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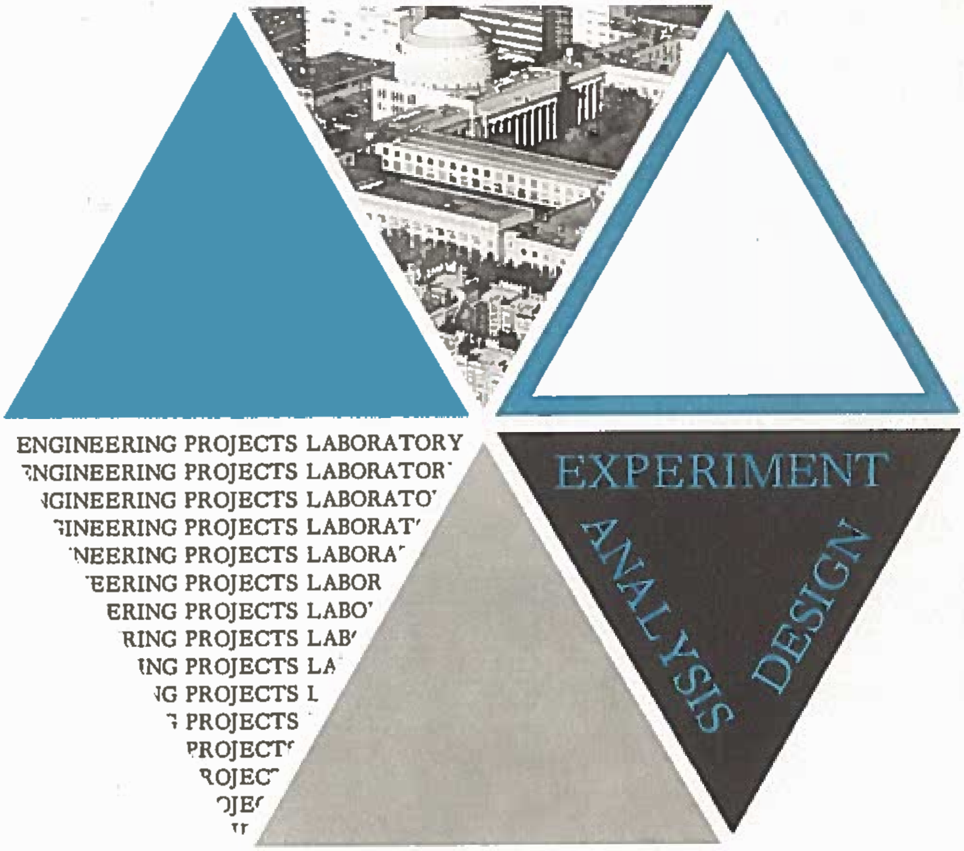
EVALUATION REPORT ON WORK IN PROGRESS ON SENSORY AIDS AND PROSTHETICS

October 31, 1962

Report No. 8768-3
Department of Mechanical Engineering
Massachusetts Institute of Technology



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EVALUATION REPORT ON WORK IN PROGRESS ON SENSORY AID AND PROSTHETICS

OCTOBER 31, 1962

DEPARTMENT OF HEALTH, EDUCATION
AND WELFARE
OFFICE OF VOCATIONAL REHABILITATION
WASHINGTON 25, D.C.

Contract No. SAV 1004-61

3/29/66
M.I.T.

FOREWORD

The Sensory Research Discussions originated and chaired biweekly at M.I.T. since the fall of 1959 by John K. Dupress, Director of Technological Research of the American Foundation for the Blind, influenced several faculty in the Mechanical Engineering Department at M.I.T. to interest themselves and their students in research and development problems associated with human deprivation. Initial investigations were unsupported and conducted entirely within the context of undergraduate laboratory and design project and thesis work. Subsequently a small grant from the American Foundation for the Blind made possible the fabrication of, and experiments with, several research devices. By January 1961 the activity blossomed under formal support from the Office of Vocational Rehabilitation of the Department of Health, Education, and Welfare (contract SAV-1004-61) which partially supports the principal investigators, Professors Dwight M. Baumann, Robert W. Mann, and Thomas B. Sheridan, and a number of graduate-student research assistants in the Engineering Projects Laboratory (EPL) as well as underwriting the work of nonsalaried full-time students engaged in related design, laboratory and thesis projects.

This report is one of three summarizing the first year's program. Engineering Projects Laboratory Report 8768-1,8649-1, "Tactile Communication Using Air Jets", by Lester Saslow and EPL Report 8768-2, "Evaluation of the Energy and Power Requirements for Externally Powered Prosthetic and Orthopedic Devices", by Igor Paul represent substantial projects which have reached a reasonable conclusion. EPL Report 8768-3 is an Evaluation Report on Work in Progress. The projects discussed in this interim report were either not complete as of the reportorial time, or were of insufficient scope to warrant a separate report. As projects reach logical termination points, individual summary reports will be published. A bibliography appended to each of the three reports identifies reports, theses, papers, and design and laboratory projects conducted under the EPL-M.I.T. Sensory Aids and Prosthetics Research and Development Project.

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1. TYPE-COMPOSITOR-TAPE TO MECHANIZED BRAILLE SYSTEM

R. W. Mann, A. S. Ivester and P. J. Siemens

Braille material is made available to the blind by means of press embossing of these textbooks and periodicals which warrant distribution in excess of several copies. Original Braille transcriptions are produced as single copies, on Braille writers (such as the Perkins) and duplicated by recently developed vacuum-forming plastic processes. However, it is generally accepted that these facilities for Braille reproduction severely restrict the quantity and range of material in Braille for the blind. Dedicated private and institutional efforts, coupled with government subsidy make possible, through printing presses such as the American Printing House, Howe Press, etc. the reproduction in quantities incredibly small, compared to ink-print productions, of selected titles of text and recreational reading material. At the single copy Braille transcription level, numerous volunteers translate printed material into Braille for the benefit of students, professionals, etc. The actual total output of Braille material is, of course, restricted firstly by the production capacity of existing presses, and secondly by the availability of widely geographically distributed volunteers (154 groups in all) who have the talent and time to prepare individual transcriptions. Efforts are underway to increase the efficiency of the machinery for Braille press reproduction. Much could be done to encourage the training of volunteer transcribers and to provide devices which will make more efficient their efforts. The description in this report of the Braille encoding-typewriter-accessory and the high-speed Brailler are examples of the latter.

However, in all these cases Braille reproduction hinges upon the availability of a sighted reader who has the language and Braille training and experience necessary to convert the visual printed letter, word, or page into its corresponding Braille symbolism. One can divide the activity of this sighted Braille translator into two steps: the visual reading of the ink print pattern and the intellectual translation of that ink print into corresponding Braille symbols.

These two processes, pattern-recognition and translation, are fields subject to extensive investigation quite apart from the problem of blind communication. The vast problem of our ever-growing store of library reference material, particularly in technological areas, the problem it poses of storage, referencing and access, the problem of making printed symbolic material available directly to data processing equipment for correlation and analysis, military and commercial problems of identifying particular patterns in a field of view for aircraft control, surveillance, and other reasons motivate a broad spectrum of generously funded activity in the pattern-recognition or reading machine area. While progress is being made in this field, we are still far from the point where a machine is a demonstrated effective substitute for the human reader.

The second activity of the sighted Braille transcriber is that of translation, conversion of the printed ink symbol into its Braille counterpart. Goals other than blind communication again justify a substantial investment of time and money in this field. Language translation is an obvious example. The devising of computer programming codes which facilitate either input-output from the computer to its environment or the manipulation of information inside the computer are other examples of work in the translation area. Specific efforts are, of course, underway to devise and test the adequacy of computer translation of alphabetical word input to a computer into its corresponding Grade II Braille.[+] These efforts illuminate the theorem applicable to all machine translation programs - only where clear, unambiguous rules for the translation correspondence (no matter how complicated they may be) can be defined can the machine be expected to carry through the process. The Braille translation work underway underscores the need for studies of the present ambiguities in the grade II Braille code. This is a separate investigation which has had some beginning scrutiny by the M.I.T. group.[++]

[+] As for example the work of Mrs. Schack of IBM in the cooperative program between IBM and the American Printing House for the Blind and Dr. Abraham Nemeth of the University of Michigan.

[++] See the discussion in the Minutes of the Conference on Automatic Data Processing and the Various Braille Codes, M.I.T., March 17-18, 1961 published by the American Foundation for the Blind, New York, N.Y.

In light of the difficulties of mechanizing pattern recognition, it seems appropriate to ask whether in the preparation of Braille material it would be possible to circumscribe the need for interpreting and encoding, in machine-interpretable form, the information content of the printed page. Could this step be avoided the first and, at the present, most intractable of the contributions of the sighted Braille transcriber could be avoided.

In fact, most printed material (which of course circumscribes all that material under any circumstances of interest for translation into Braille) is at sometime prior to its final ink-print publication encoded in a machine-interpretable form. This development comes about as a consequence of advances in the printing industry itself through which virtually all type composition is done automatically; and also as a consequence of the frequent desire to transmit editorial material by means of wire between a point of origin and the point of publication. Thus we have the Teletypesetter wire transmission system, and Linotype, Monotype and Photon type composition. Each of these is a somewhat different process which poses a somewhat different problem in terms of utilization for blind communication. But all offer the intriguing possibility of capturing the content of the printed page in an encoded form directly digestable for further data processing, rather than reliance upon the sighted reader, or waiting for the development of reading machines.

The system to be considered then consists of obtaining the material to be ultimately presented in Braille in the form of type compositors' tapes, using these tapes as the input to an centralized data processing system which would edit, translate, and reproduce the information in a form suitable for wide-scale distribution through the mails to the individual blind and to libraries. Recipients would have transducers which would convert the distributed form of the material into the equivalent of embossed Braille.

The feasibility of such a scheme depends, of course, upon the kind of material which the blind need and want, and its availability in the form of type compositors' tape.

On the question of what the blind want, there is unfortunately little in the way of systematically collected, unbiased data, although there are indications that this situation will improve. The blind's access to the printed page includes Braille tactile input and aural inputs including "talking books" tape recordings, and listening to sighted readers.

In the way of specific data on the proportional use of these various techniques by the blind, a frequently cited statistic is that while the number of current titles available in both recorded and Braille form are about the same (with the aggregate number of titles available in Braille substantially larger) according to the records of the Library of Congress, only three per cent of the 380,000 legally blind population in the United States borrowed a Braille book from a library, whereas some 30 per cent of the blind population took one or more recordings from a lending source.

The hazard of too literal an interpretation of this data is that, first, neither the estimate for Braille books nor recordings represent the total use of either of these techniques by the blind. In the case of Braille, the figure does not include the vast amount of material made in small quantities for use in the elementary, high school and college education of the blind as well as for professional activities, and the use by the blind of Braille for their own personal notation and correspondence. In the case of recordings similar exclusions are obvious. The second reservation on casual interpretation of these figures is the influence of the type and total amount of material available on its use by the blind. In the case of Braille books, for example, the total annual production at the present time is something like 160,000 Braille page-plates per year, which roughly corresponds to half that many ink-print pages. Now a total of 80,000 pages a year represents very few books, implies very few titles, and implies a gross least-common-denominator basis for choosing titles. Beyond this, a typical press run is 28 - 30 copies, which considering the nationwide distribution of the estimated 380,000 legally blind, presents an incredible waiting list problem for the popular titles. Similar arguments could be mounted for restrictions on the availability of aural material. Thus, in considering the various means by which the blind can take advantage of existing sensory channels for communications purposes, it appears unwise to attempt to draw exclusive recommendations between alternatives but rather to attempt to enhance the availability and efficiency of all demonstrably practical modes as well as to explore new alternatives.

The spectrum of blind constitutes a microcosm of the total population - a wide range of ages and vocations, from the elementary school child learning to read through high school and college training, which in turn, ranges from fields in which the assimulation of a great deal of straight copy is essential as in the liberal arts, to fields in which symbolic representations and exceedingly concise presentations dominate as in the physical sciences.

A recent study[1] concerned primarily with blind college students' use of recorded textbooks provides some data on comparative uses of tactile and aural reading aids. Thirty-four per cent of the students' queried (91 per cent of the 402 blind in college known to be using "Recordings for the Blind") preferred recordings for all their reading; an additional 40 per cent preferred recordings for long descriptive nontechnical texts; 91 per cent preferred recordings for light reading. But in the very areas where Braille texts are scarcest, many students said they were desirable: the survey indicated a demand for Braille texts in languages, mathematics, and complicated materials. About 60 per cent found Braille important in reading and learning formulae and the like. These preferences are at least in part due to the fact that a reader's comprehension increases as the amount of active participation in reading increases; thus the Braille reader, who must follow the text with his fingers, finds it easier to comprehend than the passive listener who used recordings. Also, it is easier for the user of Braille to reiterate phrases he fails to grasp on first reading. For grade-school children, where integration of blind and sighted children in public schools rather than the blind residential system is becoming more predominant, it is important to have a display of the text corresponding as nearly as possible to the books their sighted peers are reading.

Beyond educational reading needs, there is the professional literature, scientific, medical, legal, or otherwise, whose availability to the blind is severely restricted due to the vast and growing amount of material and the small, varied, and unpredictable need of parts of it by individual blind. Then there is the wide range of recreational reading, including periodical and full-length books, informational reading, including contemporary news media, etc.

The general lack of sociological data on the reading needs for the blind and the scope of the project at M.I.T. has made it impossible to carry out any comprehensive study of these needs. But a study of the available literature, results of conferences, some of them held at M.I.T., concerning communications with and for the blind, conversations with numerous knowledgeable blind and those concerned with blind rehabilitation, have indicated that, at the very least, additional Braille transcribed information is essential for the educational process from the elementary through the college levels, particularly those stages where the child is actively learning to read and when the teen-ager or young adult is studying in the field which involves symbolic and concise notation, including, at all levels, those learning processes in which active involvement of the learner are essential. A second prime need is the whole field of professional journals which are essentially unavailable to the blind except through services of individual and cooperative volunteers. A third obvious though less numerous need is that of the approximately 3000 deaf-blind for whom the tactile input is the only communication channel.

On the availability of type compositor tapes of material of especial interest to the blind, a partial survey of publishers has revealed that between 40 per cent and 65 per cent of the elementary-school texts published by major houses are published using either Monotype, the most common equipment, or other tape-operated systems such as a modified Linotype. Beyond the elementary level, use of Monotype dwindles, since it is a somewhat more expensive process than the widely used Linotype. But the exception to this rule is in the fields of mathematics and science, the very area in which Braille texts are most needed, where texts are almost universally printed in Monotype. In the field of professional journals, those in scientific fields again use Monotype exclusively (one large publisher reported their intention of changing to the Photon method, another tape-operated process).

The punched typesetting tape must be made available to the agency sponsoring the transcription into Braille. The publishers surveyed uniformily expressed their willingness and ability to make the tapes available and to cooperate concerning copyright restrictions.[+] Since the tape is only used once in setting up galleys of the printed books and is then discarded, there are no intrinsic technical reasons it cannot be used for an input to a transcription system.

[+] Replies were received from Ginn and Company; Scott, Foresman and Company; Ladlaw Brothers; Row, Peterson and Company; and the U.S. Government Printing Office, as well as from the American Mathematical Society and the American Institute of Physics.

An important obstacle to the Monotype-to-Braille system is the multiplicity of differences between the printed product and the text contained on the tape. For example, many of the headings that appear in a printed book or magazine are set by hand and inserted into the galleys of text. Illustrations, displays, tables, and other visual aids are inserted later. In the case of Braille transcription, these latter pose a special problem, for these displays must be presented in a modified form for the benefit of a blind reader. At present, Braille texts leave out all illustrations except those essential to the content; for these are substituted either simplified embossed-line diagrams or brief descriptive paragraphs. In any case, this material must receive special treatment.

Even within the textual material itself, the Monotype tape contains many deviations. Errors in the tape are corrected directly in the galleys of type. Often unusual characters or special symbols will not be contained on the Monotype tape; later they are inserted in the galleys of lead. Last-minute changes in content of textbooks may be made by hand without using the Monotype machine. Taken together, these differences comprise a very sizeable error. This error must not be carried over into the transcriptions made for the blind; but its correction may require much time and effort.

The Linotype source represents potential advantages relative to Monotype provided provisions is made for the simultaneous generation of a punched tape on those Linotype machines which mechanically compose the tape while providing no permanent record. Wherever Linotype is used for remote or multiple type-setting such a tape is prepared. However, in many of the older Linotype machines, no such provision is made. Either the utilization of standard Teletypesetter equipment or a typewriter accessory, such as is described in Sec. 3. of this report could be used. The Linotype process has the intrinsic characteristic that, since type is cast in a single slug comprising an entire line, errors are more awkward to correct than in a case of Monotype, where single letters can be removed and replaced. Thus with Linotype once one has line length slugs (or the tape equivalent of them) one is assured of the absence of typographical errors. Beyond this the Linotype is frequently used in conjunction with the Teletypesetter process by which means editorial material is set from a point of composition to a remote point of publication. In such cases, the tape is a pluperfect edition of the final copy, since all typographical and editorial corrections have been made. Generally speaking, Teletypesetter tape represents current periodical news and editorial commentary. While, as a general rule most of the blind receive such information through standard radio audio perception, the deaf-blind could maintain contact with their contemporary world were it practically possible to convert these Teletypesetter tapes into their Braille equivalent.

2. MECHANIZED BRAILLE DISPLAYS

R. W. Mann, E. E. Blanco, A. S. Ivester and K. F. Johansen

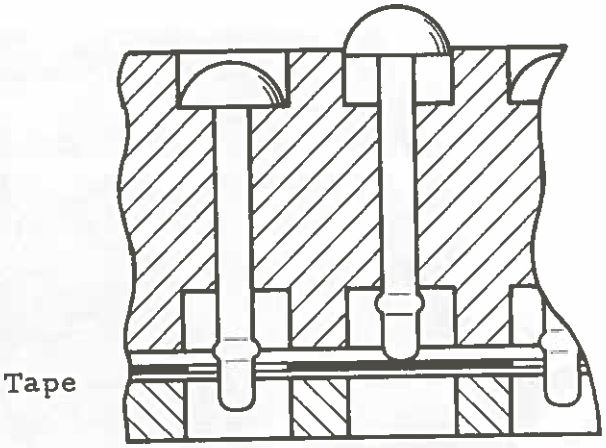
Large-scale effective utilization of the type-compositor's tape-to-mechanized-Braille system discussed in the previous section of the report implies the availability of simple, small, rugged and reliable transducers with which the distributed medium can be interpreted by the blind as embossed Braille. Beyond this use, such transducers would be very useful in research investigations on variations of Braille coding and presentation methods. There are, for example, ambiguities in the present Grade II Braille code from a human interpretation point of view which suggest study quite aside from possible changes in the code which would facilitate machine interpretation and translation from letter-by-letter into Grade II. Actually the primary consideration of human interpretability is really inseparable from the secondary consideration of machine translation, since the complications and ambiguities in the code which slow down and frustrate the human reader are, in many cases, the same vicissitudes which make machine interpretation impossible. Thus, while respecting both the evolution of contracted Braille and the extensive study of it by teachers of and workers with the blind, it is deemed desirable on a research and investigatory level to explore advantages which might be derived from changes in the code, or going beyond the present Braille and considering quite different modes of presentation. Theoretical studies of such alternatives can postulate possible advantages, but the effectiveness of changes can be demonstrated only after patient, thorough experimentation leads to acceptance by the blind. The existance of mechanized transducers would greatly facilitate the educational and psychophysical testing essential to the evaluation and acceptance of such variations.

Experiments at M.I.T-EPL have been carried out thus far on three transduction approaches, all based on punched tape as the distributed or experimental information storage medium. Fortunately, the hole spacing on standard punched paper tape corresponds to cell spacing in Braille symbolism. Thus the Braille symbol to be "embossed" by the transducers can be punched into tape and used directly to position pins with heads shaped like the Braille embossing, up to correspond to an active cell or down to indicate the absence of a Braille bump. Figure la illustrates the use of hemispherical-head pin elements in this approach. Figure 2 is an instrument using this principle in which the presentation is analogous to a standard page presented a line at a time. The tape feeds from left to right, and is advanced one line segment by means of the lever shown. As an alternative, a continuous presentation scheme, Fig. 3, utilizing a belt has also been built. Figure 4 is the original device. A second improved model is just about complete. We plan to experiment with both these devices in order to understand more completely the kinesthetics of the blind's hand and finger as he reads Braille in order to shed some light on how the standard presentation, line-by-line on a fixed page, compares with the somewhat more passive continuous presentation.

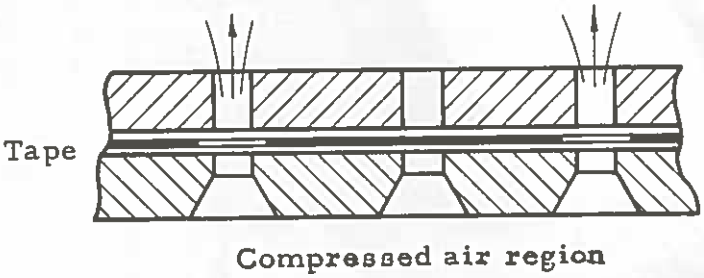
Figure lc illustrates a second technique for direct mechanical tape-to-Braille output. Small ball-bearings are entrained by holes in the tape, in this case a hole corresponding to the presence of a Braille bump. An embodiment of this scheme is illustrated in Figs. 5 and 6. The motion of the tape strips ball-bearings from a hopper. The balls are restrained and the tape is supported (at the equator of the balls) by grooves in a magnitized supporting plate. A receiver and vibrator would return the balls to the supply hopper.

A third scheme which has had some cursory investigation is suggested in Fig. ld. A tufted or flocked textile fabric would be arranged so that fibers could extend through the holes in the punched tape, thus providing a tactile stimulation. Samples of a number of textile fabrics have been investigated and additional inquiries as to suitable material, textures, fiber distribution, etc., have been made.

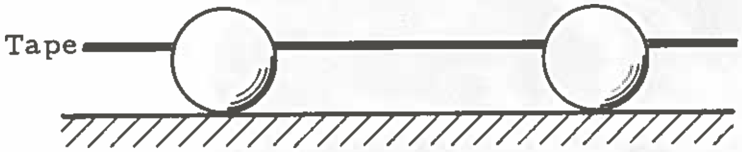
Finally, Fig. lb illustrates the use of air jets as the tactile stimulator. An EPL-M.I.T. report 8768-1 on the Office of Vocational Rehabilitation of the Department of Health, Education, and Welfare contract entitled "Tactile Communication Using Air Jets", by Lester Saslow, describes psychophysical research conducted using this stimulation technique. In Mr. Saslow's apparatus the air jets were controlled somewhat differently, but the tape could be used directly as a pneumatic valve as indicated. However, this scheme implies the availability of compressed air which in turn requires additional machinery and input power, and therefore contravenes, to some extent, our original



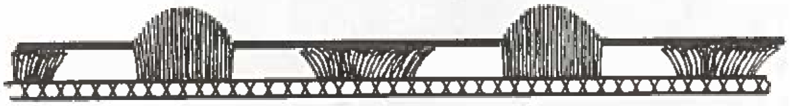
1a. Hemispherical-head pin elements



1b. Compressed air jets



1c. Spherical elements



1d. Tufted fabric

Fig. 1. Basic Transducer Elements.

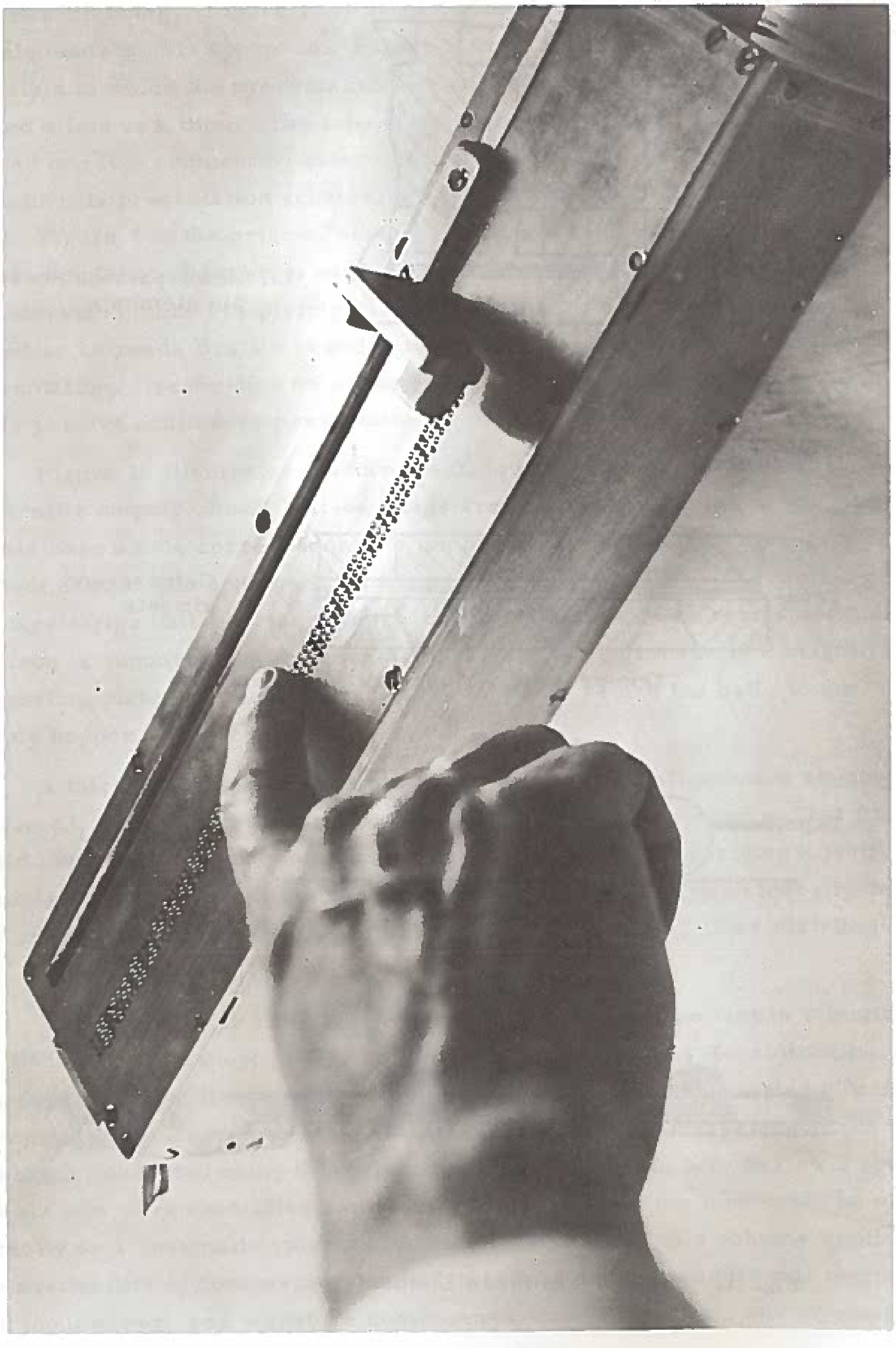


Fig. 2. Line-at-a-time, Pin Element Tape-to-Braille Transducer.

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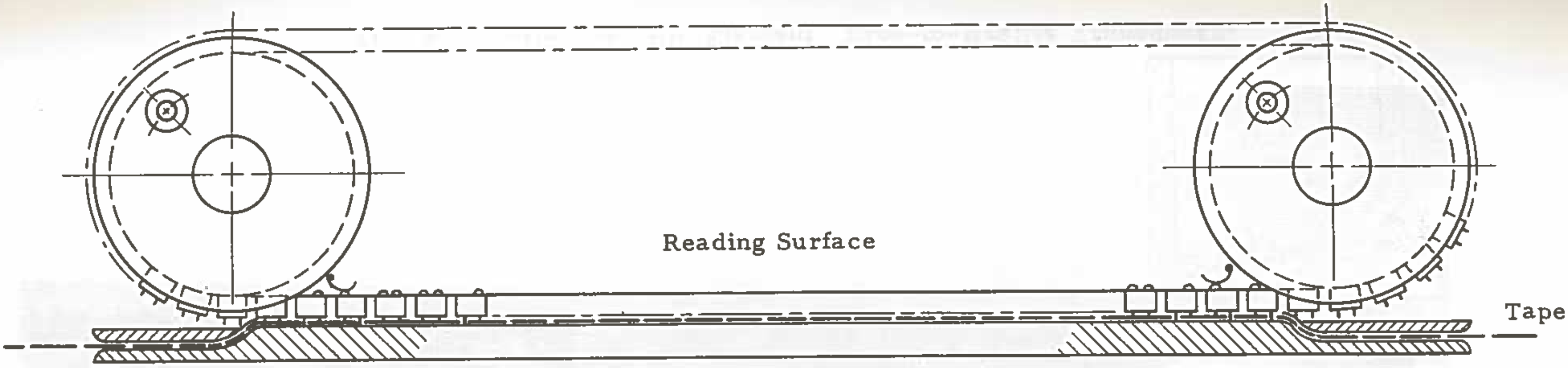

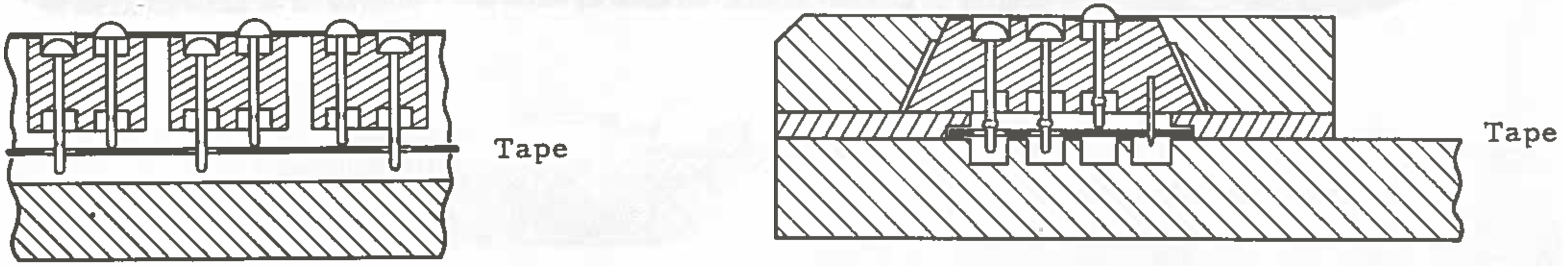

Longitudinal section

Transverse section

Fig. 3. Belt-Type Continuous Reader.

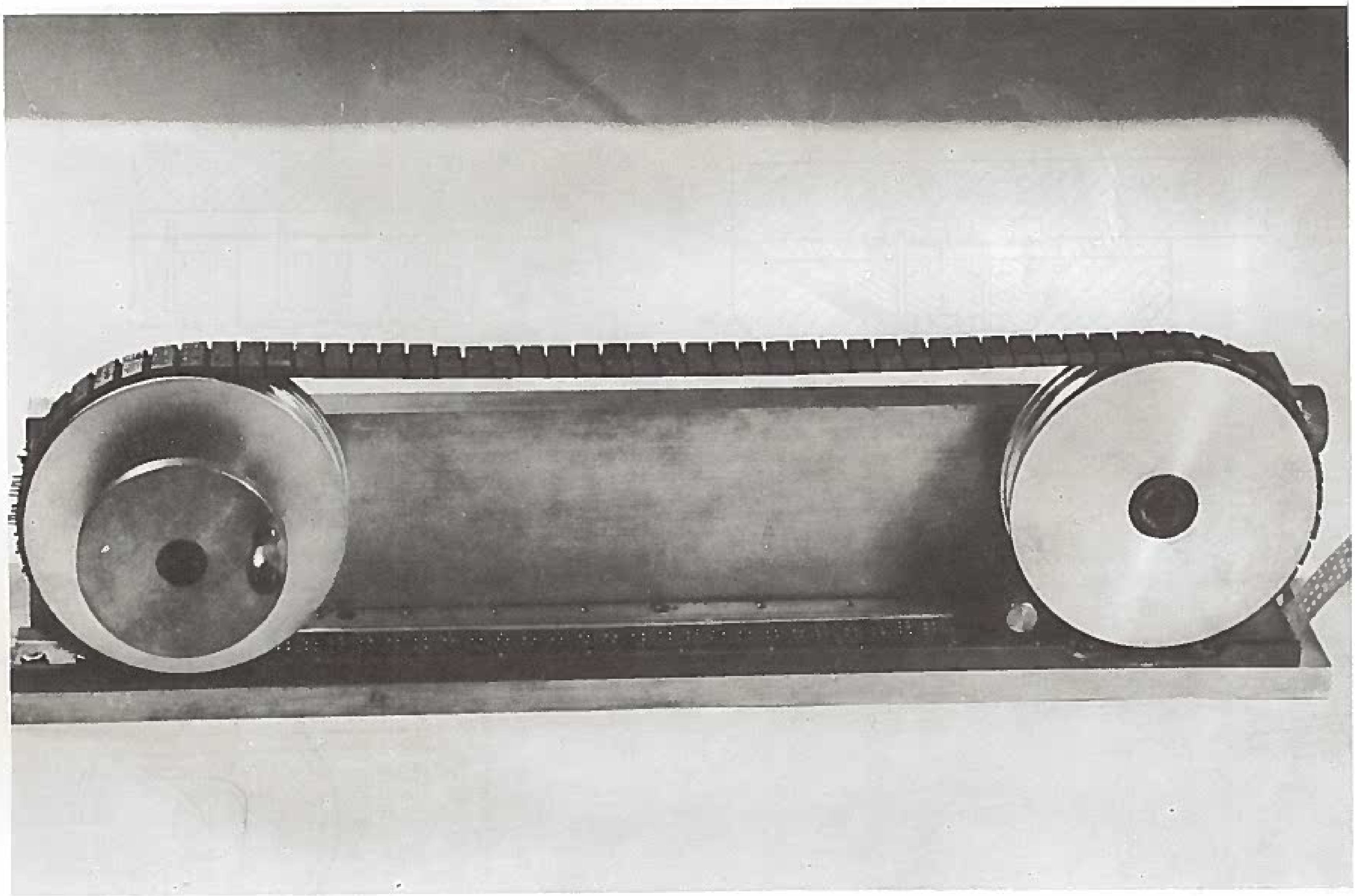

Fig. 4. Continuous, Pin Element, Tape-to-Braille Transducer.

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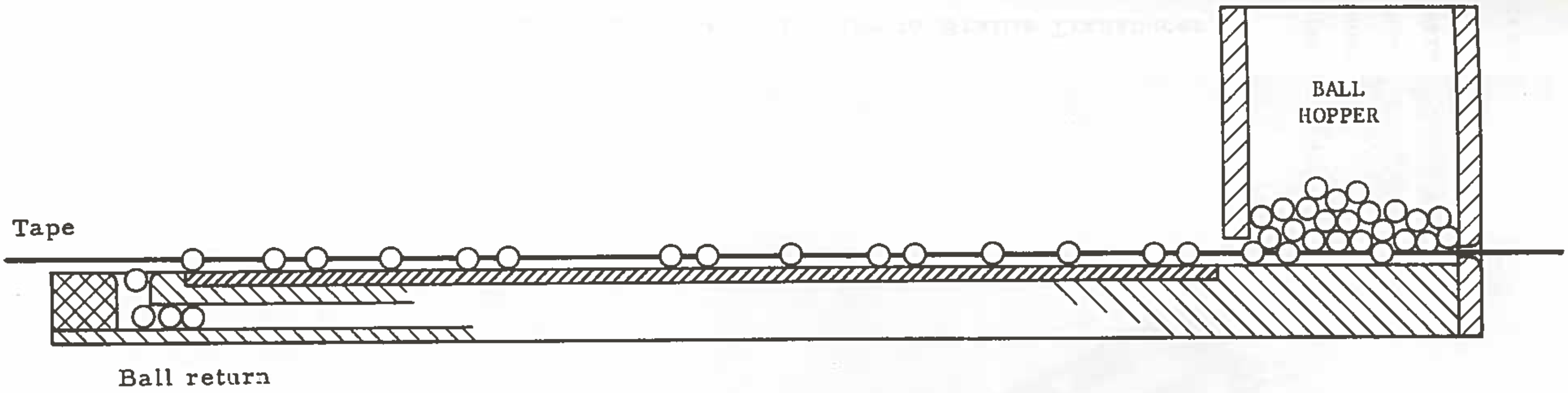


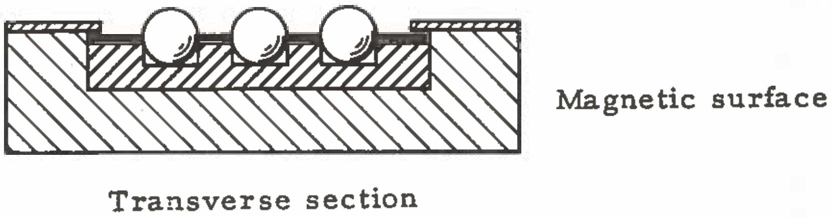


Fig. 5. Continuous Ball Reader.

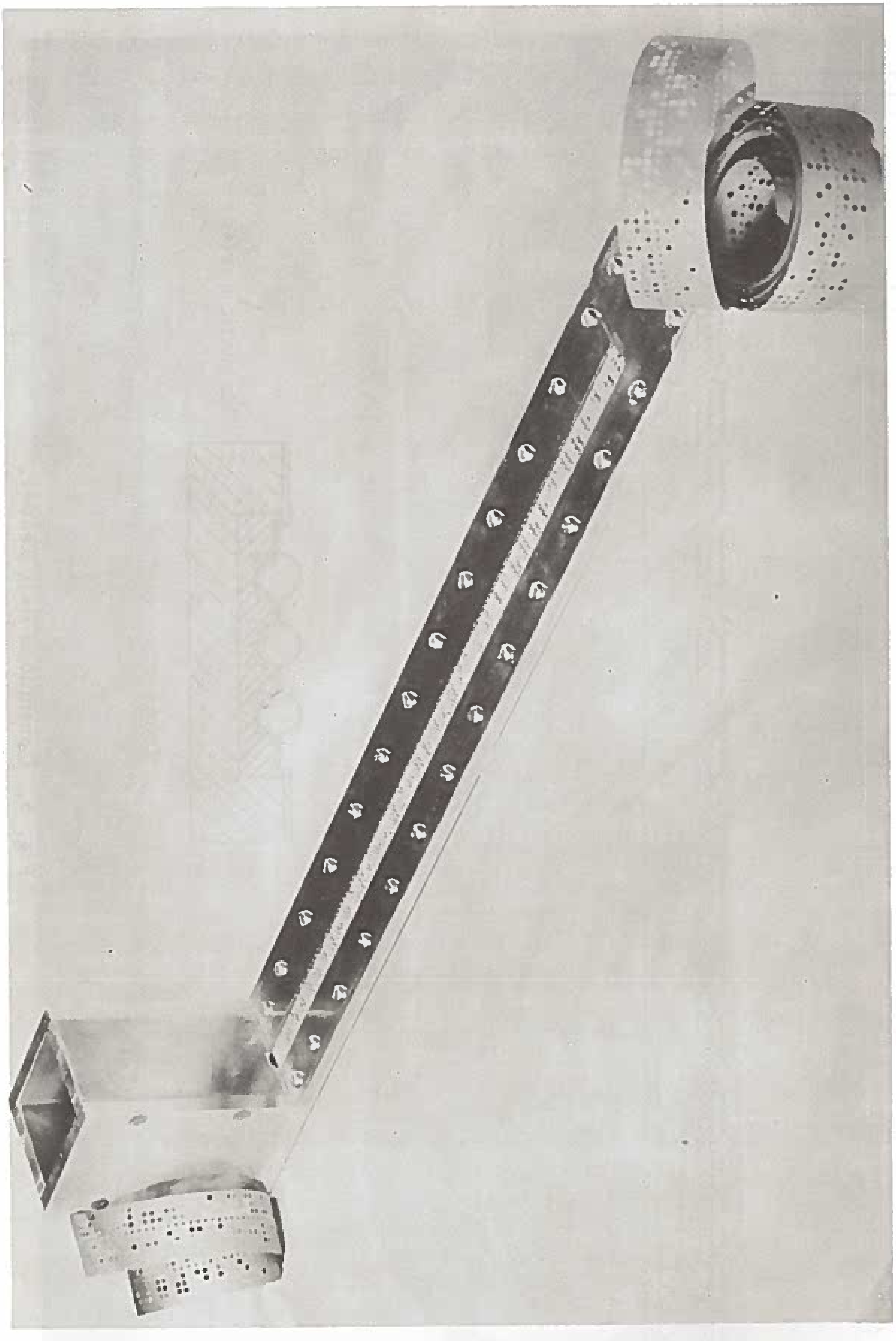


Fig. 6. Ball Element, Tape-to-Braille Transducer.

design goals of a simple, possibly portable, device. In this same regard, it might be appropriate to observe that the "IBM Belt Reader" in which pins were translated in a thick plastic belt for continuous presentation as Braille involved considerable complication and complexity. A tape reader converted punched tape to electrical impulses which were processed and converted by electromagnets into a mechanical motion which, in turn, set up the pins.

3. HIGH SPEED ELECTRIC BRAILLER AND TYPEWRITER ACCESSORY

D. M. Baumann, D. Eglinton, G. Staack, D. Kennedy

Presently available devices for the production of single copies of Braille are limited in speed and effectiveness by the requirement that all the energy for the embossing of the Braille cell must come from the operator of the Brailler. Present Braillers require the operator to have a thorough knowledge of the rules of Braille and require a degree of coordination and muscular energy to operate several keys at one time. The present and projected availability of computers and coding devices and the potential utilization of printed material now in the form of Monotype tape or Teletypesetter tape makes it important that devices be developed to produce regular embossed Braille printing from an electrically coded information source. Furthermore, the difficulty of obtaining sufficient volunteer Braillers and the trend of increasing the integration of blinded students into the normal classroom requires that methods be developed to reduce the skill required to produce adequate Braille text.

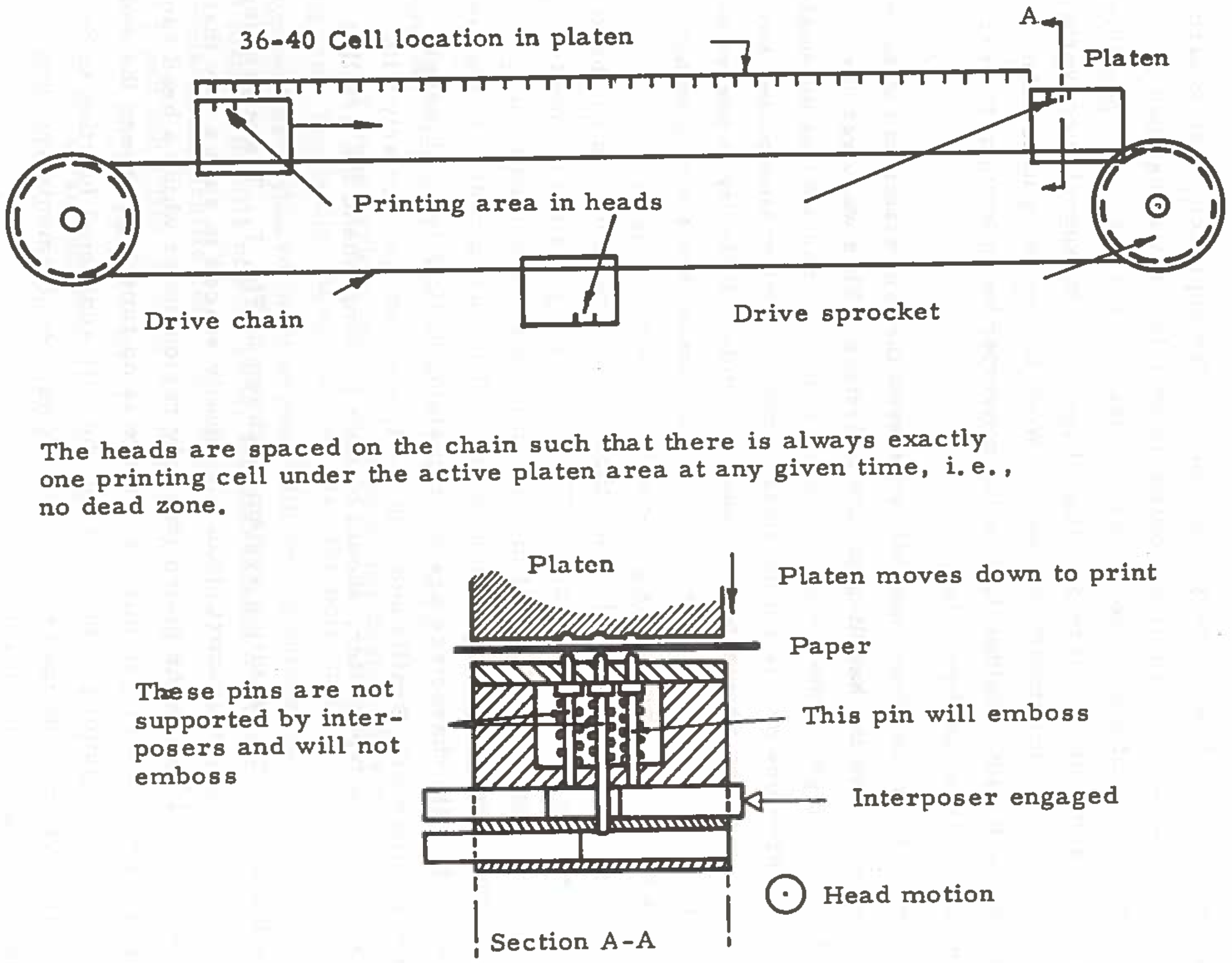
These requirements of a new, high-speed Brailler led to the initial work on design concepts of an electric Brailler.[2] It was determined that the device should operate at a speed comparable to a standard electric typewriter. Also the input to the electric Brailler should be entirely flexible to allow its use with computer output, paper or magnetic tape output, Braille keyboard input, and typewriter keyboard input.

Of these various inputs the typewriter keyboard is the most challenging from the design viewpoint, but also the potentially most useful. With a typewriter keyboard input anyone with typing ability can be utilized to produce a form of Braille copy. Thus, the classmates of blinded students could supply much of the Braille copy. In office situations a need exists for producing both a typed and a Braille copy. A blinded member of an office group could thus have available to him a Braille copy of all documents typed. A blind typist could use an adjunct Brailler as a device for allowing him or her to proofread his typing. Even if such proofreading were not necessary the availability of the device should break down some of the barriers to employment of blinded office workers.

Anyone familiar with the rules of Standard English Braille will immediately object that there are symbols in Braille that are not found on the typewriter, also that the most often used Grade II Braille has many rules and conventions that would make a one-to-one correspondence between typewritten and Braille copy impossible. The approach taken toward the solution of this incompatibility problem is twofold. It was decided to incorporate as many of the Grade I Braille rules into the system as possible. Furthermore, some preliminary planning of possible, inexpensive converters to make the proper corrections was made. Work is now being undertaken on the first approach with consideration of the converter being brought to bear on the design decision as they arise.

The most important incompatibility between the typewriter and Brailler at first appeared to be the handling of capital letters. This was overcome by adding a seventh pin to the embossing head in such a manner that the position six of the previous cell is automatically embossed when an alphabet key and the shift key on the typewriter is pushed. Another difficulty is presented by the fact that the Braille cell takes much more space than the typewriter letter. This was overcome by designing a Braille embossing head that travels on an endless chain. In this way three heads are used with one head in position over the paper at all times. The number sign exists on most typewriters,however, it is difficult to build in the logic required to precede a series of numbers with a single number sign. This last problem and some of the special Braille characters are the remaining difficulties. However, any person familiar with Braille and with the typewriter, particularly with the limitations of the typewriter, should be able to comprehend the Brailler output.

A schematic of the resulting system is shown in Fig. 7. There printing heads are mounted on a transport chain and equally spaced in such a way that as soon as one head leaves the platen (the only region under which a head can print) the next head enters. In this way, there is no time lag between the end of one line and the beginning of the next and the only additional function to be performed is advancing the paper one line. Power requirements are thus maintained at a low nominal level.



The heads are spaced on the chain such that there is always exactly one printing cell under the active platen area at any given time, i.e., no dead zone.

Fig. 7. Operation of Heads and Transport Mechanism.

Concurrent with the conception of the improved transport mechanism was the design of a small, high speed, low mass printing head. The approach taken is to actuate a small, low power support mechanism for each printing pin and provide the printing power through the single, movable platen. The latter concept is incorporated into the head design. Figure 7 describes the method of operation of the printing head and Fig. 8 is a photograph of the first model.

Thus, the basic concepts of power conservation, the method of controlling that power and a physical configuration allowing very rapid operation of the machine were formed. The task remaining was to convert low power external signals into mechanical motions of appropriate power and location to operate the functional mechanisms.

The similarities of control functions of the proposed Braille system and the IBM Selectric Typewriter became apparent. Through arrangments with the Cambridge Office of International Business Machines Corp., a Selectric Typewriter was made available for a compatibility study and disassembly. The operation of the working typewriter was studied as it was disassembled into logical operation groups; namely, character selection, function power and head power. These groups were to be evaluated individually for inclusion or exclusion to the Braille system.

The first function scheduled for evaluation was that of powering the printing heads. The Selectric employed a clock spring to power its printing head forward and a motor to return the head to the beginning of the printed line and at the same time rewind the clock spring. This method proved to be incompatible since the Braille system was to have three heads advancing in one direction and no necessity for returning a single head to the beginning of the line. The various methods of providing an intermittent force were studied. A small slip clutch was designed, built and tested but the life of such a device was found to be very short. Commercially available slip clutches were studied but a formidable amount of power was dissipated while the heads were not in motion. It was also required that the machine be capable of back spacing without an undue amount of power input (that which might be required to overcome a continuously acting forward force). For that reason, the idea of applying a forward force of the magnitude re-

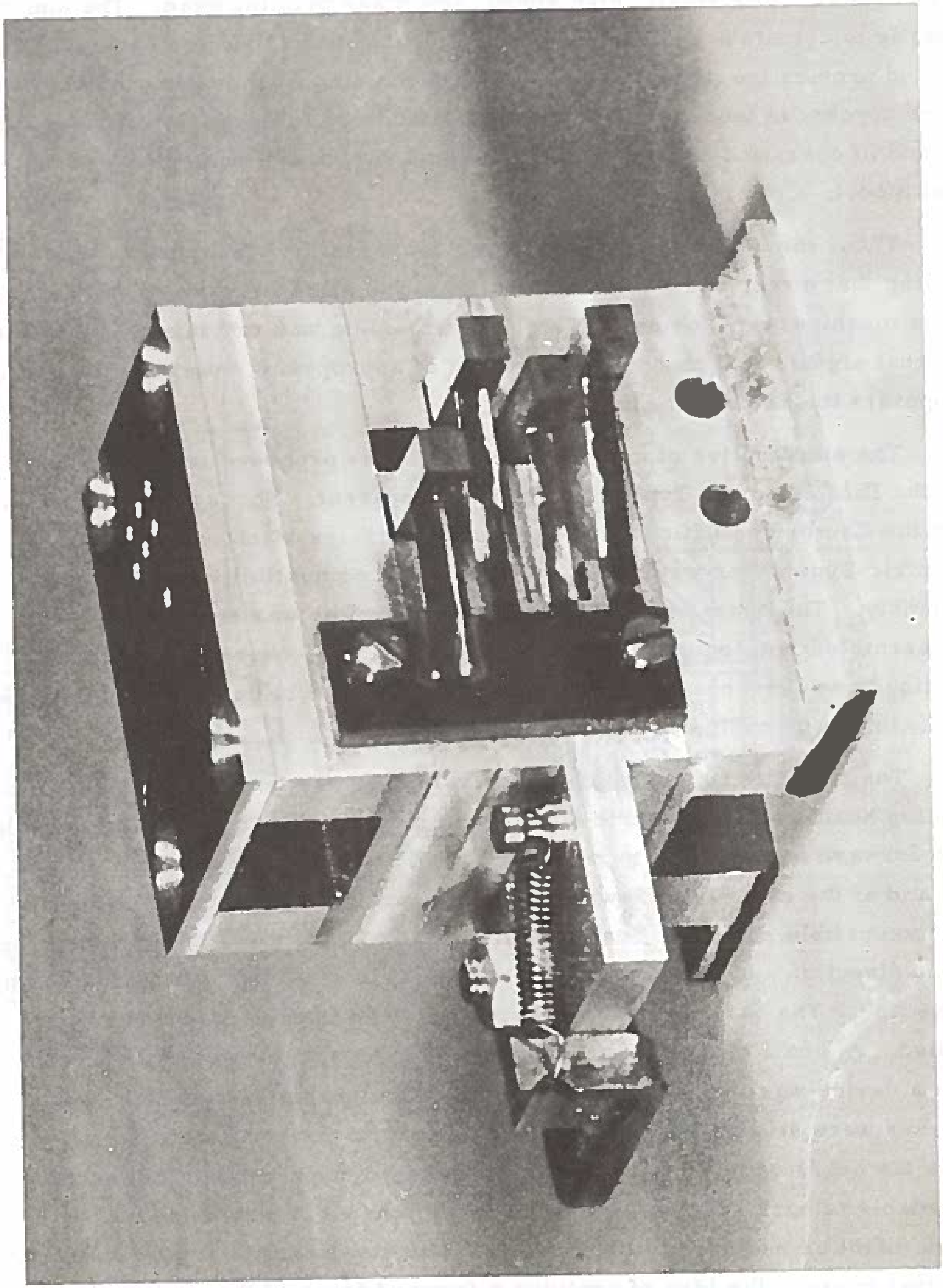


Fig. 8. M.I.T. Brailler Printing Head.

quired for full power to the heads was ruled out. Torque motors were investigated because it was felt that with reasonably simple controls, a small tensioning force could be applied to the heads and at the appropriate time, full power could be applied to advance the heads. However, the exclusive use of a torque motor was discarded because of size and cost. At about that time a backspacing mechanism was designed which would be cam powered and which would not dissipate energy while it was not functioning. This backspace mechanism was subsequently redesigned so that it could be used for either backspacing or advancing the printing heads. The experience gained with torque motors revealed that a small, inexpensive motor was available to apply the tensioning force to the heads (the force required to keep the chain taut and to hold the alignment surfaces of the head and frame together). The final head powering system involved the backspace/advance mechanism and a small inexpensive torque motor.

The next function for evaluation was the character selector for the printing head. The IBM mechanism appeared to be ideally suited to this application since it employed a mechanism which made the output motion completely independent of the duration of the input pulse and its nature demanded very few mechanical changes. A preliminary design was made incorporating the IBM selector group. It was then discovered that an electronic device could be built very cheaply which would accomplish the desired input/output isolation and since the power available from the IBM mechanism was not demanded by the selector pins in the printing heads, the IBM mechanism was no longer considered for this function.

The tentative decision was also made at that time to include much of the electronics of the typewriter-to-Brailler-converter into the Brailler since the electronics could be made to serve dual functions.

The resulting selector mechanism consists of one solenoid for each embossing pin and appropriate linkages between the solenoid and pin. Studies were made of several solenoids to determine operating times and forces before a solenoid was chosen for the selector assembly.

Work then followed on an assembly to provide several functions--platen alignment and support and handling of the paper or zinc plates. The system consisted of an aluminum "I" beam for the platen and a set of rollers and gears connected to a solenoid and a manually operated knob for the paper advance system.

Fig. 8. M.I.T. Brailler Printing head.

Since the electrical components were becoming numerous, work then followed on an operational diagram detailing the interconnections and logical relations between the various elements of the entire system. It is shown in Fig. 9.

At present, work is being conducted on the cam-powered device to activate the backspace and advance mechanisms and the platen. The original intention was to use a similar device found in the IBM typewriter but it provided more functions than were needed and it was unnecessarily complicated by its input/output isolation which was obviated by the added electronics.

The primary value of the IBM Selectric Typewriter to the Brailler project has been the existence of a good model for certain design practices involving basic linkages and the fabrication of stamped sheet metal parts. Several IBM components have been employed in the present Brailler design but in all cases they are basic elements, not assemblies. The mode of operation throughout the project has been to try to utilize as many standard parts as possible because of the realization that only limited numbers of devices would ever be built. This thinking also prevailed in the decision to utilize somewhat more electronic circuitry because of the lower cost in small quantities than would be possible for machined parts to perform the various holding and timing operations.

All in all, over 200 different parts have been designed and are now in various stages of completion. Photographs of the assembly that has been completed thus far is shown as Fig. 10.

Concurrent with the design of the electric Brailler the typewriter keyboard attachment has also been undergoing development.[3] A system of light shutters is used to interrupt the various combinations of 14 beams of light. Figure 11 shows the prototype device. Each shutter is actuated by a spring connection to the key levers on the underside of a typewriter. By breaking off various blades of the optical shutters each key is coded. As the shutter is actuated the remaining blades interrupt the light. This is detected by a bank of photocells and transmitted to the Brailler.

Work is underway to complete and debug the prototype and then redesign the device for limited production.

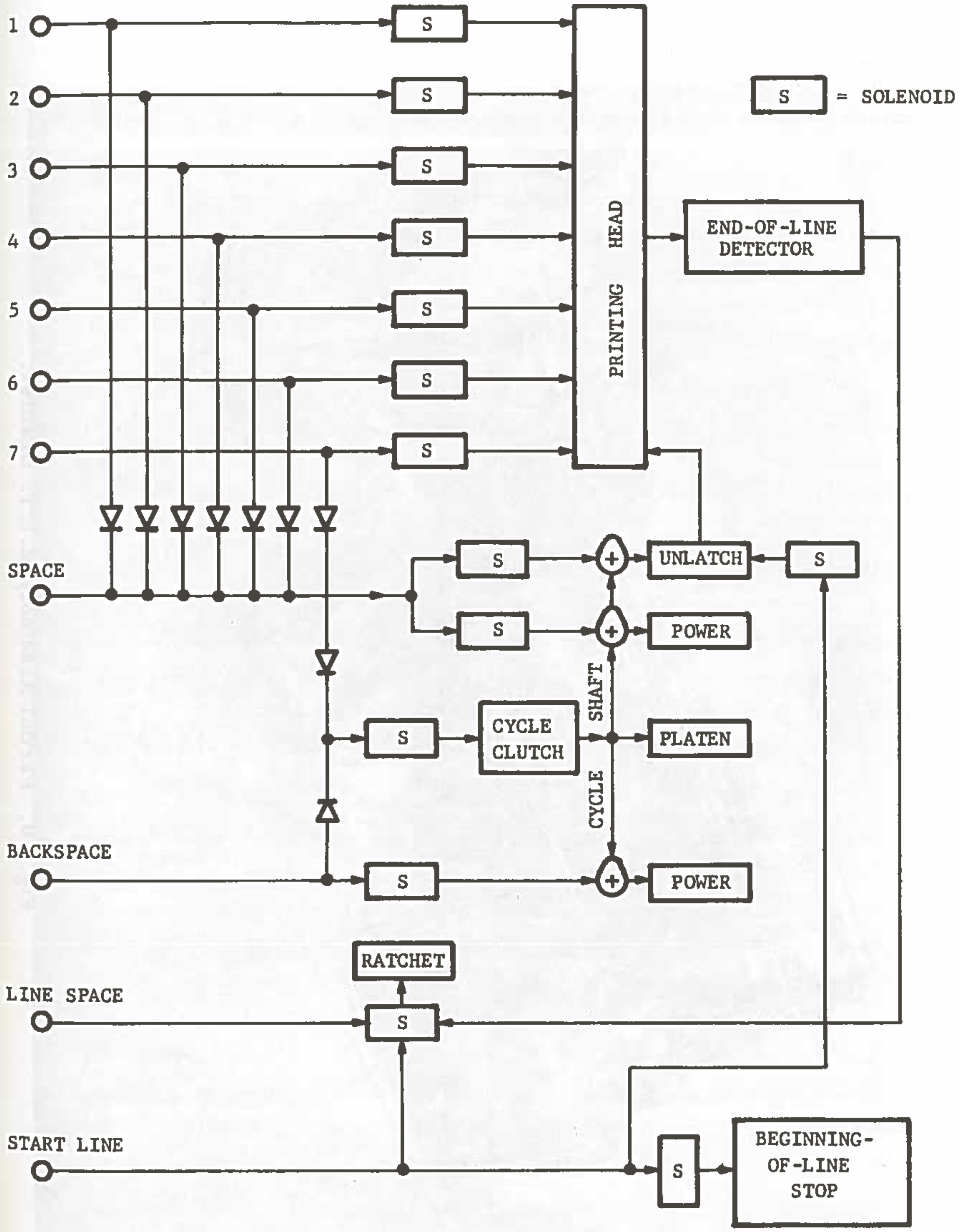


Fig. 9. Block Diagram - M.I.T. Brailler Printer.

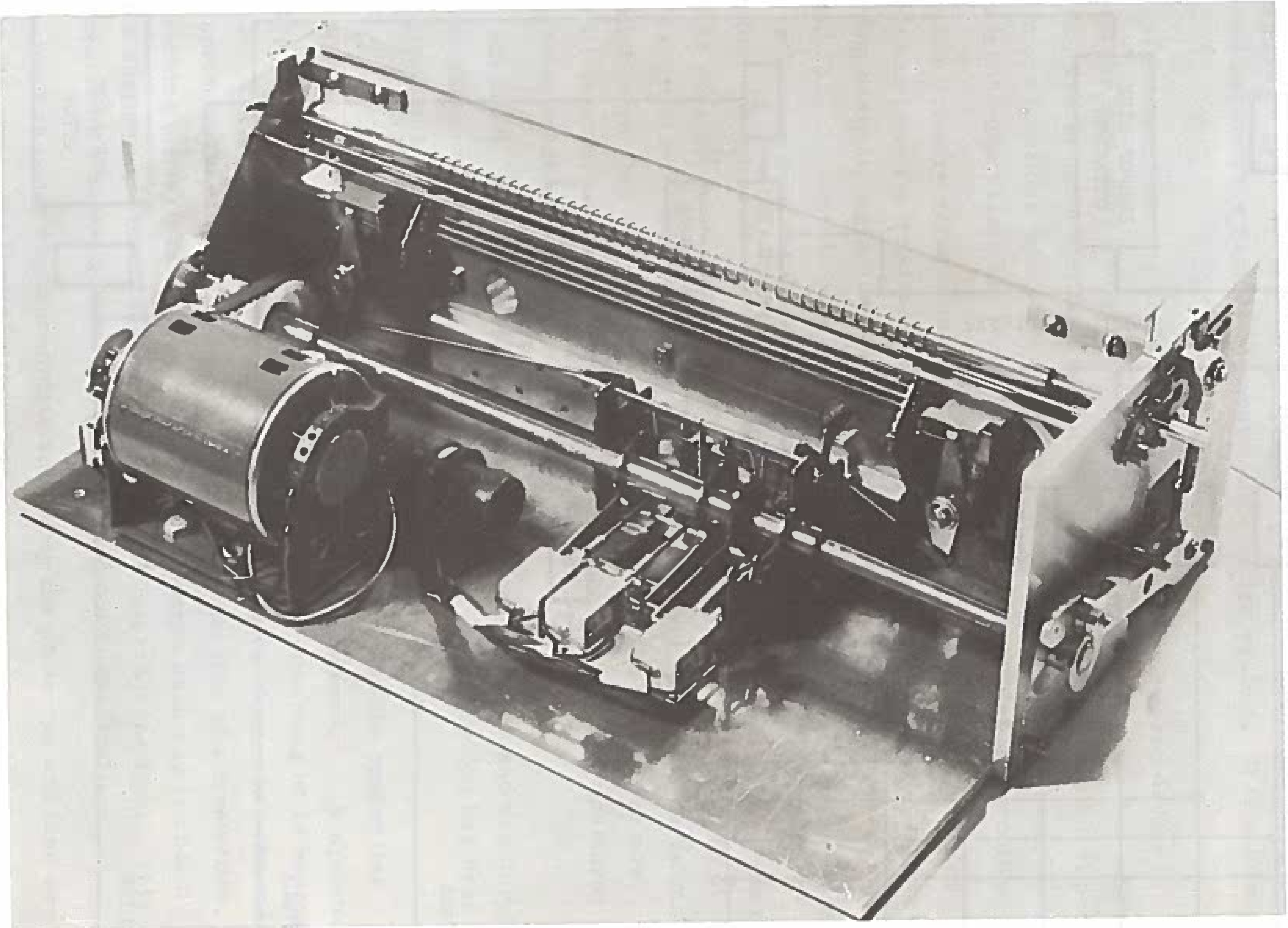


Fig. 10. Partial Assembly M. I. T. Brailler.

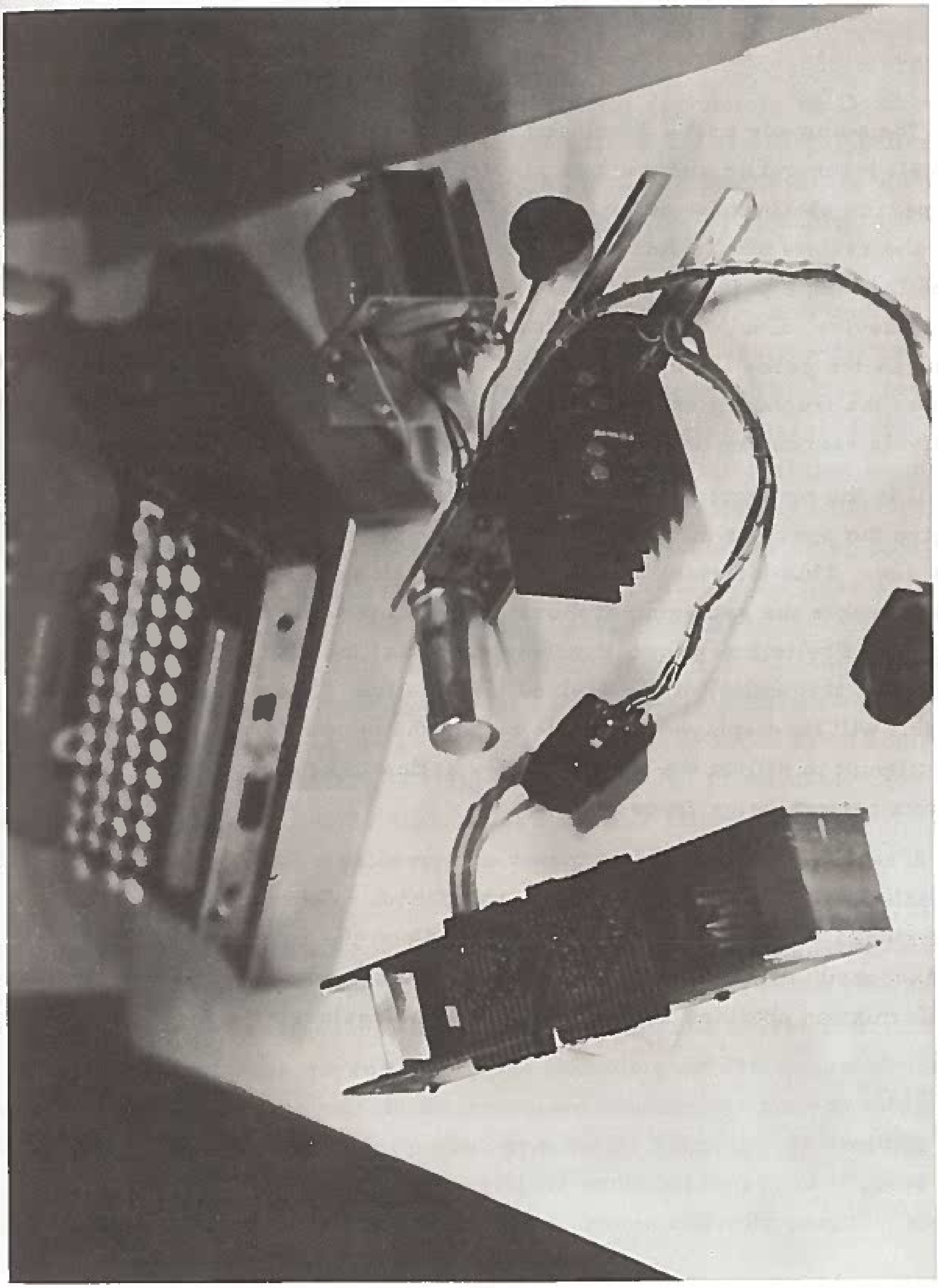


Fig. 10. Partial Assembly M.I.T. Brailler.

Fig. 11. M.I.T. Brailler Typewriter Accessory.

4. AUDIO-VIS PROBE

D. M. Baumann, A. Genachowski

The audio-vis probe developed by the late Dr. Witcher, utilizing a photocell input and an audio output, is an instrument designed to help the blind person obtain information otherwise barred to him. Specifically the probe assists him in following a line on paper, traces on an oscilloscope, locating a pointer on a meter, etc. The probe, however, is a one channel device, i.e., the audio output transmits a constant frequency tone as long as the probe is kept on the line traced. The moment the probe leaves the line, the frequency changes. As a result the person using the probe has to actively search the line.

It is the projected plan of the present study to design a probe which will give the operator advance notice of an impending change in the direction of the line. This information will make it much easier to operate the probe and will enable the gathering of more information with fewer stochastic searches. Preliminary investigations[4] show that four photocells will be suitable for the transmital of the desired information. The output of a multiple photocell will be displayed in tactile rather than audio form. This is done in an attempt to utilize the natural reflex action to keep from going off the edge of a pattern being traced.

A search of available low power commerical vibrators suitable for our application was made; however, none was found. Consequently a vibrator was designed and is presently being built. Upon the completion of this task a "breadboard" probe is going to be constructed, and tested. From the data and information obtained the new probe will be designed.

5. THE COLLAPSIBLE CANE PROJECT

D. M. Baumann, R. Gerstley, L. A. Neuman, D. S. Nokes and R. Ochsner

The collapsible cane project came into being at the Mobility Research Conference held at the Massachusetts Institute of Technology on October 11-13, 1961 jointly sponsored by the American Foundation for the Blind, Office of Vocational Rehabilitation, Seeing Eye, M. I. T. and the Veterans Administration. The meeting was attended by practitioners in the area of mobility training, mobility researchers and mobility aid users.

During the course of the conference many techniques now under study or development were discussed. Throughout these discussions the new techniques were continually compared to the existing mobility aids the cane and the dog. The comments pertaining to the canes revealed that one of the predominent disadvantages of the cane was the fact that the most acceptable canes, based upon length, strength, durability and balance were not collapsible. After more detailed questioning of the cane using participants it was found that in many situations a cane user would prefer to be able to collapse his cane so it could be carried in pocket or purse. Several types of collapsing canes are available, however each seems to have some undesirable characteristics in the extended position. The primary problem seems to be that the joints of the presently available canes become loose after some short lifetime and lose their ability to transmit information to the user. Some of the canes are simply an individual leg of a camera tripod that was not designed for impact loading and very frequent and prolonged use.

At the end of the conference it was summarily determined that, aside from any new or exotic ranging device, a very great need exists for a sturdy, long life, collapsible cane that is mechanically equivalent to the duraluminum long cane when it is extended but which would collapse to less than a foot in length. Furthermore, the collapsing and extending operation should not be difficult or time consuming. In the collapsed position the cane should readily fit in a gentleman's inside coat pocket or a ladies handbag. It would be advantageous if the cane could have a variable extended length so it could be fully extended for travel in relatively clear spaces and only partially extended in congested areas.

It is agreed that cost is certainly a factor that should also be part of the specification of a collapsible cane. However, it was decided that rather than to restrict the cost at this stage of the project and thus be insensitive to possible configurations that may be insignificantly more expensive, the cost of the product should be disregarded during the initial stages of the development. Later, methods of reducing the cost should be investigated. In the past there have been strong feelings expressed that a cane should cost less than five dollars. Certainly this is true but there is also the factor of useful life of the cane to consider. Also, sighted individuals do purchase eyeglasses at costs in excess of twenty-five dollars and even the blind are furnished with dogs that cost an order of magnitude more than the canes. It was thus determined that the proper procedure was to find out how "good" a cane could be developed and then to compromise the cost if necessary.

The collapsible cane project was therefore initiated as a junior project by R. Gerstley, L. A. Neuman, D. S. Nokes, and R. Ochsner all students in the Department of Mechanical Engineering at Massachusetts Institute of Technology. The project was divided up into several portions. Each student worked on a separate portion and meetings were held weekly to coordinate the efforts. This first junior project is considered to be only a first phase of the solution of the collapsible cane project. The next phase will be to construct improved prototypes to be tested under simulated and actual conditions.

Four different cane configurations were evaluated by each of the four students. Excerpts from their reports are given here.

The Friction Joint Canes. (R. Gerstley)

A cane was made of five sections of type 304 stainless steel with one section each of 1/2, 9/16, 5/8, 11/16 and 3/4 inch diameter tubing. Mr. Gerstley found that the 304 was the only steel readily available in these tubing sizes but would have preferred type 410 heat treatable steel if more time had been available for its procurement.

Each of the tubes were relieved except for a small portion at the end and a ring was sweat soldered to the end to make a section as is shown in Fig. 12. The extended length is 51 inches and collapsed length of the five sections was 11 inches. About 10 pounds of force was required to extend or collapse the particular cane that was built. However, the cane also became looser with use because the material was unhardenable.

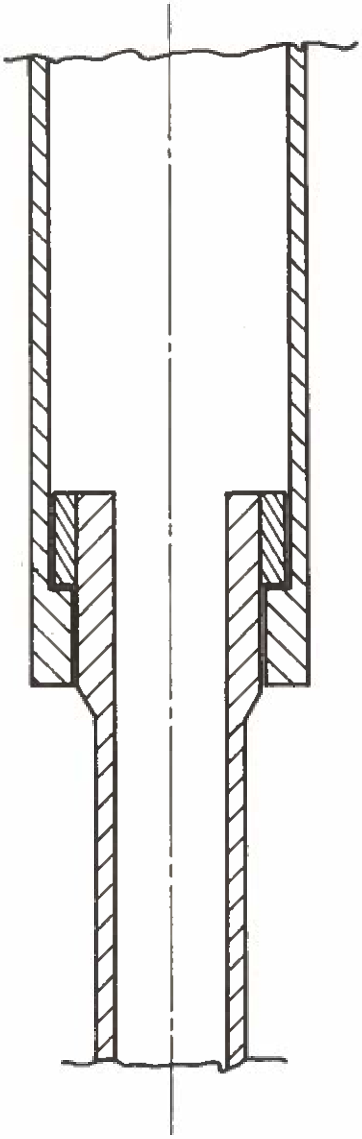


Fig. 12. Sample Friction Joint.

The problem areas with this type of construction are in the accurate control of tolerances and the desirability of a harder and thus more wear resistant material. A special order of 410 stainless steel would improve this type of cane. The main disadvantages are related to the forces needed to extend the cane as they must of necessity be greater than the force to be placed on the cane when extended. Various methods of locking the joints by bayonet or screw configurations were investigated but none were tested in the available time.

The Spiral Cane (L. A. Neuman)

The spiral cane is a helically coiled strip of beryllium-copper. The strip used was eight feet by three inches by 0.005 inches wrapped in a spiral to make a wand 50 inches long when extended. The collpased length is thus three inches plus the cane tip for a total length of about four inches. (Shown in Fig. 13)

A Description of the Spiral Cane

There is a fixture soldered in the bottom that is threaded for the standard cane tip. At present, the cane is held rigid in the extended position, by locking its maximum diameter with a pipe clamp. It is collapsed into a metal can with a screw top. Total weight is ten ounces.

The cane is heat treated with its equilibrium in the extended position. This was done so that the blind person need not do too much adjusting when he extends it. All he need do is twist the cane for about one turn to tighten the coils and lock it. In the locked position, the cane is almost twice as stiff as the long cane (see Fig. 14). The heat treatment of the cane was found to be best as follows:

(i) To anneal - 1450°F for one half hour.
(ii) Form in the annealed state.
(iii) To temper - 600°F for three hours. This is actually a precipitation hardening process.

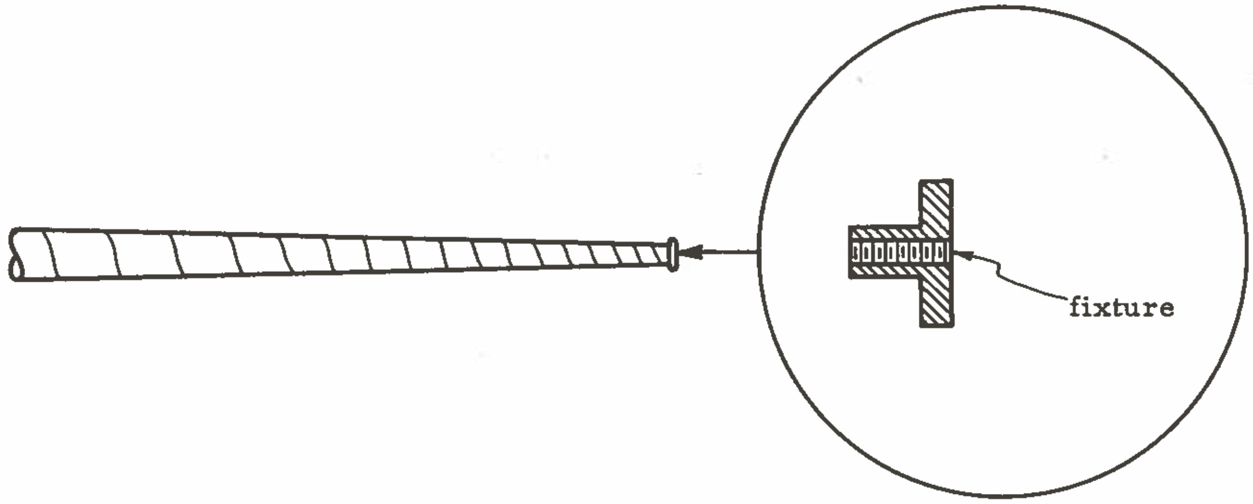


Fig. 13. Spiral Cane Extended

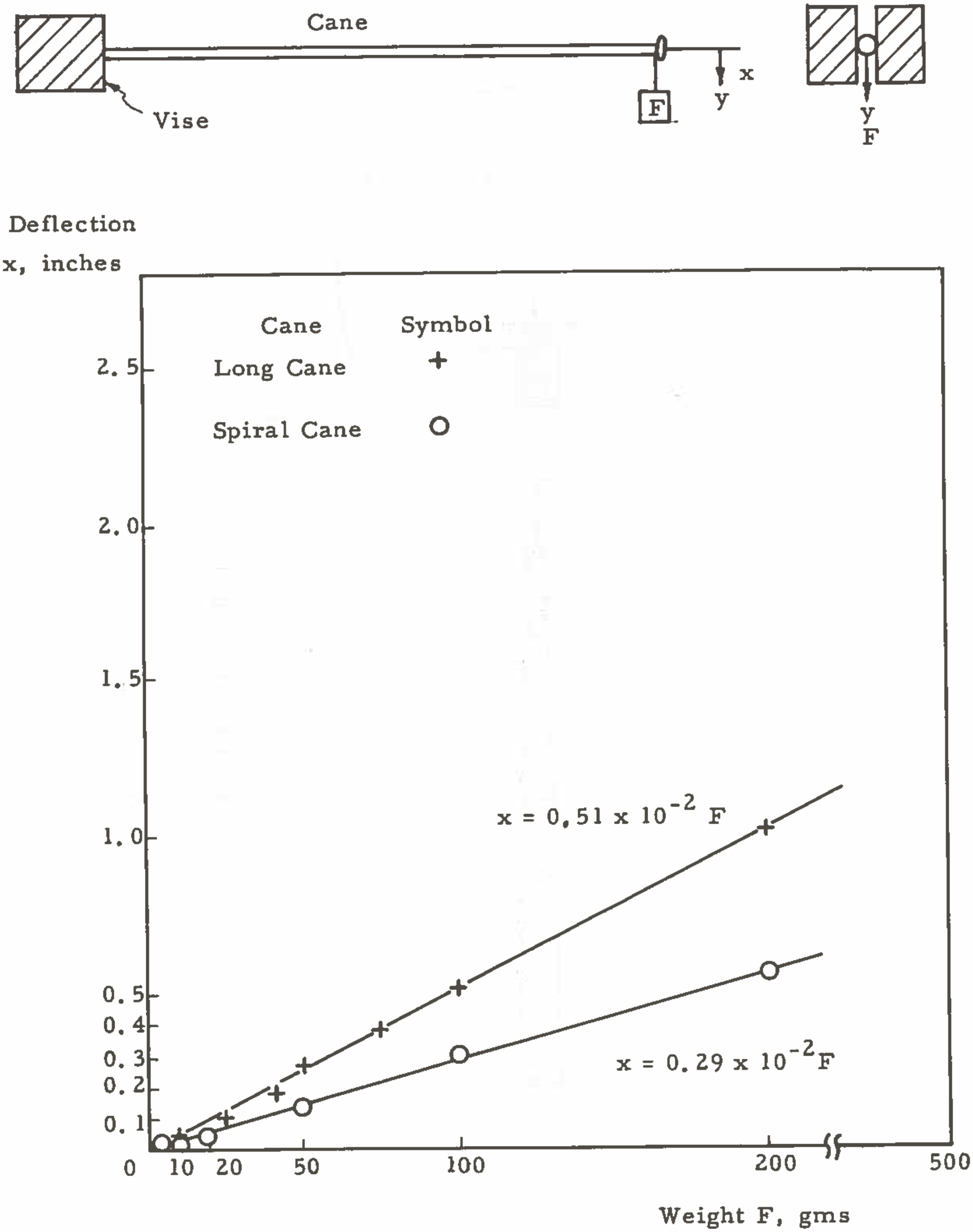


Fig. 14. Force-Deflection Measurements.

Heat treatment results in the formation of various oxides on the surface of the cane. These were taken off as follows:

(i) Fifteen minutes immersion in sulfuric acid, 30 per cent solution by volume, at 160°F.
(ii) Rinse in hot water.
(iii) One minute immersion in nitric acid, 20 per cent solution by volume, at 110°F.
(iv) Rinse in hot water.
(v) Final polishing can be done by copper cleaner, Ajax and water, or similar metal polish or soap.

This process results in a cane that is actually one big spring. The spring is completely variable in length. A particularly good feature of the spiral, is that it is relatively unbreakable. A force that is greater than it can take as its elastic limit, will cause some slipping and some bending of the coils so that the spiral cane breaks, by slipping apart. A blind man that is familiar with his cane, can just unwind it and then rewind it back to its original form. A slight "kink" is left, but the cane is still operative.

A final note of caution must be expressed about the manufacturing technique of step (ii) on page 32. In coiling the cane, each coil of succeedingly increasing diameter should be further spaced from the coil before it. This is necessary because the collapsed circumference of a coil equals the extended circumference plus the spacing. A smaller spacing along a line of increasing diameters will cause binding when the cane is collapsed. (See Fig. 15)

Selection of Materials

The choice of the material used presented a major problem. Many materials were considered, before the final choice was made. The initial choice of material was brass, but when it was decided that the cane should have its equilibrium position, in the extended position, brass was rejected, as it was found experimentally that the diameter that brass would have to be rolled to, so that its elastic spring back gives the desired position, is too small to make. Since brass cannot be heat treated, it was rejected in favor of a metal that could be. Table 1 shows a tabulation of all the materials considered, and their properties which were compared.

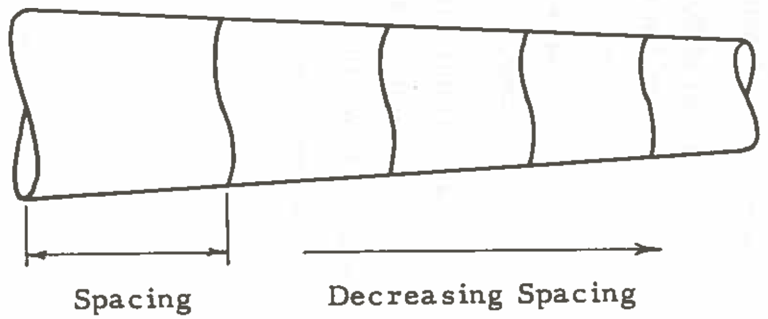


Fig. 15. Spiral Cane.

Beryllium-copper was chosen for the following reasons:

- (i) It can be heat treated.
- (ii) It is non-corrosive.
- (ii) It has very good friction properties, i. e., it slides over itself in the non-lubricated state quite easily, while aluminum and all steels need considerable lubrication to do as well. This property is extremely important, as binding is a problem which is quite bad in the spring steel model tried.
- (iv) Alloy 25 which was used, has a yield strength of 175,000 psi, which makes it quite strong for its weight.
- (v) Its shear modulus is 2/3 that of stainless steel, and it therefore takes approximately 2/3 the force to collapse a beryllium-copper cane, that it would take to collapse a stainless steel cane. The approximation was made from the analysis of a helical spring with a rectangular cross-section. That is,

$$F = \frac{yGt^3(0.56\ t + b)}{5.575\ D_m{}^3 n}$$

where

y is the change in length, 46 inches
G is the shear modulus, 7×10^6 psi
t is the thickness of the material, 0.005 inches
D_m is the mean diameter, 3/4 inch
n is the number of turns in the spring, 38
b is the width of the material, 3 inches
$F_{theoretical} = 1.35$ lbs.

It actually takes about five pounds to fully collapse the spiral cane. This is within an order of magnitude of the estimation. The error is a consequence of the fact that the geometry of the spiral is quite different from helix. In fact, it would be impossible to have a helix with 38 turns of the specified cross-section.

TABLE 1

The following is a list of the materials considered and their properties:

	Spring Steel	Stainless	Pure aluminum	Alumninum 2024-T4	Alclad	Brass	Be-Cu
Heat Treatment	high temp	high temp	none	low temp	low temp	none	low temp
Shear Modulus x 10^{-6} psi	11.9	10.6	3.7	3.9	3.8	6.0	7.0
Max, yield Strength x 10^{-3} psi	188	145	21	47	42	80	175
Friction Properties	poor	poor	poor	poor	poor	good	good
Corrosion Resistance	poor	good	good	good	good	good	good
Specific Gravity	7.85	7.85	2.7	2.77	2.77	8.5	8.92

The fixture on the top of the cane is at present a pipe clamp that is removed from the cane, and clamped on to the can into which the cane is collapsed for storage. The main problem with this design is the inconvenience because there are loose parts to it which the blind person might possibly drop; the clamp, the can, the screw top. Because the cane is changing its diameter as it is changing length, and because the coils rotate with respect to the cane axis at the same time, any permanent attachment to the cane is not simple. Before this approach can be utilized more fully a permanently attached clamping device and an integrated retaining mechanism for holding the cane in the collapsed condition must be developed.

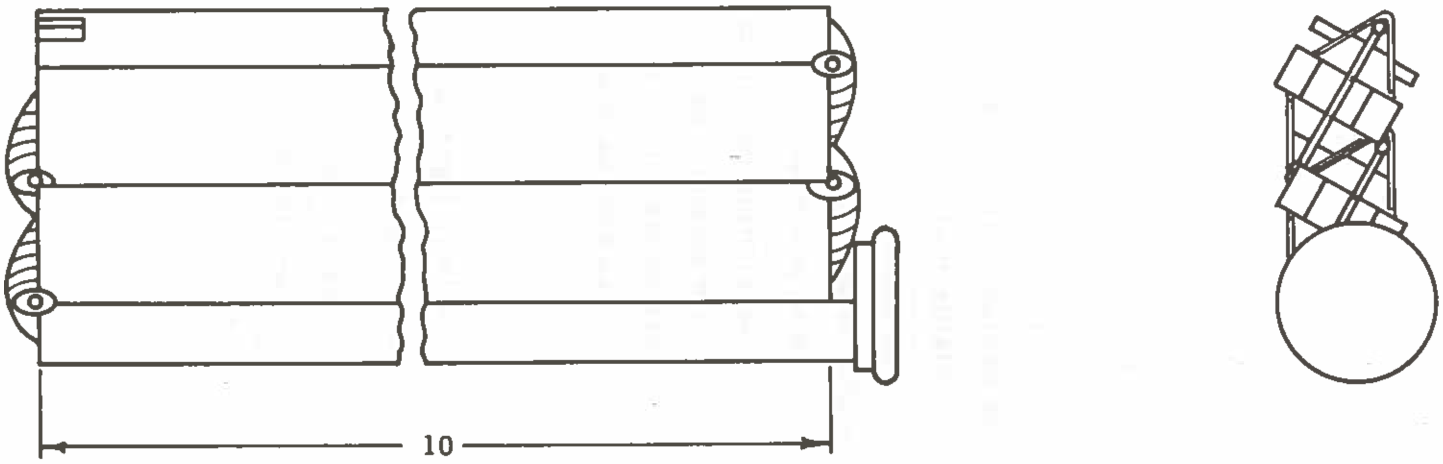
The Triangular Cane (D. S. Nokes)

The triangular cane is the result of a search for a shape that has a large section modulus and thus is rigid, but that rests into a small rectangular package that can fit the pocket or purse. By a unique placement of hinges the triangular tube sections can be folded together to make a rectangular package. (See Fig. 16).

The triangular section used to construct a prototype cane is shown in Fig. 17. Notice that the material used in this case was SAE 1010 steel. Actually 410 stainless steel was again preferred but the time required for a special order exceeded the length of the term project. It is suggested that 5056-H18 aluminum alloy would also be a suitable material for the triangular section because it could be formed as an extruded shape. The aluminum also has an excellent strength to weight ratio and good corrosion resistance. A 5/8 inch tube of the aluminum would have a maximum bending moment of 20 feet-pounds. The hinges, cable and tensioning bar should be made from 410 stainless steel heat treated to a tensile strength of 200,000 psi. This is necessary for wear and high strength in these parts. (See Fig. 18). The total weight of the aluminum cane with the stainless accessories should be approximately six ounces.

Notice that the cable is captured at each joint so that it is always at the apex of the triangle opposite the hinge. When this cable is tightened by means of the toggle on the tensioning bar the sections become rigid.

Extrapolation from the results of the SAE 1010 cane and from calculations of the strength and stiffness relationships of the proposed model, it appears that a triangular cane can have approximately the same strengths as the present long cane. Other questions to be answered pertain to the reliability and life of the hinges and cable under prolonged use.



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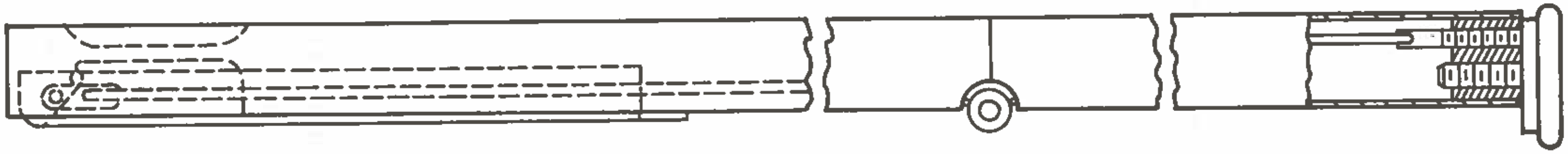
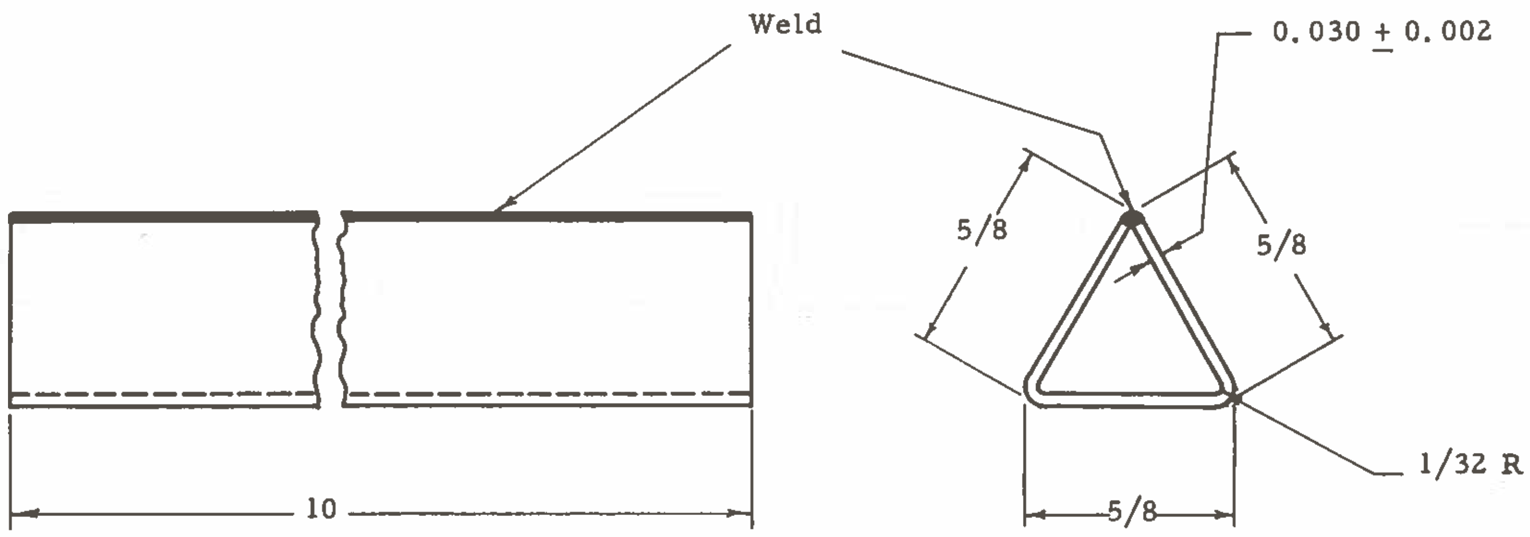


Extended - Triangular-hinge Cane - Full Scale

Fig. 16. Triangular-Hinge Cane.

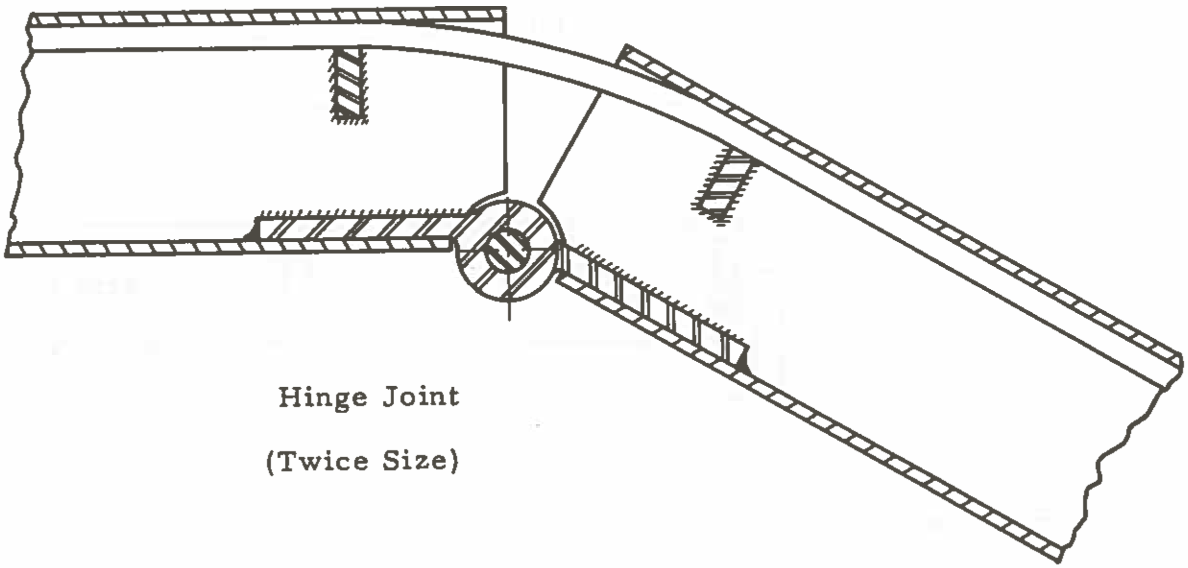
SAE 1010 Sheet Steel



All dimensions ± 1/32

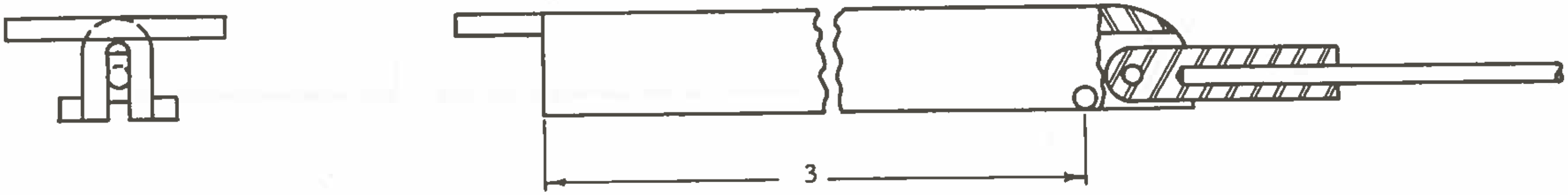
Drawing Twice Size

Fig. 17. Triangular Cane Section.



Hinge Joint

(Twice Size)



Locking Lever (Twice Size)

Fig. 18. Hinged Cane Details.

The Hydraulic Cane (R. Ochsner)

During the course of the term project discussions of the various methods of fixing the joints lead to a proposal by D. M. Baumann of a hydraulically pressurized joint. Mr. Ochsner chose to develop a model based on the initial suggestions.

The hydraulically operated collapsible cane consists of telescoping cylindrical sections of steel tubing with an internal hydraulic mechanism as shown in Fig. 19. The rubber bulbs shown in the sketch are connected by means of plastic tubing to a pump mechanism in the handle of the cane. When the system is pressurized the rubber bulbs expand, forcing the overlapping sections together and thus locking the joints.

To facilitate the contraction of the hydraulic mechanism to the collapsed length of the cane, the plastic tubing was wound into a spiral and annealed, so that its final shape resembled that of a telephone cord. The steps in this operation are as follows. A piece of flexible wire is first inserted in the 1/8 in. Tygon tubing. The tubing is then wound around a 1/8 in. metal rod, and secured in this position. The assemblage is placed in boiling water for 15 or 20 minutes, and after this heat treatment the tubing will retain a spiral shape without support.

The rubber bulbs were made by coating a form with air curing latex and subsequent removal of the form. Ten or twelve coats administered at intervals of not less than half an hour proved to be adequate. The forms were made of Wood's metal, and were cast in moulds of plaster of paris, after which they were machined to their final shape. Wood's metal melts at 60°C., and originally the forms were removed simply by melting them out. However, it was found that if the mould was given a good polish, and if the rubber was allowed to cure for several days before removal of the form, the bulbs could with some difficulty be peeled of the form without destroying the latter.

To bond the rubber bulbs to the plastic tubing, Pliobond cement was used. The joint was then coated with Epoxi to provide added strength.

To test the ideas and materials discussed above, a sample joint was produced and tested. It consisted of two overlapping sections about 1/2 in. in diameter surrounding a rubber bulb 2 in. long. The inner of the two sections had two slits cut in it. At an internal pressure of 30 psi the joint became quite

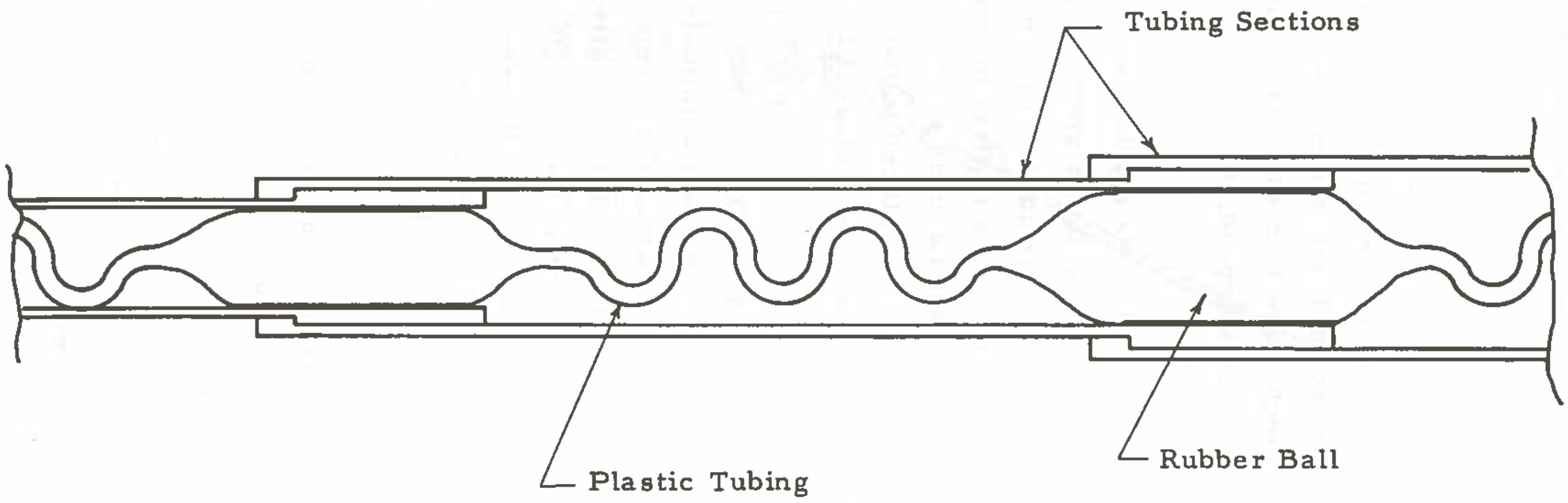


Fig. 19. The Hydraulic Cane.

firm, with no apparent slop, and by 40 psi it was sufficiently strong so that it could not be pulled apart by the experimenter.

The results of the above experiment indicate that the hydraulic telescoping cane is a practical and promising design. A piece of hydraulic apparatus suitable for use in a five section cane whose smallest section has an I. D. of 7/16 in., the length of each section being about one foot, has been produced and is available for further testing. To minimize the internal pressure needed, it is recommended that the overlapping sections be machined to a close tolerance, that interlocking grooves be machined in them, and that four slits rather than the two used in the experimental joint should be cut in the inner section.

Contingent on the development of a suitable pump mechanism, it would appear that the hydraulic telescoping collapsible cane will be a valuable mobility aid for the blind.

6. EXPERIMENTS IN TACTUAL PERCEPTION

T. B. Sheridan, S. Karp

This section discusses a series of 5 experiments in tactile discrimination. The experiments concerned the effects of various physical stimulus configurations in identifying "braille-like" stimuli with the index finger. Of special interest was the role of motor activity in tactile sensing of such stimuli.

The stimulus configurations involved are as follows:

1. The "place" method. In this procedure the skin of the index finger was displaced in a normal direction, held there momentarily then removed.
2. The "movement" technique. Under these conditions the stimulus was moved across S's finger at a speed controlled by the experimenter (approximately 2 in. per sec.).
3. "Free movement". The subjects were allowed to move their fingers freely over the stimuli.

It was predicted that the subjects would do best under condition 3, second best under condition 2 and least well with the place method for braille-like stimuli. Studies of Austin and Sleight, 1952, a and b, 1952[5, 6]; Bauer, 1952[7], Groth and Lyman, 1958[8], have shown that movement facilitates tactual perception.

In the first experiments, the subjects received 36 test trials under each of the above described conditions. The conditions were counterbalanced in order to control for a possible "ordering" effect. The conditions appear as main effect "A" in the analyses of variance (the design of which is stated in the appendix to this section).

Training in the first four experiments consisted of three presentations of each of the six stimuli under the condition given first. Under the following two conditions the stimuli were presented once each. Main effect conditions were counterbalanced for ordering during learning as well.

The four experiments and their results are as follows:

The Distance Judgement Experiment

In this study fifteen male M.I.T. student were trained to give absolute judgements of the distance between two blunted 1/32 in. diameter pins attached to the end of a pair of dividers. In this experiment, as in the following, there were six stimuli involved. The distances between pins 1/6 in., 2/6 in., 3/6 in., 4/6 in., 5/6 in., 6/6 in. They were called 1, 2, 3, 4, 5, 6 in the order of their magnitude. The data were analyzed using a two way analysis of variance. This is reported in Table 1. The number of errors made under the different conditions was considered the critical variable.

TABLE 1

Analysis of Variance for Distance Judgement Experiment Using Number of Errors

Source	df	SS	MS	F
(between S's)	(14)	(1118.6)		
Ordering(b)	2	112.1	56.05	<1
Error (b)	12	1006.5	83.27	
(Within S's)	(30)	(359.4)		
Methods (A)	2	25.2	12.60	<1
Interaction(AB)	4	15.5	3.88	<1
Error(ω)	24	318.7	13.28	
Total	44			

It can be seen from Table 1 that the methods did not differ significantly from each other under these conditions. The actual raw data for the whole group showed 113 errors under free movement conditions, 122 under place and 140 under movement. It appeared that the especially poor results under movement conditions, may be a result of conflicting cues set up by the motion which are irrelevant to the distance judgements. The ordering effect and the interactions were also insignificant.

The Braille Card Experiment

In this study the subjects were trained to discriminate the following six stimuli printed with a conventional braille machine on 3 x 5 cards.

1

2

3

4

5

6

The braille cell is a 3 x 2 block  Thus the above configurations represent six out of the seven possible configurations of two bumps which can be discriminated apart from any surrounding context. The subjects in this experiment were twelve male M.I.T. students. The procedure apart from the stimuli themselves was identical with the one used in experiment one. The data collected were analyzed using the same analysis of variance design. The results appear below in Table 2.

TABLE 2

Analysis of Variance in Braille Card Experiment

Source	df	SS	MS	F
(Between S's)	(11)	(678.9)		
Ordering(B)	2	70.1	35.0	<1
Error(b)	9	608.8	67.6	
(Within S's)	(24)	(1732.7)		
Techniques A	2	779.1	389.5	6.45^{+}
Interaction AB	4	235.4	58.8	1.47
Error(ω)	18	718.2	39.9	
Total	35	2411.6		

$^{+}$ significant at the 0.01 level

The three techniques caused different numbers of errors to be made. The differences are significant at the one per cent level. The rank ordering of the three conditions with respect to error is as predicted: 272 errors were made under place, 232 under movement and 139 under free movement. However, interactions and order were statistically insignificant.

Braille Card-Pin Experiment

A total of 644 errors in 1296 presentations occurred in the previous experiment. In an effort to reduce errors the heads of brass pins were stuck through the cards, and the experiment was repeated. The pins were chosen because they were about the same size as the original cardboard raised dots. It was felt that the metal would be easier to perceive than the cardboard end would not deform by touch. It was found that on the contrary the pins caused more errors to be made (700 as compared with 644). The data was further examined to see whether this experiment produced any different results than the one before. The analysis of variance performed is shown in Table 3.

TABLE 3

Analysis of Variance in Braille Card-Pin Experiment

Source	df	S	MS	F
(Between S's)	(11)	(1196.22)		
Order (B)	2	96.22	48.11	<1
Error(b)	9	1000.00	111.11	
(Within S's)	(24)	(966.67)		
Methods (A)	2	502.39	251.20	10.79^{+}
Interaction AB	4	45.28	11.32	<1
Error(ω)	18	419.00	23.28	
Total	35	2162.89		

$^{+}$ significant at the 0.005 level

Methods are again shown to be the only significant effect in the experiment and in this sense the experiment may be regarded as a replication of number two.

Braille Cards With Revised Training Procedure

This procedure was an attempt at improving learning and reducing the error rate. It involved giving full "feedback" (telling the subjects the result of each trial) to the first 12 to 36 stimuli on the first presented method and to the first six on the second and third methods. It was again found here that learning was less good than under the original conditions of experiment two (702 errors as compared to 644). The analysis of variance follows:

TABLE 4

Analysis of Variance for Experiment Using Braille Cards with Revised Training Porcedure

Source	df	SS	MS	F
(Between S's)	(14)	(2394. 33)		
Ordering(B)	2	1485. 22	742. 61	9. 80^{+}
Error (b)	12	909. 11	75. 76	
(Within S's)	(30)	(862. 67)		
Method (A)	2	366. 50	183. 25	9. 12^{+}
Interaction(AB)	4	13. 78	3. 44	< 1
Error(ω)	24	482. 39	20. 10	
Total	44			

$^{+}$significant at the 0. 005 level.

This showed quite a different pattern than previous experiments. Both the methods and the ordering were found to be highly significant. The explanation for the ordering effect must lie with the increased training on the first presented method.

An Experiment Using Revised Stimulus Presentation.

The purpose of this additional experiment was to determine whether the physical techniques used in the previous experiments would hold up when the stimuli were varied in such a way as to facilitate learning and avoid errors in forgetting the stimulus ensemble per se.

In previous experiments, with the exception of the distance judgement experiment, the performance was poor enough so that it was felt that the learning of the stimuli themselves was a problem - this in addition to the tactual recognition.

The new stimuli were chosen specially so that they would not present the above problem as before. They consisted of rounded escutcheon pins mounted on a cardboard base and raised about one diameter. They are pictured in Fig. 20 in full scale.

In the training session, the following instructions were read to the subjects (12 M.I.T. male students).

> "You are going to be presented with six different stimuli. They will consist of 2, 3, or 6 pin heads pushed through small pieces of cardboard. Here are the 6 stimuli." (Arranged on the desk so subjects may look at them). "As you can see they are identified by the number of pins in the pattern. The appearance of a prime means that there is a space in the line and a double prime means that there are 2 spaces. Your task will be to learn to identify these stimuli with your index finger and without looking at them".

It was predicted that the three methods of presentation (place, movement, and free movement) would order themselves as before and that if anything the effects of these methods would be even stronger than in previous studies. It was felt that in the previous methods by introducing the additional learning, the main effects (methods of presentation) were diluted.

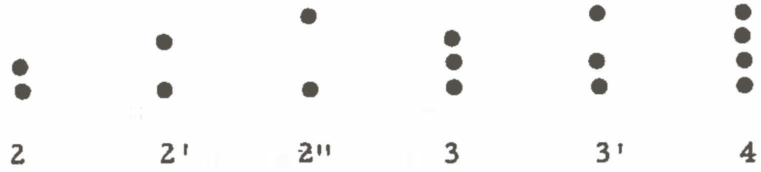


Fig. 20

The analysis of variance done on the data follows: (The design used is as before - see appendix).

Analysis of Variance for Supplementary Experiment

Source	df	SS	MS	F
(Between S s)	(")	(75.57)		
Ordering (B)	2	5.73	2.86	1
Error(b)	9	68.84	7.56	
(Within S s)	24	(1175.32)		
Method (A)	2	943.73	471.86	49.05^+
Interaction(AB)	4	58.43	14.61	1.52
Error(ω)	18	173.16	9.62	
Total	35	1249.86		

$^+$significant at the 0.001 level

It may be seen that the main effect A was very highly significant. The number of errors in the experiment was found to be 285 as compared to 644, 700, 702, in previous experiments with the same number of trials. Thus as predicted, the errors fell tremendously and the effect was far stronger than before.

Lateral or Tangential

The experiment also tested for an additional effect. The relevant instructions given to the subjects during training follow:

> "There will be 2 methods of presenting the patterns, one half of the stimuli being presented each way. In the first case the stimulus will be given so that the line of pins is parallel to the line of your finger." (termed "tangential" below) "In the other half of the trials, the presentation will be perpendicular," (termed "lateral" below).

This was done to see whether any sizeable differences between the two methods would occur. The following table summarizes some of the results.

Method (Number of Errors)

Movement		Free Movement		Place	
65		57		162	
Tan.	Lat.	Tan.	Lat.	Tan.	Lat.
37	28	25	32	80	82

Thus it may be seen that the differences between number of errors was insignificant. A breakdown of errors by stimuli is also given:

Errors

Stimulus	Lateral	Tangential
2	3	10
2'	23	34
2"	23	13
3	31	38
3'	28	22
4	30	30

	2	2'	2"	3	3'	4
2	x	5	1	5	0	
2'	13	x	10	5	26	1
2"	2	18	x	3	13	0
3	11	17	4	x	30	6
3'	1	17	28	4	x	1
4	0	5	3	33	20	x

It can be concluded that while there were definite differences between the difficulty of the stimuli, the differences were minor between the methods of presentation. Possible exceptions to them are 2 and 2".

Although there are obvious differences in where errors are made, there is no systematic trend.

Conclusions

1. Simple absolute judgements of distance between two point stimuli was not significantly better with any of the three methods of presentation for subjects with limited experience (experiment 1).
2. For point stimulus patterns of up to 4 dots spaced in two dimensions, "free movement" was best, "movement" next, and "place" least good (experiments 2, 3, and 4).
3. Use of metal pin heads over embossed cards did not appear to enhance learning of braille-like tactile patterns where absolute judgements of stimuli are required (experiments 2 and 3).
4. When absolute judgements were not required in the above sense, i.e., a comparison ensemble of stimuli was always available, free movement by the subjects finger over the raised dot pattern yielded much better recognition than when the pattern was presented by the experimenter in one place or moved across the skin at a constant rate (experiment 5).
5. Neither direction of tangential motion in the "movement" or "free movement" conditions, i.e., lateral or tangential, was significantly better (experiment 5).

APPENDIX

Experimental Design Employed

a

Order $j = 1$		$k = 1$ $k = 3$	$k = 2$ $k = 4$	$k = 1$ $k = 3$	$k = 2$ $k = 4$	$k = 1$ $k = 3$	$k = 2$ $k = 4$
$j = 2$	b	$k = 1$ $k = 3$	$k = 2$ $k = 4$	$k = 1$ $k = 3$	$k = 2$ $k = 4$	$k = 1$ $k = 3$	$k = 2$ $k = 4$
$j = 3$		$k = 1$ $k = 3$	$k = 2$ $k = 4$	$k = 1$ $k = 3$	$k = 2$ $k = 4$	$k = 1$ $k = 3$	$k = 2$ $k = 4$
		$i = 1$		$i = 2$		$i = 3$	

a = total number of methods i (3 in all cases)
b = total number of orders j (3 in all cases)
c = total number of subjects in each cell k
n = total number of subjects
T = total sum of scores across subjects, orders and methods
= sum of all entries in table
N = total number of entries

Design of Variance

Source of Variance	degrees of freedom	Sum of Squares	mean square	F
between subjects	n - 1	$SS_s = \Sigma_j \Sigma_k (\Sigma_i x\ i_j k) \frac{2}{a} - \frac{T^2}{N}$	+	
Ordering B	b - 1	$SS_B = \underset{i}{\Sigma} (\underset{i}{\Sigma} \underset{k}{\Sigma} x\ i_j k) \frac{2}{ac} - \frac{T^2}{N}$		$\frac{SS_B}{SS_{error(b)}}$
error (b)	n - b	$SS_{error(b)} = SS_s - SS_B$		
within S's	n(a-1)	$SS_{\omega}S = SS_T - SS_s$		
methods A	a - 1	$SS_A = \underset{i}{\Sigma} (\underset{j}{\Sigma} \underset{k}{\Sigma} x\ i_j k\ \frac{2}{h}\ \frac{T^2}{N}$		$\frac{SS_A}{SS_{error(\omega)}}$
interaction AB	(a-1) (b-1)	$SS_{AB} = \overset{++}{SS_{AB}} - SS_A - SS_B$		SS_{AB} $SS_{error(\omega)}$
error (ω)	(a-1) (n-1)	$SS_{error(\omega)} = SS_{\omega}S - SS_A - SS_{AB}$		
Total	a(n-1)	$SS_T = \underset{i}{\Sigma}\ \underset{j}{\Sigma}\ \underset{k}{\Sigma}\ (x_{ijk}) - \frac{T^2}{N}$		

[+] In all cases mean square is equal to sum of squares divided by degrees of freedom.

[++] $SS_{AB} = \underset{i}{\Sigma}\ \underset{j}{\Sigma} (\underset{k}{\Sigma}\ x\ ijk)\frac{2}{c} - \frac{T^2}{N}$

7. LEARNING A TRANSIENT RESPONSE

T. B. Sheridan and R. Brady

A bachelor's thesis by William Frazier[9] dealt with the learning of a simple one-dimensional transient response by three different stimulus-response comparison methods. For a succession of twelve trials under each condition, the subject was presented the motion pattern (actually the rotation of a knob) by a tape programmed servomechanism; he then repeated the pattern with no "feedback". The pattern if ideal knob rotation is shown in Fig. 21. The three teaching techniques were:"compensatory" (seeing only error); "pursuit" (seeing the ideal response separately and in addition to the actual response); "kinesthetic" (feeling the knob turn through the ideal response while gripping with fingers - no vision). Figure 22 shows the results. It is clear that for early experience in repeating simple patterned responses, some experience as a "kinesthetic spectator" is desirable. Presumably this may generalize to swinging golf clubs and writing alph-numeric characters without vision.

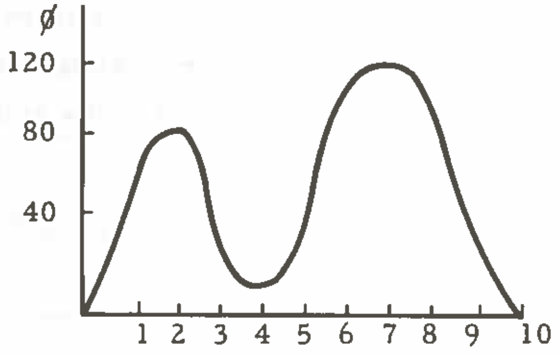


Fig. 21. Pattern of Ideal Knob Rotation Used in This Experiment.

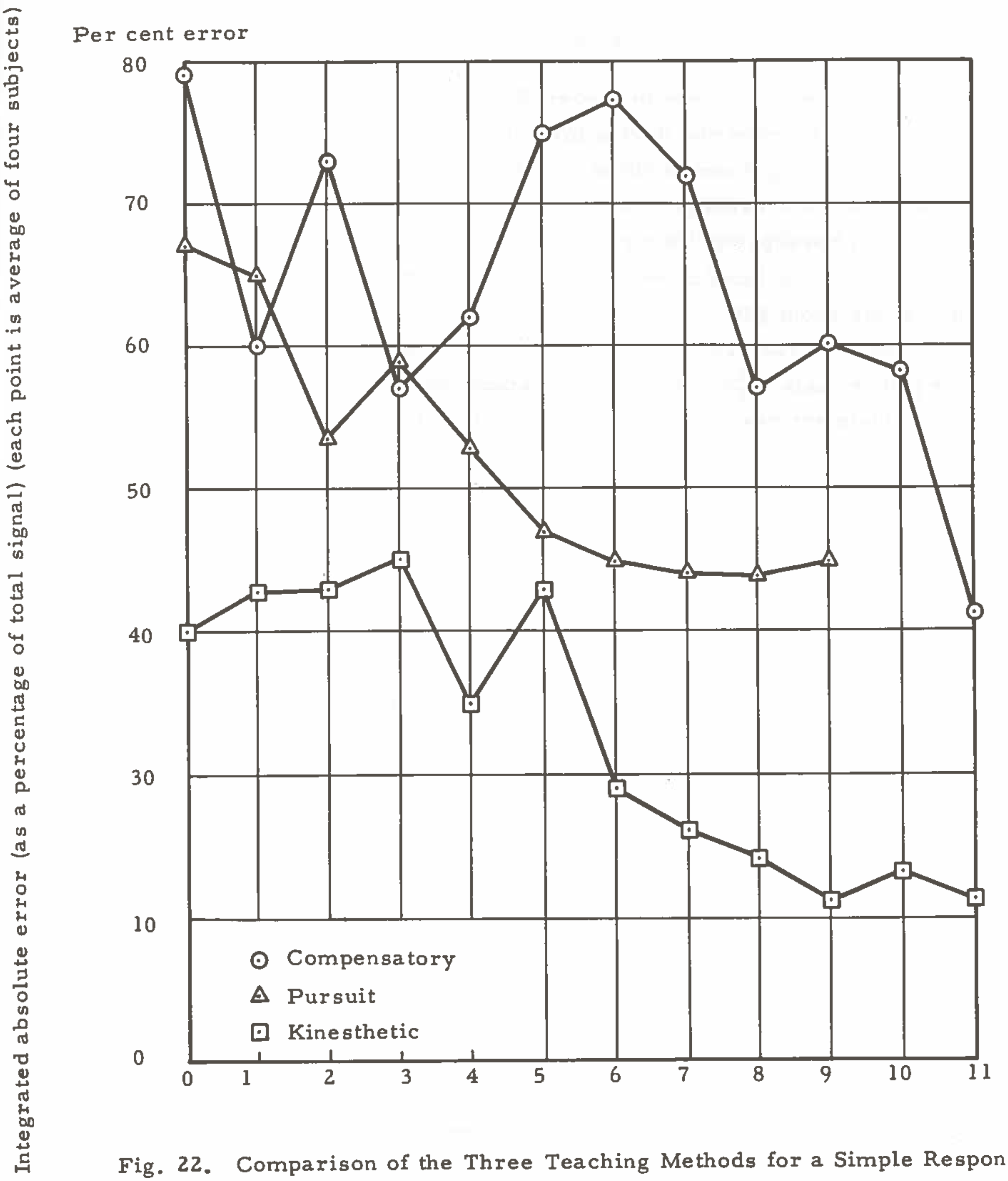


Fig. 22. Comparison of the Three Teaching Methods for a Simple Response

8. INERTIAL GUIDANCE WITH CHEAP COMPONENTS

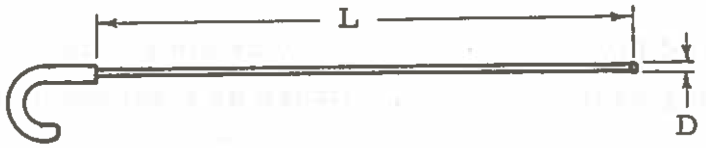
T. B. Sheridan, W. Frazier

A bachelor's thesis by Robert Brady[10] was concerned with the design of an inertial navigation device for helping the blind cross streets or other areas where alignment must be maintained without sufficient auditory or cane cues. A breadboard device was constructed using an inexpensive fractional horsepower motor gimbelled with ordinary ball bearings and connected to the cane in series with a simple dashpot. (Total cost of parts was about $10.00). Ideally any precessional translation in walking a straight course results in a resulting translation (of the dashpot) around the gimbel axis. Unfortunately vibrations in the motor and lack of balancing adjustment resulted in excessive drift of the gyro within several seconds.

9. VIBRATION ANALYSIS OF THE CANE

T. L. DeFazio and T. B. Sheridan

The following is a vibrational analysis of a standard aluminum cane provided by the American Foundation for the Blind. The analysis is not completed, because the evaluation of the expressions obtained becomes impracticable in the present context. Obviously, then application of the numerical data is not possible. The analysis is presented rather as an example or approach to how one would consider a cane according to classical vibration theory.



The cane consists of a length of aluminum tubing about 50 in. long, with a light tip and a curved handle of heavier tubing.

L/D is about 100, so that any shear deflections would be small compared to flexure deflections.

Compression waves are possible, but the fundamental natural frequency for compression waves is about 12,000 per sec. or about 2Kcps. (This fundamental is given by

$$\frac{\pi}{L}\ \frac{\sqrt{E}}{p}\ ;\quad \text{E - Young's modulus, p - mass/volume)}$$

This frequency is presumably above human threshold, so the cane may be considered a rigid body in compression so far as the human operator is concerned, but not necessarily as far as instrumention is concerned.

Neglecting other than the flexure modes, the behavior between the ends of the cane is described by:

$$\frac{\partial^2 y}{\partial t^2} = \frac{EI'}{\rho}\ \frac{\partial^2 y}{\partial x^4}$$

E - Young s modulus

I - Area moment of inertia

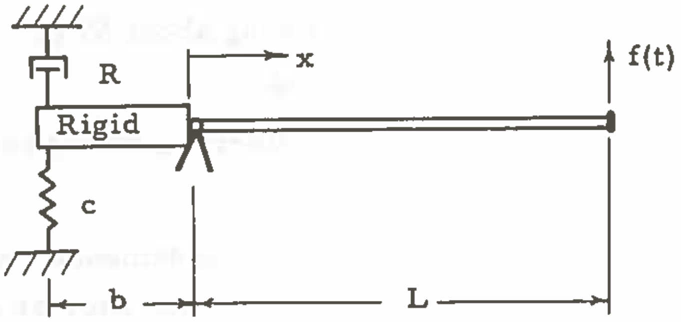
ρ = mass/length

t - time

Appropriate right-end conditions are:

$$y = f(t) \qquad \frac{\partial^2 y}{\partial x^2} = 0$$

Several sets of left end conditions may be considered. The first is a result of considering damping and compliance as a representation of a hand, thus:



such that $y = 0$ and $EI\ \partial^2 y/\partial x^2 + (R\ \partial/\partial t + 1/c)(b\ \ \partial y/\partial x) = 0$

but

$$y = \frac{\partial y}{\partial t} = 0$$

so

$$EI\ \frac{\partial y}{\partial x} + g(t) + c = 0 \qquad\qquad g,\ c,\ \text{arbitrary}$$

Natural frequencies and frequency response can be evaluated by assuming $f(t) = \alpha \sin\omega t$ and

$$y = \Upsilon(t)\ \Upsilon(x)$$

for

$$x = \sqrt{\frac{B}{\omega}}, \quad \lambda_n = \sqrt{\frac{B}{\omega_n}} \quad , \quad B = \sqrt{\frac{EI}{\rho}} \quad ,$$

letting,

$$\overline{Y}(x) = c_1 \sin \frac{x}{\lambda} + c_2 \text{ sinch } \frac{x}{\lambda} + c_3 \cos \frac{x}{\lambda} + c_4 \cosh \frac{x}{\lambda}$$

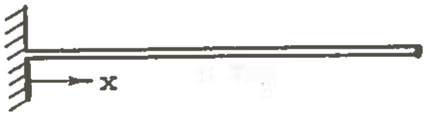
We get $c_3 + c_4 = 0$ from the right end, and from the left end we get:

$$\left[\begin{array}{c|c|c} \sin \frac{L}{\lambda} & \sinh \frac{L}{\lambda} & \left(\cos \frac{L}{\lambda} - \cosh \frac{L}{\lambda}\right) \\ \hline -\sin \frac{L}{\lambda} & \sinh \frac{L}{\lambda} & -\left(\cos \frac{L}{\lambda} + \cosh \frac{L}{\lambda}\right) \\ \hline 2 & 2 & -2p \end{array}\right] 0 \begin{bmatrix} c_1 \\ c_2 \\ c_3 \end{bmatrix} = \begin{bmatrix} a \\ 0 \\ 0 \end{bmatrix}$$

$$p = \frac{\omega}{b} EI \sin \omega t; \quad 2 = \sqrt{\omega b} \left(R\, \omega \cos \omega t + \frac{\sin \omega t}{c}\right)$$

Inversion is difficult.

The second assumes a fixed left end, implying that the cane is held very tightly:



Thus

$$y = \frac{\partial y}{\partial x} = 0$$

Solution is given in <u>Engineering Vibrations</u>, Jacobsen and Ayre, p. 496. The form is again $y = \sum_{n-1} Y(t) Y_n(x)$ with $Y(t) = a \sin \omega t$ and

$$Y_n(x) = B_n\left(\cos \frac{x}{\lambda_n} - \cosh \frac{x}{\lambda_n}\right) + D_n\left(\sin \frac{x}{\lambda_n} - \sinh \frac{x}{\lambda_n}\right)$$

where

$$\frac{B_n}{D_n} = \frac{\cos \frac{L}{\lambda_n} + \cosh \frac{L}{\lambda_n}}{\sin \frac{L}{\lambda_n} - \sinh \frac{L}{\lambda_n}}$$

$\frac{L^2}{\lambda_n^2}$ is given by $\cos \frac{L}{\lambda} \cosh \frac{L}{\lambda} = -1$

for n = 1, 2, 3, 4, we have:

n	1	2	3	4
$\frac{L^2}{\lambda_n^2}$	3.52	22.1	61.8	121

$\omega_1 \approx 40$/sec. or 6.4 cps, by experiments on a specific cane, so for n = 1, 2, 3, 4,

n	1	2	3	4
ω_n, sec.$^{-1}$	40	266	743	1450

A third set of left end conditions, approximates a cane tightly held between two fingers; that is, free to pivot, but neglects the mass of the cane handle. (The cane handle may be accounted for by letting

$$y = 0 \qquad \frac{\partial^2 y}{\partial x^2} = \frac{J}{EI} \, \frac{\partial^3 y}{\partial t^2 dx} \quad \text{at } x = 0$$

J is effective mass moment of inertia of handle about origin of coordinates

Thus

$$y = 0, \qquad \frac{\partial^2 y}{2x^2} = 0$$

and the following Jacobsen and Ayre, p. 494,

$$C_n = \frac{\cos \frac{L}{\lambda_n} + \cosh \frac{L}{\lambda_n}}{\cosh \frac{L}{\lambda_n} - \cos \frac{L}{\lambda_n}}$$

and

$$Y_n(x) = \left[C_n + 1 \right] \sin \frac{x}{\lambda_n} + \left[C_n - 1 \right] \sinh \frac{x}{\lambda_n}$$

where

$$\lambda_n^{\;2} \text{ given by } \tan L/\lambda_n = \tanh L/\lambda_n$$

n	1	2	3	4
$\frac{L^2}{\lambda_n^{\;2}}$	0	15.4	50	1042

or for the specific cane

n	1	2	3	4
ω_n, $\sec^{-1}$	0	175	568	11900

Considering no support and a weightless handle, (handle weight can be accounted for by letting, at $x = 0$,

$$\frac{\partial^2 y}{\partial x^2} = \frac{J}{EI}\,\frac{\partial^3 y}{\partial t^2 \partial x} \quad \text{and} \quad \frac{\partial^2 y}{\partial t^2} = \frac{EI}{n}\,\frac{\partial^3 y}{\partial x^3}, \ n = \text{handles mass})$$

the solution (Jacobsen and Ayre, p. 493) is

$$C_n = \frac{\cos \frac{L}{\lambda_n} - \cosh \frac{L}{\lambda_n}}{\sin \frac{L}{\lambda_n} + \sinh \frac{L}{\lambda_n}}$$

$$Y_n(x) = C_n \Big((\cos \frac{x}{\lambda_n} + \cosh \frac{x}{\lambda_n} \Big) + \sin \frac{x}{\lambda_n} + \sinh \frac{x}{\lambda_n}$$

where

$$\lambda_n{}^2 \text{ are given by } \cos \frac{L}{\lambda_n} \cosh \frac{L}{\lambda_n} = 1$$

n	1	2	3	4
$\frac{L^2}{\lambda^2}$	0	22.3	61.5	121

or for tubing of specific cane,

n	1	2	3	4
ω_n, sec.$^{-1}$	0	254	700	1375

Note that a model such as this implies that no information is transmitted to the user of the cane.

It is our opinion that a set of boundary conditions that accounts accurately for the hand of the user is necessary for any such calculations to be useful. Empirically, the damping due to the user's hand is "greater" than internal damping in the cane to such an extent that damping in the cane can likely be neglected if a good set of hand conditions is available. It is seen, however, that calculations quickly become difficult even for a linear model of a hand, as in our first example.

10. USE OF AN OBSTACLE COURSE IN EVALUATING MOBILITY OF THE BLIND

J. Mickunas, Jr., and T. B. Sheridan

General

The problem in this study was to design a representative obstacle course for the blind and to develop techniques to evaluate their behavior in traversing such an experimental obstacle course. Efforts were made to embody in the obstacle course the most salient features of the environment with respect to which the blind traveller interacts. In constructing such a course the following characteristics of the environment were considered: bounded and open spaces, type and distribution of the obstacle objects in the traveller's path, step-ups and step-downs, and auditory cues. The techniques of evaluation were objective and simple so that inexperienced observers could administer the necessary tests.

One group of five blind subjects traversed the obstacle course, under three environmental conditions, using Hoover's "long cane" technique. A second group of four naive, sighted-blindfolded subjects did the same. A third group of four naive, sighted-blindfolded subjects used two long canes. A fourth group of two naive, sighted-blindfolded subjects used a modified cane ot "T" shape.

Each group traversed the course under three conditions of auditory cue availability starting with a quiet room, progressing to a background noise produced by ventilation fans, and going finally to a condition of complete auditory masking. Experimental measures were number of taps, total traverse time, and number of "harm events" observed in several categories.

Results of analysis of variance for taps and time suggest that both travel experience and cane configuration affect number of taps (and time, which is proportional to taps under all conditions). Moderate ambient noise does not increase taps required, but complete auditory masking does. Experienced blind travellers had fewer harm events as a group than the normally sighted, but differed considerably from one another.

The feasibility of an experimental course composed of artificial objects is demonstrated. An objective "success of travel" scale based on "harm events' is proposed.

Obstacle Course

The entire course was set up in a large, otherwise empty room, thus providing control over weather, interruptions by curious pedestrians, etc. The obstacle course modelled such characteristics of the environment as bounded paths, open streets, solid objects at ground level, objects protroduing from above ground level, step-ups and step-downs, automobiles, sound reflectors, and stairways. Most of the obstacles and environmental features were of wooden construction. Their arrangement and purpose was to sample some characteristic features of the real environment. The diagram in Fig. 23 indicates positions of the obstacles in the course. The distance from the starting point to the finishing point was 170 feet. Figure 24 shows several views of the obstacle course.

Procedure

The subject reported to a room on the first floor. The experimenter put a blindfold over the subject's eyes and then led him to the third floor, where the obstacle course was set up. To reduce the subject's tension and give him some practice with the cane, he was instructed to walk a section of the room which was free of obstacles. The total distance of this free course consisted of two segments of 170 feet, the same total distance as the obstacle course. The time spent traversing this course was measured with a stop watch. The number of taps made by the subject with the cane was recorded on a portable tape recorder which the experimenter carried walking just behind and to the side of the subject. After traversing the free course, the subject was led to the starting point of the obstacle course. The following instructions were given to the subject to provide some mental image of the course:

> "This is the starting point of the obstacle course. To your right there is a brick wall. You have to walk straight until you reach a brick wall opposite you. Then, turn left and follow a confined path. To your right there will be a brick wall and to your left two by fours placed on the cement floor. You have to stay within the confined path until you reach a wooden platform - we call it a sidewalk. You have to step up on to the sidewalk, and walk to the end of it, At the end of the sidewalk you have to step-down on to the street - it is the concrete floor. Keeping a straight line, you have to cross the street and find a second sidewalk -

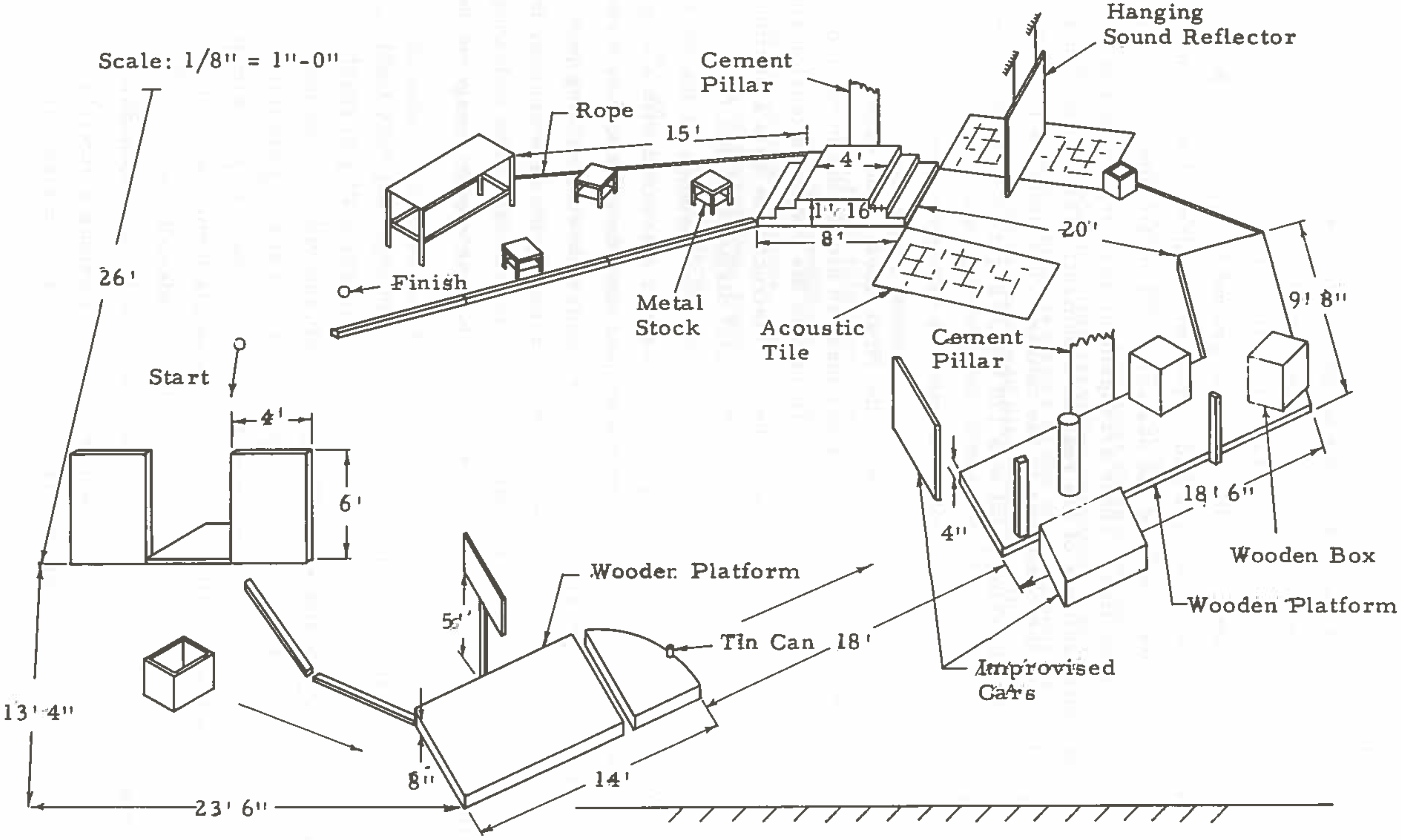


Fig. 23. Layout of Obstacle Course

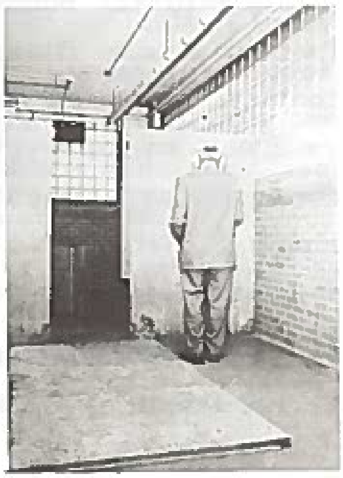
Avoiding sound reflector

Antitipating crack in sidewalk

Successful street crossing

A narrow passageway

Confirmation of path



Finding the doorway

Fig. 24. Several Views of the Obstacle Course.

a wooden platform. You have to step on it and walk to the end - even though it turns sharply to the left at one point. Once you have reached the end of the second sidewalk, you have to step down on to a concrete floor. The path you have to follow is bounded by sheets of acoustic tile placed on the floor. Walking along this path, you will come to a stairway. Your task is to go up and go down the stairway. When you are on the concrete floor again, follow the bounded path until I ask you to stop. Any questions?"

If the subject asked questions, they were answered by the experimenter. Then the following resume was given to the subject:

> "As you have gathered, the course is roughly circular, in a sense that the finishing and starting points almost coincide. When you come up to an object, you will have to decide how to navigate further."

When the experimenter completed recording the date, subject's name, and the condition under which the course was to be traversed, he started the subject walking the course. For recording purposes the course was divided into eight segments. As the subject approached the end of a given segment, the experimenter identified it by recording on tape a coded number as well as the cumulative time up to that point. Likewise, an index of harm inflicted by the subject either upon himself or upon the environment was devised. These harm events were recorded as they occurred along the course. Three types of harm events were identified: bumping into an object, tripping upon an object, or getting the cane stuck. Bumping into an object was predicted upon significant body contact. Tripping was based upon the subject's momentarily loosing his balance due to an unexpected collision of his feet with the environment. Through the entire experiment no subject was injured in any way as a consequence of tripping. Getting the cane stuck typically resulted whenever it got lodged between two objects or in the "cracks" of the sidewalks.

The subjects traversed four times the course which was a quiet room free of obstacles. The length of a single segment of this course was 170 feet.

The obstacle course was also 170 feet long. All subjects traversed the obstacle course three times under each of three different conditions. The first condition was a quiet room. Under the second condition two exhaust fans were turned on, providing background noise of about 60 db sound pressure level. For the last condition subjects wore Willson Sound Barrier earphones which damped external sound energy and provided 80 - 100 db white noise (from a modified transistor radio) which effectively masked out all residual auditory cues from the environment. The sighted subjects were not permitted to see the course until they had traversed it under all regular conditions. At the end the blindfolds were removed and the sighted subjects were asked to traverse the course still using the canes. Everything was tape recorded exactly in the same manner as under the previous conditions.

Three variations of canes and techniques were used to traverse the obstacle course. The first, used for most of the tests, was an ordinary aluminum "long cane" used in conjunction with the Hoover technique. The second variation consisted of two such aluminum canes - the second cane held in the normally free hand and manipulated in a mirror image of the first - resulting in a sort of crisscross pattern. The third variation consisted of a modified single cane, on which a 12-inch aluminum bar was attached perpendicularly on the tip of the aluminum cane, thus providing double contact points with the environment on the ends of the "T" bar. The subjects were instructed to use the latter with the Hoover technique also.

Subjects

Five blind subjects were from St. Paul's Rehabilitation Center in Newton, Mass. All were in their sixteenth week (their last) of training in the use of the cane. The sighted subjects were M.I.T. students. Because of retraining problem, each group of sighted subjects was used with only one cane condition. Four sighted subjects participated in the one cane condition, four in the two cane condition, and two in the "T" cane condition.

Results

Tape recorded data consist of cane taps, cumulative time (in seconds) and harm events while traversing both the free and obstacle courses. Table 5 shows the arithmetic means of cane taps, time (in seconds), and harm events for four groups of subjects under all investigated conditions and considering 170 feet segments of the free and obstacle courses. Tables 6, 7, 8, and 9 in the Appendix show the number of taps, time (in seconds), and frequency of harm events for each traversing of the courses. Table 10 in the Appendix shows frequencies of three kinds of harm events - bumping into obstacles, cane getting stuck, and tripping over obstacles for individual subjects.

Plotting a number of cane taps as a function of trial time, a reasonably straight regression line was obtained. Figures 25, 26, 27, and 28 show the regression lines for each group of subjects. Figure 29 shows the frequency of harm events for three conditions - quiet room, fans turned on, and white noise. In the free walk condition no harm events occurred. Likewise, when sighted subjects walked the obstacle course without blindfolds, no harm events occurred.

Table 5: Means of Cane Taps, Time (in sec.) spent Traversing the Course, and Harm Events for Four Groups of Subjects

Measurements	Groups of Subjects	Free walking course 170 feet +	Obstacle Course, 170 feet ++			
			Quiet Room	Fans	Earphone White Noise	No Blindfold
Means of Cane Taps	5 blind 1 cane	104	268	193	243	--
	4 sighted 1 cane	117	228	222	227	85
	4 sighted 2 canes	104	280	238	237	65
	2 sighted "T" cane	93 418	361 1137	284 937	265 972	107 257
Mean of Time in Seconds	5 blind 1 cane	63	258	179	223	--
	4 sighted 1 cane	76	205	209	205	56
	4 sighted 2 canes	71	262	201	182	54
	2 sighted "T" cane	115	344	245	210	68
Means of Harm Events	5 blind 1 cane	--	7	7	19	--
	4 sighted 1 cane	--	21	21	23	--
	4 sighted 2 canes		18	15	15	--
	2 sighted "T" canes		121	121	17	--

+ Means based on four walks of 170 feet segments for every subject.

++ Means based on three replications of each condition for every subject.

Table 6. Blind Subjects Using One Cane. Results for Each Trial of Cane Taps, Time (in sec.) and Frequency of Harm Events

Subjects		Free walk 340 feet		Obstacle Course								
				Quiet room			Fans			White noise		
J.H.	taps	150	152	153	147	139	139	119	118	256	303	265
	time	124	123	114	102	109	169	98	98	263	249	215
	harm	--	---	--	--	--	2	1	1	8	9	6
L.B.+	taps	287	230	449	353		266	243	247	347	256	273
	time	248	176	487	413		241	245	245	336	280	301
	harm	—	—	2	2		5	1	2	7	3	7
F.R.+	taps	232	216	343	275	240	211	201	192	232	234	233
	time	145	134	329	219	199	205	174	162	212	193	198
	harm	--	--	3	1	4	1	2	--	5	7	3
M.A.+	taps	261	198	415	273	231	253	182	171	193	193	171
	time	211	144	406	259	199	247	195	167	208	190	156
	harm	--	--	3	2	5	5	4	5	6	8	6
E.W.	taps	178		299	195	179	195	188	177	280	219	192
	time	131		214	167	210	169	146	133	227	173	147
	harm	--		4	5	6	4	2	2	10	4	6

+ Femal Subjects

Table 7. Sighted-Blindfolded Subjects Using One Cane. Results for Each Trial of Cane Taps, Time (in seconds), and Frequency of Harm.

Sub-jects		Free walk 340 feet		Quite room			Fans			Obstacle Course White noise			No blindfolds
JD	taps	189	182	285	268	262	221	229	218	253	237	196	78
	time	174	137	337	265	232	190	195	190	213	197	171	51
	harm	--	--	8	6	5	6	7	2	10	8	4	--
JT	taps	209	225	205	174	182	187	222	202	222	205	215	--
	time	110	125	186	102	104	184	150	127	138	130	124	--
	harm	--	--	4	2	4	2	3	1	1	1	2	--
EN[+]	taps	237	--	243	269	201	238	226	269	269	241	235	96
	time	175	--	283	253	215	298	273	338	283	297	228	75
	harm	--	--	6	10	7	11	12	16	13	6	5	--
MM[+]	taps	228	201	227	223	195	236	209	203	245	190	197	82
	time	162	159	164	194	168	206	177	175	168	148	165	42
	harm	--	--	11	8	12	7	5	12	6	9	12	--

[+] Female Subject

Table 8. Sighted-Blindfolded Subjects Using Two Canes. Results for Each Trial of Cane Taps, Time (in Seconds), and Frequency of Harm Events.

Sub-jects		Free walk 340 feet		Quiet room			Fans			Obstacle Course White noise			No blindfolds
RC	taps	243		247	272	236	318	254	265	309	316	343	103
	time	217		323	267	244	301	231	298	244	234	244	85
	harm	--		4	4	6	7	8	3	2	3	4	
JH	taps	169	184	215	326	289	206	186	170	228	207	213	49
	time	126	141	152	248	194	148	138	140	158	149	150	46
	harm	--	--	6	5	2	6	5	6	5	11	9	--
BK	taps	256	175	337	321	265	226	228	178	232	213	180	66
	time	233	157	377	314	246	218	215	191	189	175	156	51
	harm	--	--	8	12	7	5	2	3	6	2	2	--
JC	taps	160	229	400	284	281	220	217	180	218	212	178	42
	time	156	136	385	259	244	192	187	158	173	173	145	35
	harm	--	--	9	5	6	6	8	3	8	3	5	--

Table 9. Sighted-Blindfolded Subjects Using "T" Cane. Results for Each Trial of Cane Taps, Time (in Seconds), and Frequency of Harm Events.

Sub-jects		Free walk 340 feet		Quiet room			Obstacle Course						No blindfolds
							Fans			White noise			
MC	taps	201	210	478	309	348	309	307	277	242	253	238	131
	time	291	165	409	230	245	213	227	179	172	165	141	76
	harm	--	--	3	2	2	3	3	2	2	4	1	--
JH	taps	273	251	351	303	379	329	252	225	303	297	259	83
	time	316	149	432	368	447	369	263	221	312	254	221	60
	harm	--	--	4	5	9	7	5	3	8	15	5	--

Table 10. Frequency of Harm Events for Individual Subjects

Subjects	Bumping into Obstacles	Cane getting stuck	Tripping over Obstacles
Blind (one cane)			
FR+	18	--	8
MA+	26	1	17
LB+	16	3	10
JH	12	--	15
EW	28	1	14
Sighted (one cane)			
JD	33	3	20
EN+	44	9	33
MM+	30	8	44
JT	12	5	3
Sighted (two canes)			
RC	21	4	16
JH	23	9	23
BK	24	10	13
JC	28	9	16
Sighted (T cane)			
MC	12	7	3
JH	35	4	22

+Female Subject

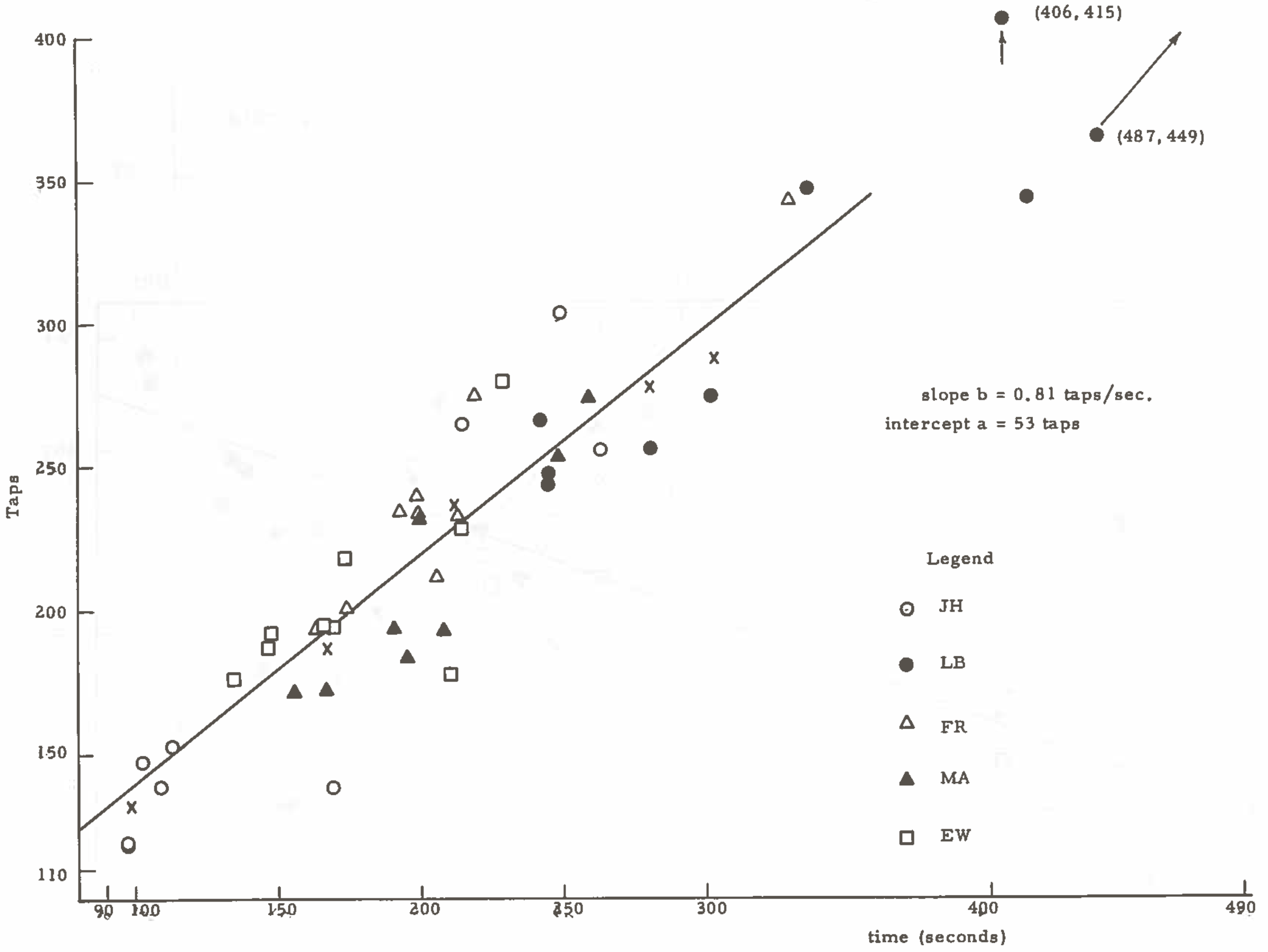


Fig. 25. Blind Subjects Using One Cane. Cane Taps as a Function of Time for Each Trial.

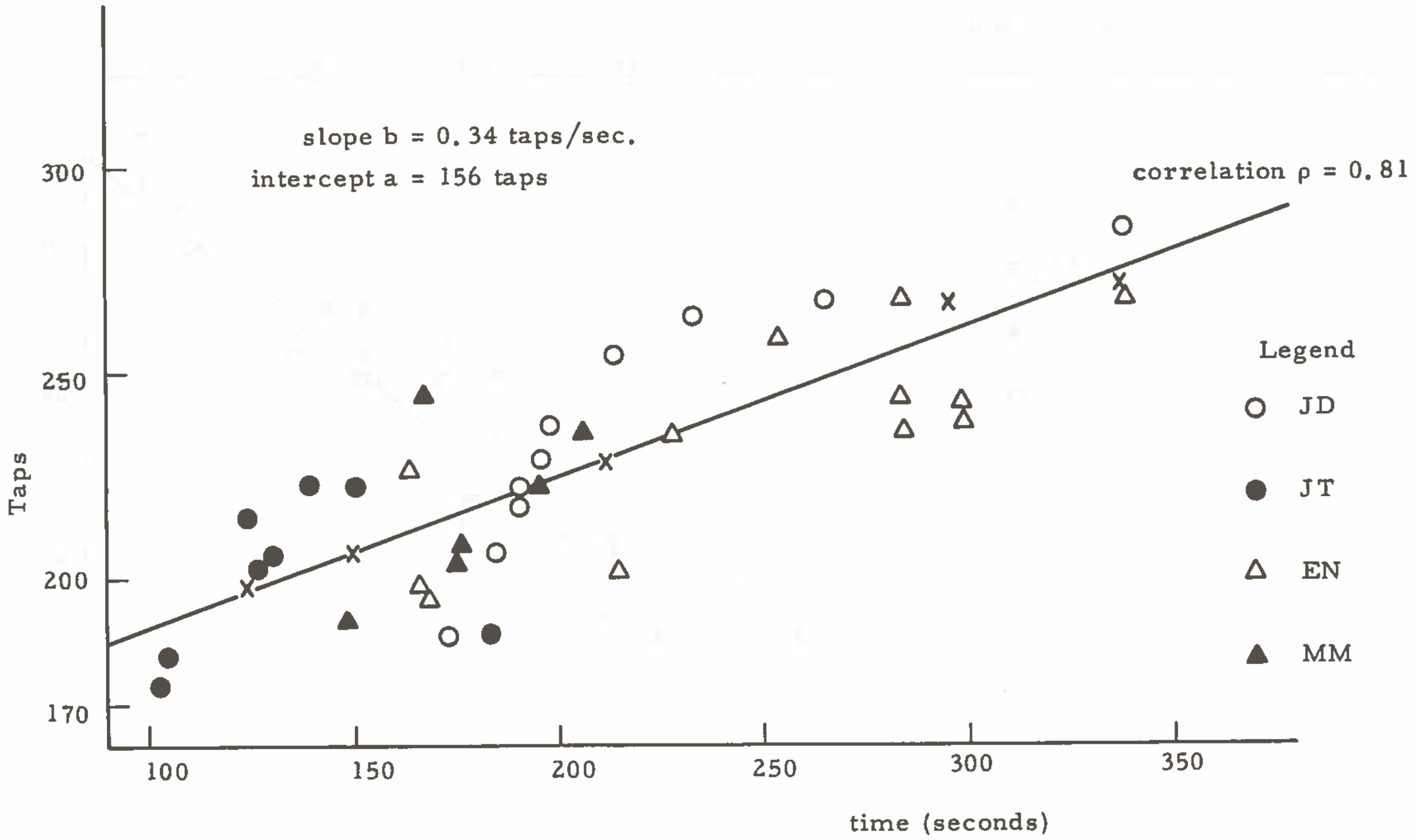


Fig. 26. Sighted-Blindfolded Subjects Using One Cane. Cane Taps as a Function of Time for Each Trial.

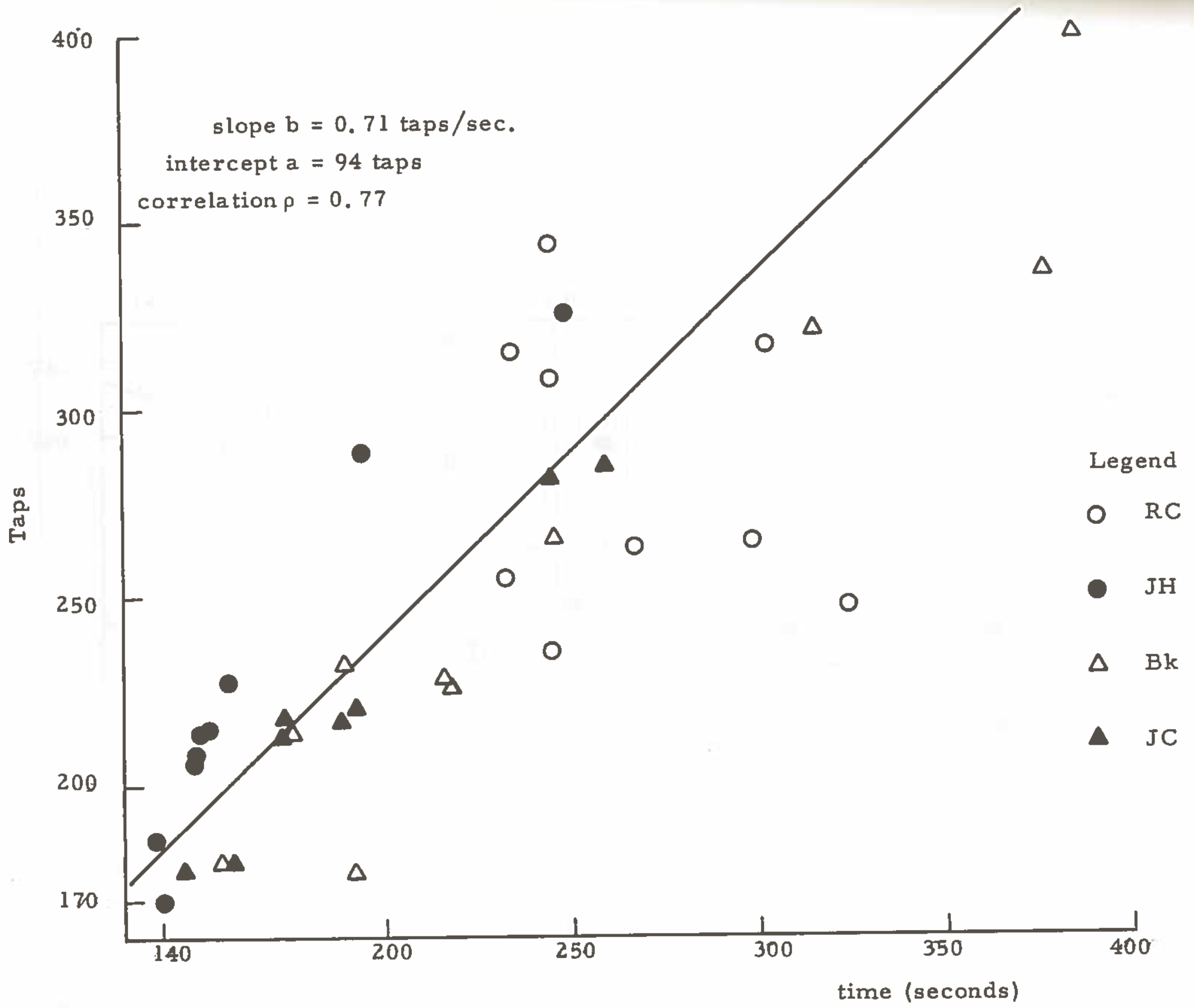


Fig. 27. Sighted-Blindfolded Subjects Using Two Canes. Cane Taps as a Function of Time for Each Trial.

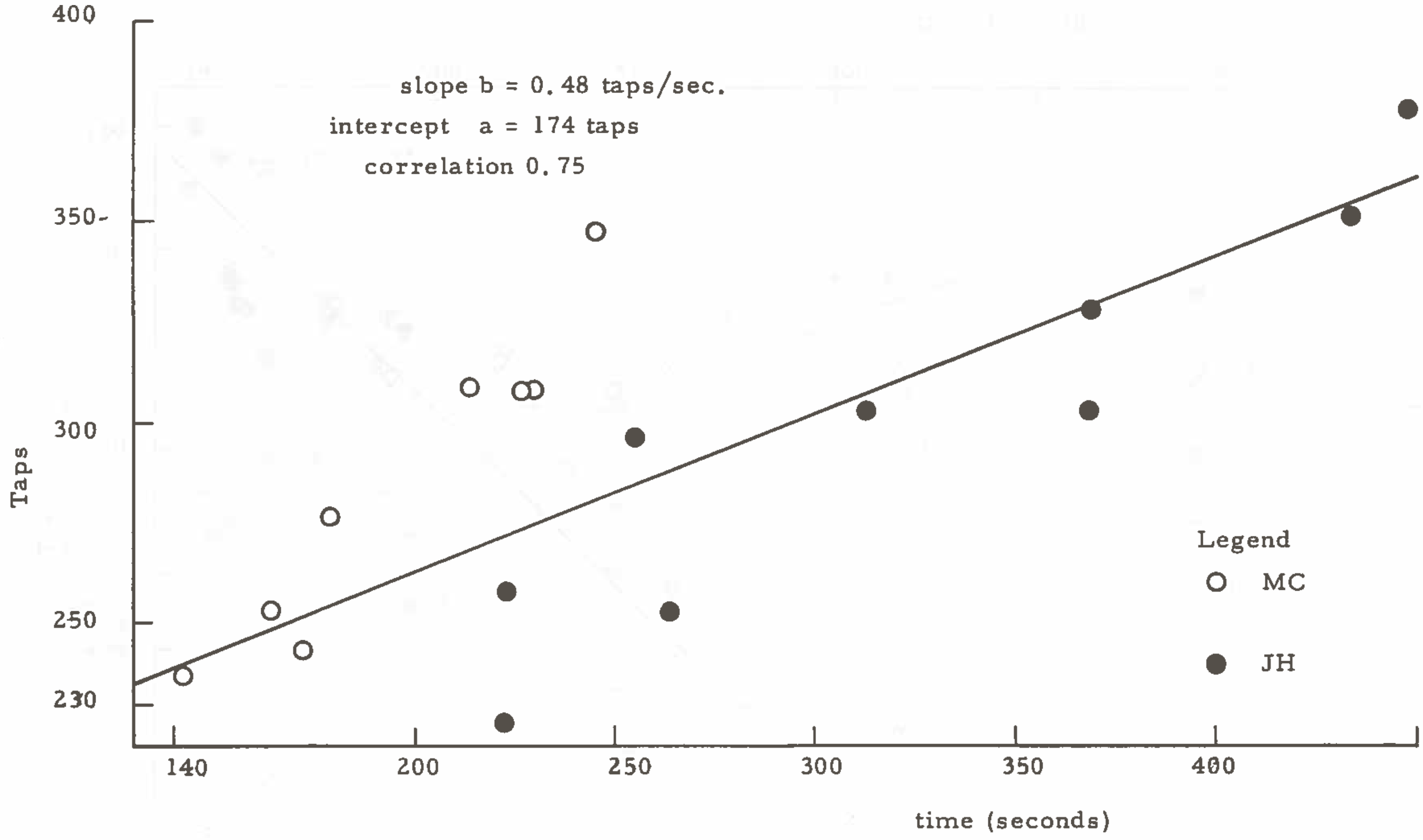


Fig. 28. Sighted-Blindfolded Subjects Using "T" Cane. Cane Taps as a Function of Time for Each Trial.

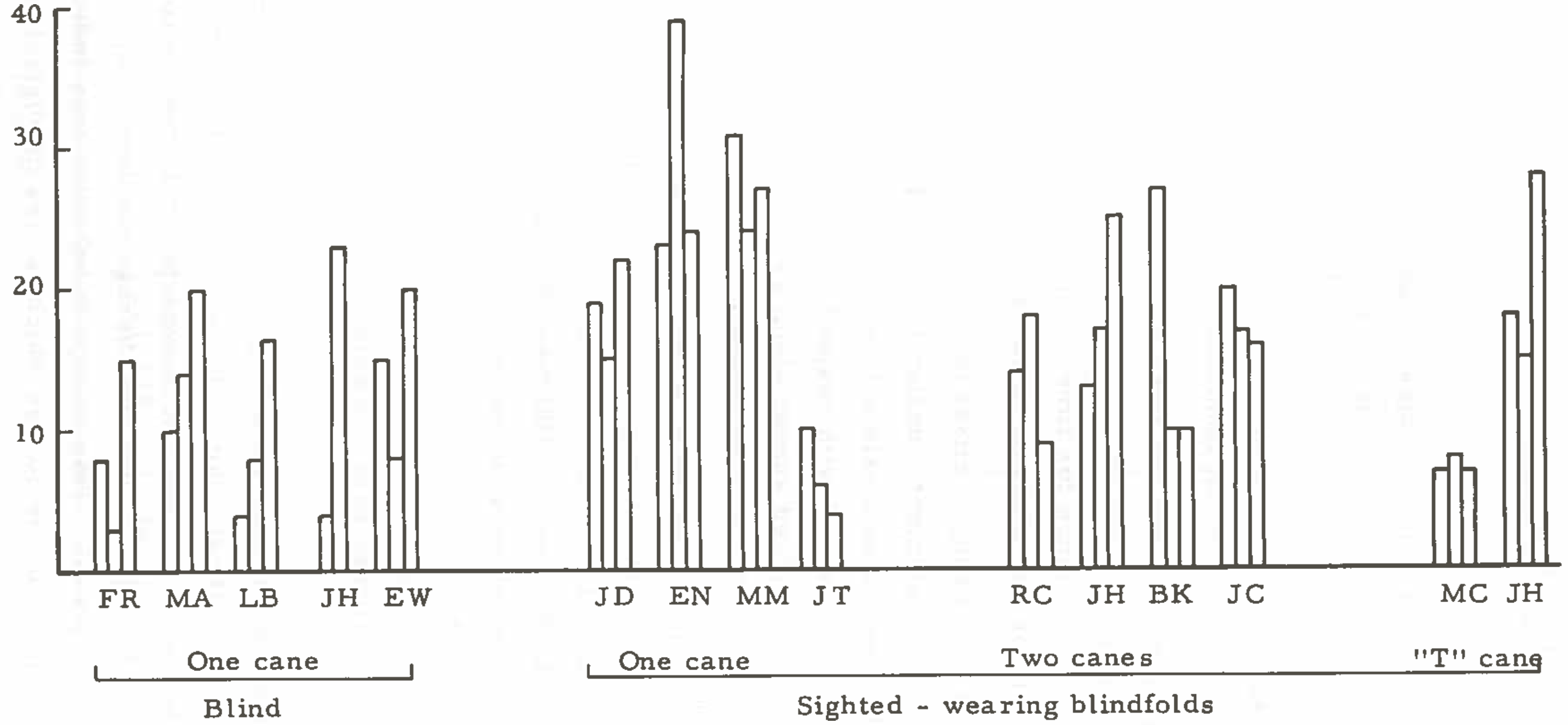


Fig. 29. Frequency of Harm Events for Individual Subjects and Conditions.

(Three columns for each subject and condition are, left to right, first condition - quiet room, second condition - fans, third condition - white noise.)

Analysis and Discussion of Results

An analysis of variance for taps, groups of subjects and conditions revealed significant differences among groups of subjects and conditions, both at the 95 per cent confidence level. Figure 30 shows the arrangement for the analysis of variance.

Table 11 shows results of the analysis of variance for cane taps of four groups of subjects under three different conditions.

In a second analysis of variance for total traverse time, only conditions revealed significant differences at the 95 per cent confidence level. The arrangement for analysis of variance for time is similar to that in Fig. 30. Table 12 shows the results of this analysis of variance.

The significance of the "groups" effect is a rough indication at best, for it can be seen from the experimental design that the differences between blind and sighted, and between cane treatments within the sighted category were confounded. Looking to Table 5 with respect both to taps and time, the differences between blind and sighted appear about as large as the differences between cane treatments within the sighted category.

The same is true for the "conditions" effect which was significant with respect to taps. The "conditions" effect per se was confounded with order. From Table 5 it is seen that both taps and time tended to decrease from "quiet room" to "fans", which suggests either an experience improvement which was not offset by a performance decrement due to lost auditory cues, or that a small amount of ambient noise was actually useful and fewer taps were needed. Both taps and time increased again for white noise indicating a tendency to more taps and slower pace, in spite of any experience on other order effect.

Table 5 appears somewhat more revealing. Comparing for the course free of obstacles, the number of cane taps and the time with the corresponding measure for the obstacle course, large (not unexpected) differences appear. All subjects show at least doubling in both the average number of taps and average time for 170 feet of travel. This change in behavior may indicate two different uses of the cane. In the course which is free of obstacles the cane was probably used to confirm a strong expectation that the future environ-

Table 11. Analysis of Variance for Total Cane Taps

Source of Variation	Sum of Squares	y	Mean Square	F
Groups of subjects (c)	27,203	3	9,068	3.91$^+$
Conditions (R)	18,060	2	9,030	3.89$^+$
(Cells)	(56,898)	(11)	--	--
Interaction (R x c)	11,585	6	1,931	0.83
Within Cells	76,545	33	2,320	--
Total	133,393	44	--	--

$^+$Significant at $P \leq 0.05$

Table 12. Analysis of Variance for Time (in seconds)

Source of Variation	Sum of Squares	y	Mean Square	F
Groups of subjects (c)	15,317	3	5,106	1.12
Conditions (R)	27,850	2	13,925	3.06$^+$
(Cells)	(64,152)	(11)	--	--
Interaction (R x c)	(20,985)	6	3,498	0.77
Within Cells	150,183	33	4,551	--
Total	214,335	44	--	--

$^+$Significant at $P \leq 0.05$

		Group of Subjects			
	Order of assignment	5 Blind Subjects one cane	4 Blindfolded one cane	4 Blindfolded two canes	2 Blindfolded "T" cane
Quite Room	1	Means of 3 trials of cane taps	---		
Fans	2	---	---		
White Noise	3	---			

Fig.30. Arrangement of Groups of Subjects and Conditions for the Analysis of Variance.

ment was like that just encountered. In the obstacle course, the cane was probably used as a probe to find an open passageway. Because the prior environment was different from the future environment, small, independent segments of environment had to be examined in detail before one decided to move forward. To explore the environment in greater detail, more time and taps were needed.

Table 5 also indicates interesting behavioral differences between groups of subjects. The blind group seemed to be more sensitive to the environmental changes than the sighted-blindfolded group using one cane. But this "sensitivity" to conditions may have been due either to the acoustic masking conditions themselves or to the ordering of conditions, which was the same for every group. Only the group of sighted-blindfolded subjects who used the "T" cane indicate a consistent improvement through all conditions. The sighted-blindfolded group using one cane remained at a stable rate of tapping throughout all conditions.

Thus the tap and time measures leave us with no one dominant conclusion except perhaps that time and number of taps correlate through all treatments, Figs. 25, 26, 27, and 28.

Table 5 reveals that the "harm events" measure differentiates the sighted from the blind groups. A chi square test for harm events among the four groups of subjects was significant ($P = 0.05$ $x^2 = 8.76$ with 3 df). The differences of harm events within the sighted group of subjects suggest that the cane provided to the user different information about the environment.

Observations during the experimental sessions and questioning of subjects revealed that the blind group and the sighted group used different criteria to detect and avoid obstacles. The blind group used "facial vision" to detect hanging obstacles. For example, the hanging platform was detected by most of the blind subjects at the end of six trials. When they received white noise through earphones, the blind subjects could not avoid bumping into the suspended platform. The sighted-blindfolded subjects rarely used, or knew the existence of the so called "facial vision" cues. They apparently preferred to estimate the distance from prior objects to the suspended platform.

The group of subjects using two canes showed an entirely different pattern of cane use. One of the canes (usually in the nondominant hand) was reserved for maintaining continuous contact with the environment and was dragged along the floor, while the second cane was tapped in the conventional way.

A second chi square analysis of harm events was performed on the individual subjects within the blind group, and was significant ($x^2 = 9.32$ 4df).

Suggestions

Even with a very limited variety of characteristics by which to model the complex environment of the blind, the factors of experience and availability of cues in mobility may be studied profitably.

Wright (1961, p. 4) suggested a 15 point mobility scale, to be used by the experienced observers to judge the behavior of the blind.person. The successful observation of cane tapping, sensitivity to environment, and harm events in this study indicate that Wright''s mobility scale could be expanded by including present measures - in particular, the "harm type" measurements. A scale of objective "success of travel" could be used to augment the subjective mobility rating scale. The present study has not provided enough data to work out a "success of travel" scale nor indices which would provide a sufficient measure of the cane user's ability to travel. Further experiments are suggested in order to refine the categorization and recording of "harm events".

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COURSE PROJECTS

Junior Laboratory

Investigation and Development of Typewriter to Brailler Converter.

Information Transmittal Via the Blind Man's Cane.

Design of Collapsable Blind Man's Canes.

Junior Design

Externally-Powered Prosthetic Limb.

Mobility Devices for the Incapacitated.

Freshman Seminar

Type Compositors Tape-to-Braille System.