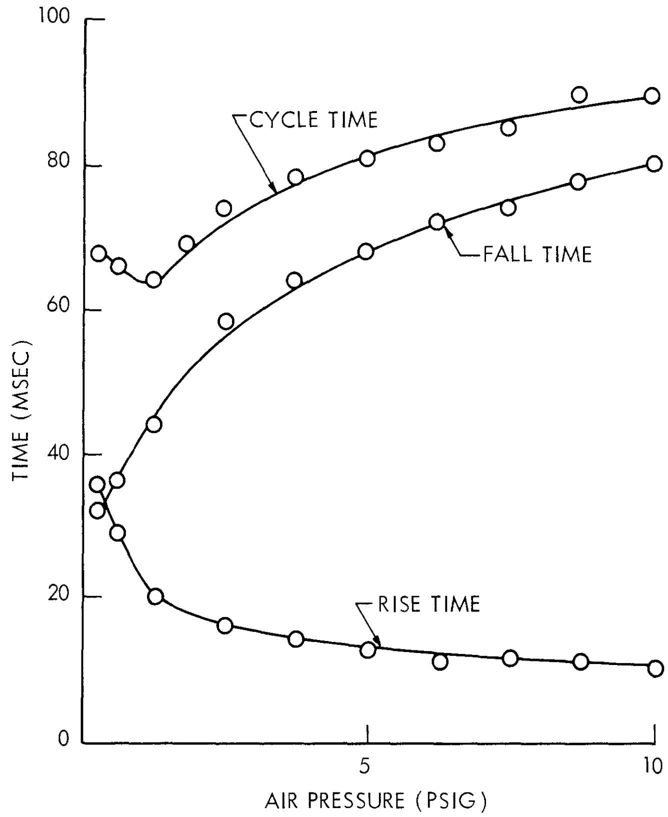

Fig. XIX-14. Response time of poke probe.

drilled in appropriate locations. Alignment of the holes in the tape with holes in the brass plates permits air to actuate the poke probes. Flexible rubber tubing was used to connect the poke probes to the valve so that the stimulators could be arranged in any

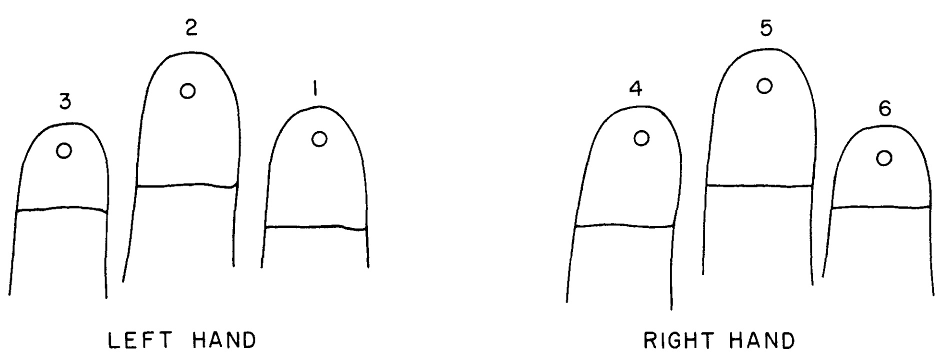

Fig. XIX-15. Six-finger poke-probe arrangement.

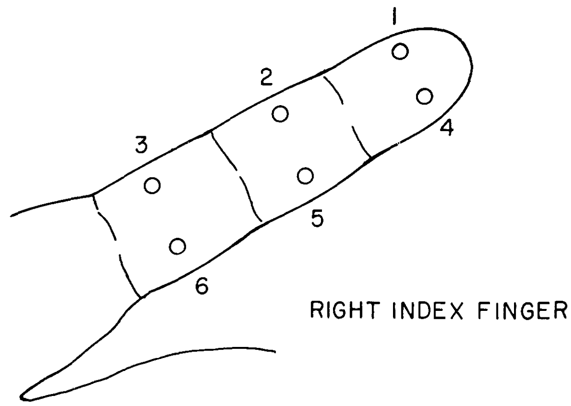

Fig. XIX-16. "Braille cell" presentation.

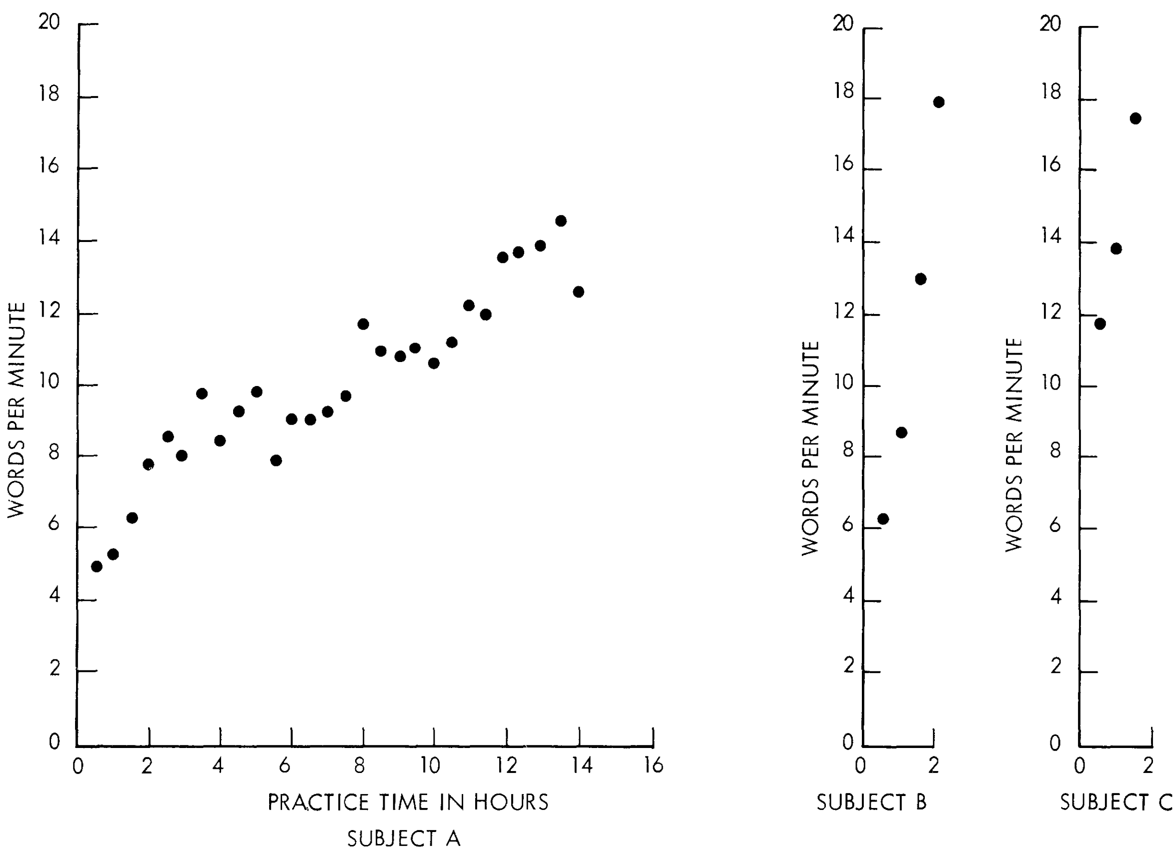

Fig. XIX-17. Tactile reading rates.

desired pattern. Throughout the reading tests the subjects were allowed to control the stimulus presentation rate with a foot-pedal speed control.

Two specific arrangements of the probes were used in the tactile reading tests. Subjects A and B were stimulated with the pattern indicated in Fig. XIX-15, while subject C received stimulations from 6 poke probes applied to a single finger (Fig. XIX-16). The code used for subject A was arbitrarily chosen, but the Braille I code was used for the other two subjects. Subject B was instructed to decode the stimuli by relating the "up" probes to the keys of the Perkins Braille-writer that would have to be depressed to form a Braille cell corresponding to a letter. Subject C decoded the stimuli by noting that they were merely an expansion of the normal Braille cell. The numbering of the poke probes in Figs. XIX-15 and XIX-16 corresponds to the usual numbering of the dots in a Braille cell. The reading rates for these subjects are graphed in Fig. XIX-17, in which each point represents an average rate for a half-hour practice session.

3. Visual Reading Speeds

An on-line experiment to measure visual reading speeds was performed with the TX-0 computer. Visual reading speeds were measured for two modes of presentation – letter by letter and word by word. In the first type of display successive letters were presented at the center of the oscilloscope output of the TX-0 computer. The end of the word was indicated by a delay equal to the presentation time of a single letter, and the end of a sentence by a delay equal to the presentation time of 8 letters. The subjects had complete control of the letter rate through a set of toggle switches on the computer console.

In the word-by-word presentation the display time was proportional to the number of letters in the word. The delay between words equalled the display time of a 2-letter word, while the delay at the end of sentences was equivalent to the display time of a 10-letter word.

The subjects controlled the word rate by means of the same set of toggle switches. The word rates attained by various subjects are shown in Table XIX-4. Each word rate is for a sample of approximately 250 words taken from the stories "Memoirs of a Yellow Dog" and "Makes the Whole World Kin" by O. Henry.

In each type of test the subjects were asked to respond with words or phrases as they wished. Invariably they chose to respond with words except when correcting a previous mistake. Subject C was allowed to make one trial on the letter-by-letter presentation in which he merely read off the letters without organizing them into words. His speed was slightly over 20 per cent higher than it was in the trials in which he answered with words. This result suggests that a major reason for the low rates achieved with the letter-by-letter presentation is the mental processing required to organize a time sequence of letters into words. It is interesting to note that the ratio of the word-by-word rate to the letter-by-letter rate very closely approximates the average number of letters in a word.

Table XIX-4. Reading Speeds.

Subject Designation	Reading Speeds (in words per minute) Letter by Letter	Word by Word	Word Rate divided by Letter Rate
M	18.4	122	6.6
B	18.2	90	5.0
T	23.4	119	5.1
G	21.4	105	4.9
N	16.9	80	4.7
K	22.0	104	4.7
C	16.5	139	8.4
Average of all subjects	19.5	109	5.6

The tactile reading rates achieved with this stimulator system are virtually identical with the visual letter-by-letter rates. If we accept the visual sense as the best possible information input to a human (a most reasonable premise), then it is clear that a departure from the letter-by-letter presentation pattern is required for any significant increase in reading speed.

This report summarizes work presented in the author's thesis.[1]

D. E. Troxel

References

1. D. E. Troxel, Tactile Communication, Ph.D. Thesis, Department of Electrical Engineering, M.I.T., September 1962.