XXIII. SENSORY AIDS RESEARCH*

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A. SENSORY READING AID FOR THE BLIND

1. Introduction

In pursuit of the long-range objective of providing better sensory reading aids for the blind, research has been carried out in the field of the tactual and kinesthetic information-transfer process by using a stenotype machine operated in reverse. A system has been designed and built in which punched paper tape, coded from stenotype output tapes, feeds a decoder, which in turn provides signals for a key-actuator console to move the keys of a stenotype machine. A stenotype-trained subject has been taught to "read" the output (key movements under the fingers), as if she were operating the machine in its normal mode, and to respond by saying the words presented. Advantage has been taken of the fact that the subject was well versed in the stenotype code (a sort of redundance-reducing phonetic shorthand using ordinary typed letters) by making the output key movements correspond to the same code, with minor restrictions.

There is need for a faster sensory reading aid for the blind. At present, the only such system in general use is Braille. This system is "read" by scanning tactually with the index finger a succession of spatial cells, each of which contains a configuration of raised bumps (or absence of same) in six positions in the cell. In the elementary Braille system, called Braille I, each configuration, generally speaking, corresponds to a single letter of the alphabet. Since this obviously limits reading to a letter-by-letter flow, it is undesirably slow. A faster system, which is more difficult to master, is called Braille II, which uses abbreviations and encodes some whole words and common letter groupings into single cells. Even Braille II is not acceptable as the final answer for a sensory aid, however, because of its slow speed compared with visual reading. Normal prose can be read visually at a rate of approximately 300-400 words per minute, while the rate for Braille II is only approximately 70-90 words per minute.

The stenotype machine, operated in reverse, was chosen as a kinesthetic/tactile stimulator for three reasons: First, sensory communication techniques using movement of and pressure on the fingers appeared to hold greatest promise. Second, the use of many fingers simultaneously as receptors appeared in a general way to increase

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the sensory channel capacity greatly as compared with single-finger stimulation (such as Braille). Third, the stenotype system reduces the redundancy of English prose into a phonetic code with some smoothing of the information rate, which was thought to lend itself to the achievement of speed in sensory reading.

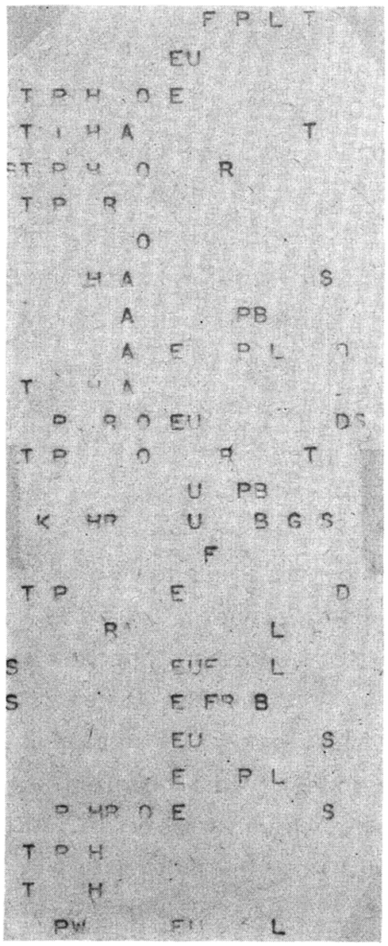

Fig. XXIII-1. Example of stenotype machine output.

The stenotype machine is a device that looks like a small typewriter with an unusual keyboard, whose keys cause a Roman type to print on an adding-machinelike paper roll (See Figs. XXIII-1 and XXIII-2). Trained stenotypists transcribe from voice to paper by depressing one or more keys simultaneously, causing the printing of letters on the paper in an almost phonetic code at approximately an average of one word per line (a new line feeds at every stroke of the keys). In order to be considered a qualified stenotypist for normal secretarial-stenographic work, an operator must be able to transcribe at least 125 words per minute, and in order to be qualified as a court stenographer an operator must be able to transcribe at least 200 words per minute.

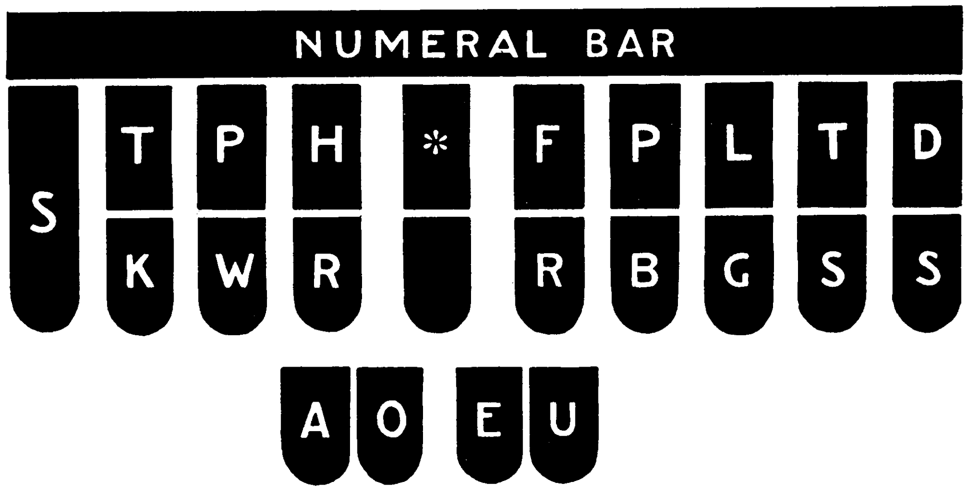

Fig. XXIII-2. Stenotype machine keyboard.

Experts can transcribe 300, or sometimes more; contests involve speeds over 350.

2. Experiment

In this research project the stenotype machine was operated in reverse. That is, a message was properly encoded on punched tape, which was fed into an electronic decoder and keyboard actuator in such a manner that the keys of the machine moved up and down as if the succession of words constituting the message were being transcribed by a disembodied operator. The subject, a trained stenotypist, kept her fingers in the proper "rest position" on the keyboard, noted the key actuation, and responded by saying the words that would have been transcribed had she been operating the machine herself.

When in the rest position the stenotype operator's fingers are in contact with 19 of the 23 keys of the machine. In this experiment, test words were chosen which used only the 19 characters that could be sensed without moving the fingers. Very little generality was lost in that the remaining four keys represented little-used characters.

Being phonetic in nature, the stenotype code uses generally one line per syllable, exclusive of abbreviations (of which there are many). Because individual syllables of multisyllable words can in many cases be construed (phonetically) to be words in themselves, multiline words added a confusion factor that was undesirable during the learning process. Accordingly, words were chosen for the speed test which could be encoded into only one line.

The subject was given a familiarization period of approximately 18 hours with punched tapes coded from three different sources: a list of the 1000 most-used English words, a jury trial transcript, and three reading-comprehension stories. During this period three modes of operation were tried: monitor-operated foot pedal, subject-operated foot pedal, and continuous operation with adjustable repetition rate. After a few hours of very basic familiarization the one-shot modes with the foot pedal became less satisfactory than the continuous because the subject tended to search for all depressed keys rather than to sense the over-all pattern as one "chunk" of information. The familiarization tapes also had what turned out to be undesirable features of multi-syllable words and the inclusion of non-sensed keys. At the initial slow reading rates, context proved to be of no help. For these reasons new tapes were made to be used in speed trials.

It was felt that it would be impossible to obtain definitive quantitative results in terms of precise information at rates from an experiment that was built around English prose encoded in a still unanalyzed code. Nevertheless, it would be desirable to obtain results that would relate in some manner (however subjectively) to the real world. Therefore it was decided to make three context-free lists of English words of varying stenotype difficulty and to see how fast each list could be "read" by the subject.

3. Discussion of Results

Three sets of one-line English words that used only the proper 19 keys were chosen at random from the previous tapes. The "easy" list contained 175 words for the most part of no more than four stenotype characters each. The "intermediate" list contained 175 words of (generally) from four to six stenotype characters each. The "hard" list contained 130 words of four or more (up to ten) stenotype characters each. Tapes were made from these lists and 12 hours of familiarization practice performed.

In reading these lists the subject made a number of different errors. These ranged from the simple omission of the beginning or final sound of a word to the loss of the entire word by missing a crucial stenotype character of a highly encoded consonant sound. These errors obviously have much different significances, so that it would be difficult to give meaning to an "error-rate." Accordingly, it was decided to operate essentially error-free. "Essentially" means that no more than two of the first kind of error described above would be tolerated in a given list.

To eliminate the possibility that context was used in the reading, scrambled versions of the lists were made. A new scrambled version was used for each of the final speed tests. Using the above-mentioned error criterion, the subject achieved the following speeds:

"Hard" List	31 words per minute
"Intermediate" List	40 words per minute
"Easy" List	62 words per minute

The speeds achieved suggest that the technique of multifinger stimulation with a good redundancy-reducing code for the reading of English has considerable promise and may be a means whereby speed comparable to sight reading can be attained.

G. Cheadle

B. AN UPPER BOUND TO THE "CHANNEL CAPACITY" OF A TACTILE COMMUNICATION SYSTEM

1. Communication System

The system reported on here consists of a device that can elicit a pressure response from the finger tip. The stimuli can be applied to any combination of 6 fingers by 6 poke probes, which are small rivets that move approximately 3/8 inch. The subject can feel the pressure of each of the 6 probes, thereby obtaining 6 bits of information per stimulus. Figure XXIII-3 shows the arrangement of the probes relative to the fingers, and illustrates the way in which a stimulus was interpreted as a two-digit octal number.

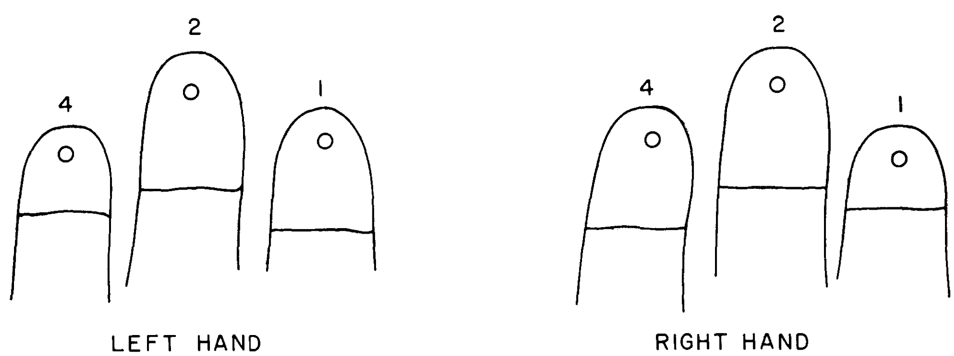

Fig. XXIII-3. Probe arrangement.

If the subject could receive a single-probe stimulus 6 times a second, then the information rate would be 6 bits/sec, provided that he made no errors. Likewise, if he received a 6-probe stimulus once a second, the information rate would be 6 bits/sec. From a communication viewpoint, both alternatives are equally good. The purpose of our experiment was to determine what ensemble size provides the greater mutual information rate.

The stimuli were presented tachistoscopically, to allow as long a time as necessary for the subject to decode the stimuli. The skin has a finite relaxation time, however, and there is an "afterimage" effect. One can easily observe this phenomenon by poking his finger tip with a pencil point and noting the response after the pencil has been removed.

To solve this problem, a mask consisting of all 6 poke probes was applied after each stimulus pulse. The purpose of the mask is to "erase" the afterimage effects of the skin. The subject is again given unlimited time to decode the stimulus. The time per stimulus is defined as the time from the start of the coded symbol to the start of the mask.

2. Preliminary Tests

To test the effectiveness of the mask a binary tape that did not contain a mask was prepared. When an ensemble size of 6 was used the error rate in tests with the mask was twice the error rate in tests without the mask. This result indicated that the subject did indeed receive some information after the probes had retracted, thereby warranting the use of the mask. The error rate, rather than the mutual-information rate, was used because of the difficulty in defining the duration of the stimulus in the maskless experiment. In the rest of the experiment, however, the stimulus duration was well defined, and comparisons were made by using the mutual information rate.

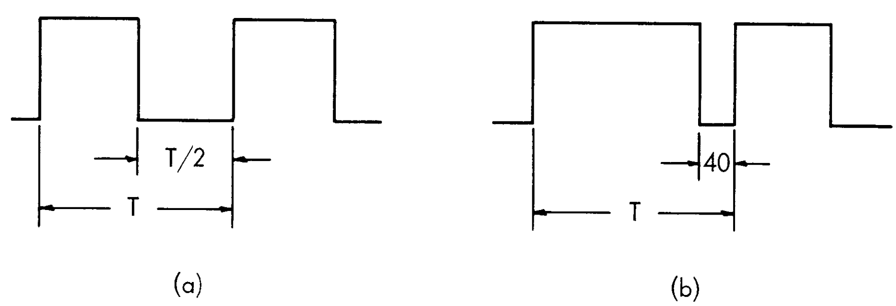

Fig. XXIII-4. Timing of stimuli.

In the early part of the experiments the time that the actual symbol was touching the finger tip was one half of the defined stimulus duration (see Fig. XXIII-4a). It was discovered later that much higher rates could be achieved by making the interval between the symbol and the mask as short as possible (40 msec) while keeping the defined stimulus duration constant (see Fig. XXIII-4b). The resultant increase in the information rate is shown in Fig. XXIII-5. Note that the information rate does not change so radically for the ensemble size of 4, and not at all for the ensemble size of 2. The reason for this is that the defined time of the stimulus duration was approximately 100 msec for the ensemble size of 2. In the last case parts (a) and (b) of Fig. XXIII-4 would be too much alike for a significant change to be noted; however, the time for the ensemble size of 6 was approximately 400 msec, and thus the top two parts of the figure would be decisively different.

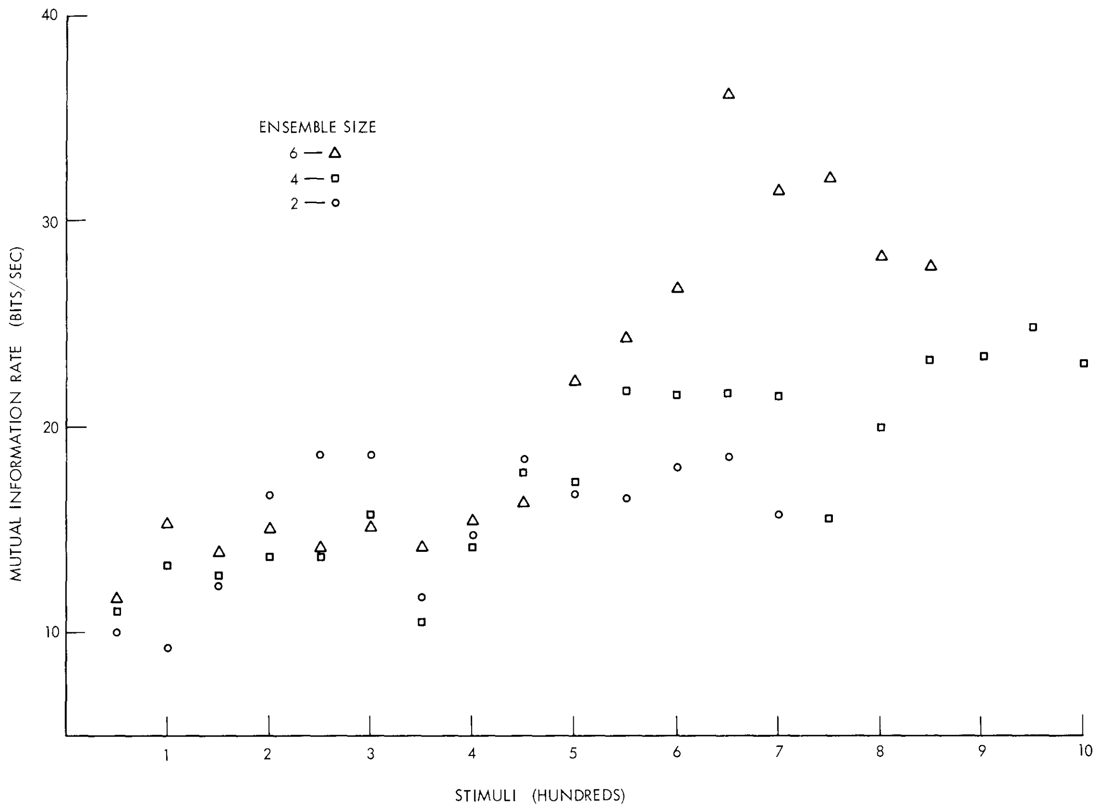

Fig. XXIII-5. Learning curves.

3. Results and Conclusions

The information rate was estimated for sequences of 50 random two-digit octal numbers. We felt that 10 per cent error would be reasonable for such a device; therefore the duration of the stimulus was adjusted to allow the error to approach 10 per cent. Learning curves for each of the three ensemble rises are plotted in Fig. XXIII-5.

To determine the asymptote of each of the learning curves, an average value after leveling off was calculated. The mutual information is not a linear function of the transition probaiblities; therefore the average was evaluated by constructing a channel matrix from the last 200 stimuli. The asymptote average for each of the ensemble sizes is given below.

Ensemble Size	I(xy) Bits/sec
6	29.5
4	23.2
2	16.2

From the experimental data one must conclude that the ensemble size of 6 gives a significantly higher mutual-information rate than either the ensemble size of 4 or 2. Although the margin between ensembles sizes of 4 and 2 is not as large, we conclude that for such small ensemble sizes the mutual-information rate increases with an increase in the ensemble size.

It must be noted that in a tachisotoscopic experiment such as this the calculated information rate is an upper bound on the actual information rate, and that this upper bound should not be compared with any reading rate. The upper bound, however, does provide a basis for comparing various parameters of the channel.

Further details can be found in the author's thesis.

J. T. Lynch

References

1. J. T. Lynch, Variation of Ensemble Size in a Tactile Communication System, S. B. Thesis, Department of Electrical Engineering, M.I.T., June 1963.