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Medical Progress through Technology

Reading Devices for Blind People

P. W. Nye

Haskins Laboratories, New Haven, Connecticut, USA

Abstract. An account is given of the social, economic, and technical factors surrounding the development of reading aids or devices for blind people. It is shown that these factors interact in such a way as to seriously constrain the approaches that can be made to device design. The progress being made in the research, development, and deployment of several types of reading devices is described to illustrate how the various constraints have affected the design goals and methods of deployment. Emphasis is laid on the development of reading machines with voice output because, ultimately, they are the most likely types of devices to be widely accepted by the blind. Looking ahead to full deployment of such devices before the end of this decade, the paper concludes with a summary of the research, development, and organizational needs that must be met.

Key words: Reading aids - Braille - Blindness - Synthetic speech - Print recognition

It is generally agreed that modern efforts toward the creation of reading aids for blind people began shortly after the turn of this century - in fact, with the birth of the first photoelectric cells. Throughout the intervening period the central objective has been to create a device, or group of devices, that could enable a blind person to function at a level closely approximating the performance of a sighted reader (13). From the viewpoint of the blind person, this has implied that he would be able to use his tactile or auditory senses to read the same books, newspaper, magazines, recipes and cereal cartons as a sighted colleague. However, while gaining access to printed matter has long been viewed as the principal problem, it is by no means the only obstacle to be overcome. A realistic appraisal of the reading aid field requires one to examine not only the technical questions, but the physical makeup and needs of the blind population, their economic status, the structure and the operation of any available delivery system, or systems, and the availability of the resources needed to make them function. The need to consider a similar set of factors is, of course, not unique in the bioengineering field. Where the present topic may be unusual is in the manner in which the various factors interact, posing the need to confront more perplexing problems and to accept difficult compromises.

Let us suppose that a newly graduated bioengineer wishing to develop a reading device for the blind were to enter the field today. What would he find? This paper will attempt to answer the question by introducing the social, economic, and institutional background to the reading aid field and then follow with an account of current research and development. The reader is advised not to overlook this background material because it is really essential to a clear explanation of the factors, which (to varying degrees) have conditioned current research efforts and objectives. The paper will conclude with a summary of the research, development, and organizational needs that must be met if genuinely useful reading aids and reading services are to reach the hands of many blind people before the end of this decade.

This marks the third occasion, during the past 15 years, on which the author has been persuaded by a journal editor to prepare (or share authorship in) a review article on the topic of aids for the blind (32, 33). Inevitably, this review will contain some overlap in subject matter with the earlier papers. However, optical aids and electronic image enhancement devices, which qualify as reading aids, have been deliberately omitted to allow space to introduce new material on reading machines with voice output and new comment on the field as a whole. The views expressed here have been influenced by the history of reading device development described in several early articles (8, 14), by recent events, and by some additional articles that have appeared during the past six years (1, 12).

CHARACTERISTICS OF THE BLIND POPULATION

The term blindness embraces a spectrum of visual deficiency, ranging from an acuity level at which it is possible to read with special optical aids to total blindness. The most commonly used rubric defining "legal" blindness is a visual acuity of less than 20/200 in the better eye using correction or a visual acuity of more than 20/200 if the widest diameter of the field of vision subtends no greater than 20 degrees. This classification is now applied by public and private agencies to determine eligibility for special benefits, which afford those with severe visual handicaps some measure of financial relief.

A search for information about the U.S. blind population reveals a surprising number of sources. However, most figures are more than five years old and lack any useful information on the occupations, reading habits, reading requirements, and geographical distribution of the blind. Even on the very basic question of how many people are affected, very few figures agree within acceptable margins of error.

The reasons are that the collection methods differ widely and the standards applied in most surveys are not sufficiently rigorous. Furthermore, continuity is not maintained. Thus, particular survey procedures are applied and their results published for a few years whereupon the procedures are then withdrawn, making it difficult to observe long-term trends. Publications of the U.S. Government are particularly prone to this fate and the unfortunate consequence is that the available data lack the detail or reliability needed for the careful planning of policy in the blind rehabilitation field (22)[1].

From among the conflicting figures for the total "legally" blind population given by various sources, the most widely accepted estimate for the United States is that published by the National Society for the Prevention of Blindness (NSPB) - a total of 478,800 estimated in 1975. Yet the NSPB methodology is prone to several weakness (19) and the society's figure is still thought to greatly understate the problem of visual disability. In a report of the National Advisory Eye Council, the director of the National Eye Institute states that there are at least 10 million people - 1 of every 20 - who suffer from significant, uncorrectable impairment of vision. Of these, about 1.5 million are so severely impaired that they are unable to read ordinary newsprint with either eye - even with glasses (26). Table 1 shows how the total blind population and the totally blind (i.e., those having no light perception) are distributed as a function of age. Also available in Table 1 are the five most common causes of blindness today, stemming largely from senile degeneration, diabetes, and other multiple etiologies of old age. Among children, the dominant causes are genetic and prenatal influences, which tend to be associated with *other disabilities* in addition to blindness (41). Nevertheless to a large degree, as Table 1 indicates, the problems of blindness go hand in hand with those of aging (39).

One of the prime motivations for the design of reading aids for the visually handicapped has been to enable them to become economically independent; however, the data on age clearly indicate that a large proportion (certainly those over 65 years of age) will probably not benefit financially. Moreover, since the blind do not form a homogeneous group (a wide range of capabilities, interests, and motivation being represented), it is extremely unlikely that many will consider a single reading aid to be universally useful or even desirable. This is indicated by the fact that although most rehabilitation professionals, for example, believe that mobility is the most important need of the blind, less than 2 percent of the blind currently use dog guides and barely 10 percent have received any training for independent cane travel. As regards reading, only 10 percent of the blind population are known to use Braille. Hence, the point being made here is that the use of existing aids may be influenced as much by personal desires as by any restrictions in their availability and utility. Furthermore, under these circumstances, one should not expect that new products of technology will

1 While it is probably correct to say that the data available on the legally blind as a market for reading aids are more abundant than on any other market (17), the relatively small size and low economic power of the blind combined with their diversity *demand* more detailed data so that careful planning can be undertaken to insure that the available resources are properly channeled.

Table 1. Distribution of the U.S. blind population by age

Legally blind

Age:	Under 5	5 - 19	20 - 44	45 - 64	65 - 74	75+
	0.5%	9.5%	17.0%	26.8%	17.2%	29.0%

Totally blind (no light perception) 10.6% of legally blind

Age:	Under 5	5 - 19	20 - 44	45 - 64	65 - 74	75+
	24.3%	15.3%	13.4%	11.1%	9.7%	15.1%

Cause

Glaucoma	Cataract	Retinal disease	Myopia	Optic nerve disease	Other
11.0%	13.1%	25.0%	3.0%	9.2%	15.2%

be used unless they are of very significant help in gaining a large number of vocational opportunities or in furthering personal goals. Therefore, if truly effective reading aids and services can be created, Table 1 may be taken to indicate that today only about 10 percent of the blind population (those younger blind having good motivation and no other disabilities comparable to their blindness) would be equipped to use reading aids for the expansion of career objectives and economic well-being. To many with concern for the plight of the remaining 90 percent, this may appear to be a distressingly small number of people on which to devote the substantial sums of money required for research, development, and deployment. However, it should be borne in mind that the results of expenditures on behalf of a vanguard of younger members of the blind community would, in time, inevitably spread to a larger proportion of the blind. This would be expected to occur naturally as the early users of reading aids (becoming older) merge into the population and provide inspiration to the less strongly motivated. Thus, given time, a research policy initially directed toward the needs of the young singly handicapped blind person may be expected to eventually embrace a far larger proportion of the blind population.

SOCIETY AND THE BLINDNESS SYSTEM[2]

Vision is the most highly valued of all man's senses and is easily the most important source of information about the complex, dynamic world in which he lives. However, despite the fact that blindness overtakes a large number of victims each year, blindness does not, for example, arouse the same degree of social concern in the United States as cancer. The findings of public opinion polls (2) and the wide differences that exist in the amount of public support given for cancer research versus research on eye diseases clearly attest to the lower position of visual defects on the scale of national priorities. The reasons are not difficult to find: blindness is not usually associated with pain and death and therefore arouses less sympathy and concern. Moreover, recent efforts to dispel the image of the blind as being a race apart have perhaps had their share in changing public attitudes toward blindness as a disabling affliction.

During the past ten years, several major surveys and research studies have been carried out on different aspects of the blindness system. Although the figures cited in these reports are now largely out of date, the basic picture conveyed remains the same today. Thus, a national systems study embracing all economic aspects of the delivery of welfare and other services to the blind and visually handicapped estimated (in 1967) that a half-billion dollars is provided annually by private, federal, and state agencies in welfare support and other services to the blind (32). Between 1967 and 1973, direct federal and state payments to the blind (about one-fifth of the total expenditure for 1967) rose by 28 percent while the number of recipients fell from 83,100 to 77,900 (50). Revised figures for the remaining categories are not readily available, but a very conservative estimate for the current annual cost of blindness would place the figure at $ 0.65 billion. Scott, in a book published in 1969 (40), reported that the funds for direct support and special ser-

2 The "blindness system" is a term commonly used to describe the network of roughly 800 public and private agencies which dispenses services or directs financial support to the U.S. blind population.

vices to the blind are funneled through approximately 800 agencies for the blind. He further asserts that this astonishing fragmentation has tended to insulate these agencies from such changes as shifts in the makeup of the blind population, so that today only about 20 percent of the U.S. blind population are served.

In 1967, a survey of research on all sensory aids (reading, mobility, and vocational aids of all types) showed that research expenditure was a little less than $ 1 million, or 0.2 percent of the annual cost of blindness in the U.S. during that year (6). A similar survey published in 1973 reveals that the total expenditure on all sensory aids research covering device development, evaluation, and training for both reading and mobility aids supported by the federal government had dropped to about $ 850,000 annually. Calculated in terms of 1967 dollars, however, this figure represents a very significant drop in research expenditure. Thus the greater portion of the money that society makes available to the blind is employed in supporting services and direct payments, which, in 1973, averaged roughly $ 2200 per person. It has frequently been argued (38, 43, 47) that a greater investment in the development of sensory aids would enable blind people of working age to command higher salaries and, in some measure, this investment would be offset by a significant return to the treasury in taxable income. For example, Schon (38) stated in 1971 that the $ 8 million invested by the federal government in the past 20 years averages out to $ 20 per blind American. Therefore, if a blind person using a Braille computer terminal developed with these funds is able to increase his income from $ 5000 to $ 10,000 per year, the income from taxes in a single year (about $ 700) is more than 35 times the research money spent on his behalf in 20 years.

Although simple calculations of this kind have been used many times to indicate that research on reading aid and other sensory devices could reduce the present costs of support for the blind, many people remain unconvinced. The failure of many social research programs of the sixties to produce all of the anticipated benefits has bred a mood of skepticism and distrust toward proposals advocating broad frontal attacks on complex socioeconomic problems. The results of this trend have been evident in the recent tendency to favor the support of low-cost technological aids distributed on an individual basis - a mode of operation to which the fragmentary structure of the agency system is well-suited - rather than to support broad coordinated research programs that endeavor to deplo eventually high performance devices or automated reading services to a larger proportion of the blind. The reasons for such a piecemeal policy may be twofold. First, it provides a ready way of metering and controlling the costs of reading aid deployment. No long-term commitments are required and the flow of devices can be more easily accelerated, or slowed, as agency appropriations wax and wane on a year-by-year basis. Second, in the U.S., the market for individually owned devices has always (ultimately) been stronger tha that for shared system services although in the initial phases of development it has been usual to adopt the systems approach.

CHARACTERISTICS OF RESEARCH, DEVELOPMENT AND DEPLOYMENT

Most of the basic research on reading aids which is currently being carried out in the United States is scattered among university departments, research institutes, and business contractors, each with their own strengths and weaknesses. Most of this work is being pursued on an autonomous basis, and few opportunities are taken for organizations to complement one another in various roles. This applies both to work on the same basic set of reading aid goals and to work concerned with other handicaps, for example, hearing loss, where the overlap may be smaller but, nevertheless, clearly visible.

A major characteristic of university research is that it can seldom stray far from the goal of serving some educational role. Consequently the reasearch tends to be basic in nature; direct competition with industry is discouraged; a lack of fixed deadlines is desirable and a rapid turnover of personnel may occur. Moreover, because of the subsidiary purpose of university research, the cost may be somewhat lower than in industry. Given these conditions, research on reading aids is an attractive project for a college with technical resources. Fundamental questions are involved in a new interdisciplinary field, providing excellent study topics and training for students. However, this also means that the main output of university-based research is likely to be graduate theses and ideas rather than sound practical applications.

Research institutions, on the other hand, maintain professional staffs and technical facilities which are solely applied to research and development problems. Thus interdisciplinary problems should be efficiently researched and the output applications often realized within a planned schedule. In addition some continuing systematic evaluation can be expected. However, manufacturing and marketing activities are usually expected to be taken up by independent commercial interests.

Since the potential market for reading aids is small and not economically strong, commercial organizations have been responsible for very little independent research activity. Such industrial research as there is tends to be either supported by government contracts or company supported and justified in terms of corporate image rather than potential profit. Unlike universities or research institutions, industrial organizations offer manufacturing capabilities as well as those of development and research, although the costs are high. These organizations therefore possess considerable resources but they are largely untapped due to severe economic restrictions which cloud the entire sensory-aids field.

While all of these types of organizations - university, research institute, and industry - have been involved at one time in the research or development of reading aids, there has seldom been any serious attempt to coordinate their activities in an effort to combine their strengths and avoid the weaknesses of each. Neither has there been any visible effort on the part of federal agencies to define priorities, set goals, and coordinate funding. As for the private agencies, very few have been willing to make funds available for research, although a somewhat larger number have provided funds for the purchase of individual reading aids from manufacturers. Also absent, until quite recently, have been many moves toward looking for common needs among populations of the handicapped - conspicuously, the blind and the deaf - both of which have communication needs which could conceivably be served by a unified approach (31).

In the arena of deployment, the existing structure of federal, state, and private agencies represents the only viable channel through which any substantial number of reading aids can be supplied today. Again, there is little mutual cooperation among these agencies and there is evidence that their fragmentation creates an inherent bias toward the support of low-cost personal reading aids. However, such aids cannot, at present, match the performance which can be offered by centrally located high speed text transcription services operating on a community-wide basis. The opportunity to establish automated reading services confronts these agencies with demands for resources which they are individually unable to find and with pressures toward cooperation and organization for which they are constitutionally unprepared. The result is that the development of reading services, which require long-term commitments of funds and relatively large initial expenditures, is seriously hampered. One example of such an automated reading service arises in connection with the computer transcription of Braille where very few of the established institutions for the blind have responded to the technological opportunities, despite the fact that they have been in existence for many years.

IMPROVING BRAILLE PRODUCTION AND ACCESSIBILITY

By far the oldest, widely used reading aid for the blind is Braille - a medium employed by barely 10 percent of the blind community. The main problems associated with Braille are the bulk, the production cost, the difficulty of the code, and the slow rate of even highly skilled manual transcription. Several attempts have been made to avoid these difficulties by storing Braille texts on punched paper tape or magnetic tape instead of the stout paper on which Braille is usually embossed. The tape is then read by feeding it into a device which senses the information and displays the text a line at a time by means of an array of electromechanically energized pins (5, 11). Another approach is to use reformable moving plastic belts upon which Braille can be written, read, and then erased (20). A survey conducted by Gill (16) lists eight Braille output devices which are either in current production or in development.

The problem of increasing production speeds and reducing costs has been attacked by employing automated methods based on computer transcription programs. However, progress is being hampered by the difficulty of converting texts into machine readable form. Usually, inkprint must be converted to computer readable tapes or cards by hand keypunching which, although much faster than manual Braille transcription, is nevertheless timeconsuming. Some hope of avoiding this input bottleneck through the use of compositors' typesetting tapes is often expressed. Modern printing plants use photoprinting machines which are controlled by computers using texts stored on magnetic tapes. These tapes are created by *typesetters* who input, edit, and correct the texts at computer consoles prior to photoprinting. Frequently, once the page plates have been made and the book has been published, the magnetic tapes - which are the property of the printer rather than the publisher - are discarded or erased. If easy access to these computer tapes could be obtained, there is no reason why Braille books could not be published at the same time and from the same input as inkprint editions. While the advantages of this approach are very attractive, the difficulties are almost equally discouraging. There are a variety of different combinations of editing facilities, computer installations, and photoprinters in use in the printing industry. For this reason and for reasons of security, the individual autonomous printing plants (which are employed under contract by major publishing houses) use different codes. To acquire the tapes, both the printers and the publishers must be approached and, at present, many months can elapse over the negotiations. Finally, when the tapes are in hand, each may require a different code-conversion program to retrieve the text and discard the formatting symbols. It has been suggested that the only solution to these difficulties is likely to come through the setting up of a clearinghouse of compositors' tapes, administered by the Library of Congress under its special powers and the adoption of a standard printing code.

Grade II Braille is a version of the Braille code that was designed to permit higher reading speeds by using single symbols, called contractions, to represent common function words, prefixes and suffixes, etc. During the past 20 years several computer programs have been written to translate orthographically coded input into Grade II Braille. Unfortunately, however, none of these programs is capable of completely satisfying the purist by producing perfect Braille. The difficulties with the computer algorithm lie in the complexity of applying a hierarchy of rules for selecting the correct contractions, some of which defy operational definition at the purely orthographic level. The answer, which has often been proposed, is simply to change the rules (45) but the scars of battles fought between the present American Braille code and New York point in the 1920s and 1930s may appear to be too fresh for the Braille institutions to want to confront this issue yet.

Despite these difficulties, versions of the MIT Dotsys Braille translation program have been used by the American Printing House for the Blind to produce books since 1964 (37). The cost of computer Braille is said to be in the "same range" as that produced manually. In the Atlanta Public School System, a COBOL coded Braille translation program (Dotsys II) has been employed for a number of years in the preparation of teaching materials. It is perhaps of more than passing interest that the conversion to a computer-based transcription system in Atlanta was triggered by a fire that destroyed the Braille library. The example of Atlanta and the few other installation mainly in colleges around the country, represent the first *systems-based* reading services for blind people. The reason for their success lies primarily in the fact that they *share* facilities assembled for other purposes and, to emboss Braille, the require relatively modest modifications applied to standard computer output device

The development of computer output devices to emboss the Braille symbols in page format is being approached in a variety of ways. Broadly, these range from jury-rigged model 33 teletypes or modified commercial chain printers to specially designed remote consoles like the MIT Brailleboss or the Page Braille Embosser produced by the IBM Corporation. Printing rates vary from roughly 10 Braille cells/sec to 400 cells/sec. No less than sixteen such devices are listed in Gill's survey (16) as being currently available commercially or in prototype form. Most of those listed come from the United States. It is notable that the development of all types of Braille production equipment, measured in terms of the number of current active projects, outstrips by a factor of more than 2 : 1 all other reading machine development projects combined (15).

While the number and the success of Braille developments is impressive, it has to be recognized that computer-generated Braille cannot begin to meet all of the needs of the blind for access to printed material. Many books and journals, especially those not widely read, will not normally be produced in Braille; more important, great volumes of informal inkprint, e.g., correspondence notes, preprints, briefs, will appear in Braille only under the most extraordinary conditions. Moreover, beyond the issue of Braille supply, there is the inescapable fact that many of the blind never learn to read Braille at all, or never succeed in reading fast enough to use the medium effectively. Thus, efforts are being made to provide a device or reading aid which will enable a blind person to obtain *direct* access to the printed page.

TECHNICAL AND ECONOMIC CONSTRAINTS ON READING AID DESIGN

The essential purpose of a reading aid is to convert the printed page into an auditory or tactual display that can be understood by a blind reader. Several possible approaches are available. The very simplest that one might use is the *direct translation* approach where the electrical output of a photocell array is displayed acoustically by different tones, or tactually as a relief image. In this case, experience has shown that blind readers need to spend a considerable amount of time learning to understand the reading aid's unfamiliar output and most can expect to read only very slowly. Alternatively, a somewhat more complicated data processing capability might be built into the aid, enabling it to generate spelled speech. Now, given a period of less-arduous practice, skilled readers might expect to reach up to 90 words per minute (wpm). Finally, perhaps, an even more complicated aid could be built that converts its output into speech. This would represent the ideal because a reading rate of up to 175 wpm would be virtually assured for all readers and little or no training would be required. Given these choices in the best of all possible worlds, the right selection would be obvious, but performance and complexity go hand in hand with high cost and immediately clash with the economic realities of blindness.

The average annual income of an *employed* blind person has always been relatively low (it is now close to $ 9000) and most engineers and researchers agree that this must be taken into consideration when choosing an approach to the question of reading aid design. Thus it is not economically, or technically, feasible to build and market a *personal, portable* reading aid that every blind person can use for a price that any blind person can afford[3]. The major difficulties have been the lack of any low-cost reliable techniques for multifont optical character recognition (OCR) and the lack of the knowledge needed to develop an efficient tactile or auditory man-machine interface requiring no unusual perceptual skills. Faced with this situation, it has been usual to approach the design of a reading aid in one of two ways.

The first approach has been to accept severe compromises in performance in exchange for low cost by building direct translation reading aids. Whatever their shortcomings, it should be borne in mind that direct translation aids do enable some blind people to read a wide variety of print unaided and their usefulness to these people should not be lightly dismissed.

The alternative, which also has drawbacks of its own, involves abandoning the ideal of individual ownership and in its place creating a high-performance reading machine system as a shared resource. Such a system is programmed to carry out the necessary OCR and linguistic processing which converts orthographically coded tapes, or printed texts, directly into speech (or pages of Braille) for recording and distribution to groups of blind individuals within a given region. In this way, the high installation costs of *systems-based* reading machines are divided among a number of clients, bringing the cost per person served to an acceptable level.

Located between the extremes of the *direct translation* approach and the *systems* approach, there have been a growing number of development projects in recent years, which have been striving toward a low-cost OCR capability allied to a spelled speech output system. These reading devices would potentially make somewhat fewer demands on the user than direct translation aids, and could potentially be lower in cost, but they have proved to be singularly difficult to design. However, there are hints that the time may be approaching when the distinction between *direct translation* and *systems-based* devices will become blurred and tend to disappear. Advances in microelectronics seem to be proceeding at such a pace that, with continued reductions in cost, it may conceivably be possible within this decade to build quite complex linguistic processing and storage capabilities into a personal, affordable reading aid. Currently, however, the design objectives represented by the majority of the reading devices reviewed in the following sections still reflect a dichotomy between direct translation and systems-based devices.

DIRECT TRANSLATION READING AIDS

The most successful direct translation reading aid available today is the Optacon produced by Telesensory Systems, Inc., of Palo Alto, California. Originally developed at Stanford University and Stanford Research Institute, the Optacon translates an area of the printed page about the size of a letter space into a facsimile tactile image. This image is produced by a 24-by-6 matrix of small rods driven by piezoelectric reeds. The entire array fits under a single finger

3 The assumption that manufacturers should expect to recoup the true cost of a reading aid under competitive market conditions has been implicit in much theorizing about the economics of reading aid research, development, and deployment. However, it is a fact that there are no reading aids being developed or commercially deployed today which have not, at one time or another, received a very substantial research and development subsidy from federal funds.

of one hand while the other hand is used to move a small electro-optical pickup probe along the line of print. A monolithic silicon integrated array of 144 phototransistors is employed in the probe in conjunction with an optical system capable of a 2.5 : 1 magnification range. Telesensory Systems is currently offering two models of the Optacon both priced at $ 2895 each, together with a range of separately priced accessories such as attachments for reading the displays of hand-held electronic calculators and a range of Optacon training aids. At the end of 1973, over 500 Optacons had been sold (18). By the spring of 1976 the number sold had reached 2000 with approximately a quarter of the total going to clients overseas.

Reading speeds claimed for the Optacon have ranged as high as 70 words per minute for highly trained, well-motivated users. However, in the report of one evaluation study, it is suggested that only a very small number of blind people - particularly adults - are likely to have the capacity to read at rates of 50 wpm or more (46). Results of a more recent educational evaluation of the Optacon show that after an average 58 hours of instruction, 112 subjects attained a mean reading speed of 12.3 wpm (51). The authors were careful to point out that the readers were continuing to improve their performances when the study terminated. They also expressed a note of caution against citing the high performances of outstanding readers as a spur to new students because it was more likely to lead to a discouraging let down.

The largest single category of support of Optacon deployment has come from private funding sources dominated by foundations. For example, the Richard King Mellon Foundation has supported a $ 1 million, two-year project to evaluate a model deployment plan that could operate in any city. Under this plan, any blind student can receive an Optacon for $ 100 - an employed blind person would pay $ 500 . The results of the study are currently being prepared for publication.

Whatever the Optacon may have achieved, or will achieve in the future for individual blind people wishing to read, it can be said to demonstrate clearly two points. The first is that there is a strong desire among the blind for the kind of independence that being able to read unaided brings. This is evident in the way users of the Optacon *and would-be users alike* are quick to rise to its defense. The second point is that if adequate research and development support is initially available, it is apparently possible (with energetic management) to fin a variety of existing deployment channel through which reading aids may be commercially distributed to clients. Whether these channels can be sustained is a que tion that urgently needs to be explored as indeed is the question of whether the channels are adequate for the deployment of reading aid services which are different in character from those provided by the Optacon.

Since 1970, several direct translatior reading aids have also been manufactured by Mauch Laboratories of Dayton, Ohio. These devices are the Visotactor (Models A and B), the Visotoner and the Stereotoner. The Visotactor is a hand-held self contained device which uses a single vertical array of eight photocells. The input image is transmitted to eight tactile stimulators, two on each of the four finger tips of the hand which holds and guides the instrument across the page. A tracking aid called a "Colineator" is also available. Reading rates of about 15 wpm are the highest reported for this device so far.

The Visotoner is a redesigned version of the Optophone which was invented in 1912 and manufactured by Barr and Stroud in the 1920s (13). Similar in appearance to the Visotactors, the Visotoner contains nine photocells and outputs an audible signal consisting of nine pure tones ascending in frequency, the lowest tone being associated with bottom cell of the array. Scanning the array along a line of print produces a series of chords which are heard through an earphone. The quality of this audible signal is much higher than the Optophone ever produced but the basic limitations on human learning capacity still prevail. Consequently, reading speeds have not been dramatically increased and one report cites the best speed as being of the order of 40 wpm. Currently at least 36 Visotoners are in use in deployment projects sponsored by the Veterans Administration (V.A.) or in training programs conducted by the V.A. Blind Rehabilitation Centers (44).

Experience with the Visotoner and some additional experimentation led to development, during 1971 - 72, of the Stereotoner. This instrument uses a stereophonic output, a small optical probe with a 10 : 1 magnification range, a switch to permit the reading of white characters on a dark background and a lightweight control box which rests on the user's chest suspended by a neckstrap. Ten musical tones are generated in conjunction with the stereo presentation which gives a horizontal dimension to the display. Production of the first 100 Stereotoners began in 1973. The current price of the

Stereotoner is about $ 1250. The American Institutes for Research have recently published a study which was conducted for the V.A. to develop a basis for trainee selection vis-à-vis the Stereotoner, to develop instructional materials and to assess and give advice on training. The course of training which has emerged from this study is now in use in the V.A. Blind Rehabilitation Centers. Other results from the study showed that after 140 hours of training a group of readers achieved an average speed of 7 wpm while the fastest reader in the group achieved a speed of 34 wpm. An unusually skillful long-term user of the Stereotoner was observed reading at 85 - 90 wpm (52).

In addition to the reading aids which carry out direct one-to-one transformations of input to output, there exists a class of aids which perform low-level processing of the optical input in an effort to reduce the training time usually required by direct translation aids while increasing the reading rate. The Lexiphone (3, 4), developed by Beddoes and his collaborators at the University of British Columbia, is an example of this approach. The input sensor consists of 54 photodiodes in a vertical column providing high resolution along that dimension and assuring that alphabetic images can be transduced within the tracking tolerance of one lower case letter height. Beddoes' reading aid output is produced by a square wave generator whose frequency is modulated according to an algorithm that discards letter thickness information and ensures that changes in the vertical alignment of the sensor array do not alter the harmonic intervals of the output, but only the "key". At least ten Lexiphones have been built and reading rates of about 40 wpm have been reported.

Another example of a direct translation reading aid is represented by the Spelltalk system being developed by Longini at Carnegie Mellon University. However, Longini's aid is not intended to operate from printed input but to utilize typesetters' tapes or a specially recorded input stored in high-density form on microgroove or magnetic disks. The output is generated in the form of a series of speechlike sounds representing the 26 letters of the alphabet. Spelltalk is therefore a code and differs from spelled speech in that the sounds are *not* the spoken names of the letters they represent. Preliminary studies *using 50-word vocabularies* are reported to have yielded reading speeds of "120 wpm or higher" (10). A figure of $ 300 per device has been estimated as the likely cost in quantity production.

PERSONAL READING MACHINES

Among the reading aids which are too complex to be classed as *direct translation* aids, which are too small to be classed as *systems-based,* and which are intended to be personally owned, there is a small group which will be referred to here simply as *reading machines*. This group employs optical character recognition circuitry at the input and some form of speech on output.

One of these reading machines is the Cognodictor which is being developed by Mauch Laboratories for the V.A. An early model of the Cognodictor was reported to read "most popular typefonts" with 90 - 95 percent accuracy at a speed of 80 - 90 wpm. At least three models have been used for a number of years in an informal evaluation study supervised by Mauch Laboratories. The most recently built version of the Cognodictor recognizes print via an array of 64 small CdSe photocells and a "Two-dimensional Multiple Snapshot" process which is the subject of an issued patent. A reasonable amount of mistracking (of the lines of print) is apparently tolerated by this recognition procedure but a Colineator is usually employed to reduce misalignment to a minimum. The output of the OCR is delivered in the form of a five-bit code which selects among 31 prerecorded spelled speech letters or ligatures. Buffer storage of up to eight letters is provided between the recognition unit and the output device - a continuously rotating drum on which the spoken letters are recorded optically. Recent reports suggest that a radical rethinking of the Cognodictor concept is underway (29). Plans are being developed with the objective of improving the OCR performance by increasing the resolution of the photocell mosaic and of improving the user performance by using a synthesizer to generate speech output.

For many years the Cognodictor has represented the most ambitious attempt at a personal reading machine. Very recently, however, its position has been challenged by a reading machine being developed by Kurzweil Computer Products, Inc., Cambridge, Massachusetts. Still in early prototype form, the Kurzweil machine uses a NOVA mini computer associated with a Charge Coupled Scanner to recognize the printed input and to convert, by algorithm, the alphabetic spelling to a form of phonetics. Continuous speech output is generated from the phonetics via a data buffer and a VOTRAX speech synthesizer manufactured by the Federal Screw Works of Troy, Michigan. The OCR system is based on a feature analysis procedure and currently uses a scanner which tracks automatically. A high degree of character skew and misalignment is said to be readily tolerated (25) on a wide variety of type styles. The OCR output is converted into a phonetic string in readiness for speech synthesis by means of a computer program containing several hundred pronouncing rules supported by a 2000-word exception dictionary.

Both the print recognition and the conversion to phonemes are not without error but the accuracy is claimed to be high enough to speak at a rate of 200 wpm (27). However, the speech quality is not as good as the speech synthesized by a computer.

Demonstrations of the device were given in January 1976 (30). In 1974 the company stated that it could build fifteen self-contained personal reading machines (employing a synthesizer of their own design) within one year for a price of about $ 15,000 per machine (27). More recent reports suggest that the cost will be in the neighborhood of $ 25,000 each for the first machines, due to be completed in 1977 and tested at Perkins School for the Blind and in the Boston Public School system (30).

SYSTEMS-BASED READING MACHINES

The term "systems-based" refers to a class of high-performance text-to-speech conversion procedures which are sufficiently complex that, with present technology, it would not be practical to attempt to implement them using less than a medium-sized computer. Such systems could be installed in large libraries and respond to the requests of individual blind subscribers by supplying recordings of texts in clearly intelligible synthetic speech. Efficient system usage could be assured by designing the plant to operate several times faster than a normal speaking rate and to record the output on magnetic tape which is moving at a proportionally faster speed. Reading machines of this type would seem to fit comfortably into the present distribution system for Talking Books and other voice recordings by meeting the demand for fast turn around - particularly on the part of blind students and the professional community - which volunteer readers cannot now satisfy.

The development of systems-based reading machines began at Haskins Laboratories in the late 1950s. Subsequently, researchers at the Massachusetts Institute of Technology (MIT) and Bell Laboratories entered the field. In each case, the main objective has been to produce highly intelligible natural sounding speech from unrestrained text but, because there are many factors which contribute to this goal and the scale of the research programs has been relatively small, special areas of emphasis have tended to develop.

For example, the Haskins group has concentrated on the development of segmental rules for speech production on a formant resonance synthesizer (9, 28) and has also more recently been concerned with evaluating synthetic speech outputs using a full text-to-speech reading system (23, 35, 36). The Haskins prototype reading machine falls short of the high-speed multifont reading system which would be needed for practical installation in a library. Instead, it is intended to be a test-bed production system for listener evaluation purposes. Using an OCR capable of reading a single typewriter font, the system translates the orthographic spelling into a phonetic string punctuated by stress and intonation symbols derived by rule from the punctuation of the original text. This translation is performed by means of a computerized phonetic dictionary which is stored on a disk and currently contains over 150,000 English words. Operating on the phonetic string, a second program computes the control parameters required to make a formant synthesizer speak.

The synthesizer consists of a source of buzz excitation whose frequency is voltage controlled, a source of random noise, and a network of tunable filters and resonators. The filters are used to shape the spectrum of the noise excitation achieving such phonetic distinctions as /ʃ/, as in *she*, versus /f/, as in *fee*. Buzz excitation is passed through the resonators whose tunable bandwidths and frequencies make it possible to generate a spectrum with energy peaks that move with time in the manner of the formant resonances of natural speech. The task of calculating the appropriate filter and resonator controls involves the replacement of each phonetic symbol in turn by a set of parameter values which specify the salient acoustic cues for that phonetic element. A group of rules is then invoked which modify the idealized phonetic states to reflect allophonic variation and context effects. Following these adjustments, the transition values between the parametric states representing each phonetic symbol are calculated and the entire parametric array is transmitted to the synthesizer. The whole computation can proceed very rapidly and hence long passages of text can be automatically converted into speech entirely automatically with only the occasional intervention of an editor to insert words not found in the dictionary. Comprehension tests have shown the resulting speech to be intelligible enough to enable inexperienced listeners to understand nontechnical narrative material at speaking rates of 130 wpm (36). Also, hand editing of the machine-generated phonetic script to adjust the speech prosodics results in a measurable improvement in listener performance, showing that a more elaborate parsing of the input text would enhance comprehension.

Recently, the Haskins group has been arguing that, despite its shortcomings, synthetic speech may, nevertheless, be good enough for many purposes where spoken transcriptions are needed urgently and quality can be sacrified. They have suggested that a pilot reading machine center should be established which would serve both a research and service function (34). Such a center would have an important catalytic role in spurring research and development on a number of the instrumental problems which have tended to be overlooked - notable among which is an OCR system suitable for library-based reading machine applications. In addition, it would give an opportunity to confront some of the unanswered human-factors, questions which surround the organization and operation of a center, as well as provide a sharper focus for basic research on speech synthesis.

At MIT, during recent years, attention has focused at various times on OCR readers (48), speech synthesis (24) and letter-to-sound rules (1). Noting that in the processing of unrestrained text, all of the words of the English language must be recognized, the MIT researchers argue that conversion to phonetics entirely by dictionary lookup would be exceedingly costly due to the large volume of storage required. They maintain that even if these costs could be met, the system would not avoid a significant interruption rate arising from the failure to recognize recently coined words or unusual personal names. The MIT group has, therefore, been developing an algorithm which separates the prefixes, affixes, and stems of orthographic words and, using a 15,000 unit English morph dictionary, constructs the phonetic equivalences. Words whose stems are not found in the dictionary are processed by letter-to-sound rules. Once the sound representations for the words of a sentence have been obtained, the sentence is parsed to provide a close approximation to the correct correlates of stress intonation and juncture as well as to resolve noun-verb ambiguities (such as *record*). When the conversion to phonetic spelling is completed, the string of symbols is operated on by a speech synthesis algorithm which computes the parameters required to control a formant resonance synthesizer.

The Bell Laboratories researchers have specialized in the development of an articulatory model of the vocal tract and on rules for parsing the input and specifying prosodic durations (7, 49). Input from an OCR system is assumed and followed by conversion from orthography to phonetics by means of a dictionary in conjunction with a parsing algorithm. At this point, a speech synthesis program converts the sequence of phonetic characters into control parameters which specify movements of the tongue, jaw, pharynx, velum, and lips of an idealized vocal tract. To simplify this conversion process, all the parametric degrees of freedom have been kept to a minimum. The resulting speech sounds slurred when compared with the best speech generated by a resonance synthesizer. However, this attempt at articulatory synthesis is notable for the fact that it requires fewer parameters specified to a less detailed degree than does resonance synthesis.

OPTICAL CHARACTER RECOGNITION

Lurking in the background of much of the foregoing summary of reading machines and reading systems is the question: What sources of input are these machines to use? One source - the typesetters' tapes - has been mentioned already together with some comments about the organization difficulties surrounding their effective use as reading machine inputs. The second and, in the long run, most important input channel has to be direct optical reading and therefore it is appropriate to devote some space to a broad summary of the state of the art as it relates to the requirements of reading machine systems.

It is fair to say that the growth of the OCR industry has not proceeded as rapidly as many people predicted seventeen years ago, for example, when the V.A. launched its research program leading to the production of a reading machine and assumed that a suitable multi-font OCR system of high accuracy would be developed by industry. However, during this period, the companies which have commanded the largest portion of the market have been concerned with reading bank checks, credit card forms and inventory documents. More recently, the market has broadened somewhat to include the newspaper industry and the commercial documents of smaller businesses. The majority of the machines being offered for these applications are only capable of reading fixed-pitch type fonts; often of a special OCR design (e.g., OCR-A). They are therefore of little practical utility in an environment where a variety of proportionally spaced type fonts are likely to be encountered. There are, however, a few multifont machines that were designed for specialized commercial applications (such as the conversion of telephone directories) and an even smaller number that were developed under government contract as document readers. These machines demonstrate that high-speed multifont recognition is possible but, because they were built in limited quantities their costs (wich ranged between $ 250,000 and $ 1.2 million) were high. If the need for a larger number of these high-performance OCR readers were to develop and computational costs continue to fall, then it could be expected that the overall availability of high performance readers in the market place would increase. However, this prospect may not offer any solutions to the problem of handling bound books. Most OCR readers available today use loose-leaf or roll film transport systems.

Summarizing the OCR situation as it affects reading machines for the blind, the implications are fairly clear although not entirely encouraging. First, there are no commercial OCR applications whose requirements exactly parallel the requirements of reading machine systems. Moreover, one cannot see that the reading of bound books is ever likely to become a viable commercial interest unless, for some reason, the development of electronic library storage receives a sudden, very sizable, impetus. Hence, if high speed systems-based reading machines are to have a part to play in providing reading matter for blind people, then there is an immediate need to commence the development of equipment which will automatically scan and turn the pages of bound books. Second, it is equally obvious that economic incentives must be provided if the resources and expertise of the OCR industry are to be brought to bear on the development of processing algorithms that are suited to the input demands of reading machine systems.

EVALUATION OF READING DEVICES AND SKILLS

The questions of what should be measured, how it should be measured and how the results can be interpreted to reveal potential improvement in a device or training procedure, are the central issues of evaluation. Unfortunately, there is such a paucity of basic knowledge of the processes involved in sighted reading that only a few testing methodologies can be borrowed from this field. Hence, a variety of ad-hoc procedures have been used by different investigators and very little intercomparison of their data has been possible. Moreover, the limited availability of resources, and the pressure to develop data quickly, appear to have had their share in undermining the value of several recent evaluation studies. Thus these studies have been obliged to use small groups of readers and have trained them for disappointingly short periods. Consequently, the results have been significantly less valuable than might have been possible.

In many ways it is apparent that the need for evaluation has caught many people - even researchers who ought to know better - unawares. In addition, the administrators of funding agencies have seemingly been startled by the needs and the high costs of conducting well planned, long-term evaluation studies at a time when, with the major costs of research and development thought to have been fully met, a reading aid is about to be deployed. However, once this initial shock has worn off it should be quickly realized that we are attempting to engage reading aids and reading machines in one of the most complex sensory-motor and cognitive skills that man possesses. We must therefore expect to make mistakes and attempt to learn from them by evolving effective evaluation procedures which are a more intimate part of ongoing research and development than is customarily the practice in industry.

Evaluation is an activity which will require considerable expansion as new devices or systems reach the deployment stage. Clearly, reading speed per se means very little of practical value if one does not know whether the reader understood what he was reading, or how complex was the reading matter. Methods have been developed by educational-psychologists to assess comprehension, content difficulty and syntactic complexity. While these procedures are still in process of evolution, they nevertheless deserve the attention of reading aid evaluators who should become more concerned about adopting some standard principles which would make the intercomparison of data possible and thereby contribute to a growing pool of useful knowledge.

COMMENTS AND CONCLUSIONS

From this brief survey it should be apparent that we are now at a point where several potentially useful reading aids are available and that, with a coordinated effort, more could follow in the near future. However, despite the fact that we stand at the point where the first real fruits of nearly twenty years of research and development could be grasped, we appear to be holding back, unable to find the resources needed to make that final push and unable to create the organization needed to make the results available. Why? What can be the reasons?

Part of the answer may lie in the inertia of human institutions but it is by no means the only reason. Another powerful restraint arises from the fact that we simply do not know how to compute the costs and benefits of providing reading aids or services to all the blind or reading handicapped who may need them. For this task we need data and these are seriously lacking. An additional problem arises from the fact that we are spending so much on direct support and on the maintenance of existing services to the blind that we are reluctant to spend more on reading aid research and development. We are caught in a vicious cycle since, without increased research and development, we cannot expect substantial numbers of blind to become independent of programs of social support (31). Finally, perhaps too few people are aware of the impact which a sustained, coordinated program of research and development could have on the lives of the blind[4].

We have seen that the creation of a family of useful reading aids and their supply to the blind population of this country embraces a complex array of social, technological, scientific and organizational issues and it may be helpful to draw together some conclusions as a summary statement of needs.

First, the formulation of a coherent policy for reading aid research and development requires a considerably better understanding of the basic demography and sociology of blindness. From these demographic data one would hope to find out not merely how many, but where, with what ambitions, with what capabilities and with what opportunities.

Second, there is a need to examine the requirements of the whole handicapped population with a view to developing a coordinated attack on common problems and making use of common resources.

Third, there is a need to develop a well-coordinated deployment mechanism which is responsive to user demand and which contains built-in capabilities for a continuous evaluation of the reading aids or reading services being dispensed.

Fourth, a larger fraction of the total funds available in the blindness system should be devoted to research on all aspects of rehabilitation services for the blind.

Fifth, the opportunities created by the past twenty years of basic research on reading aids are available to be exploited, but there is a need to commit the funds necessary for development and deployment. It makes no sense to fund research and fail to follow the undertaking through to a useful conclusion when the opportunity for application is available.

Sixth, we need to recognize the shortcomings and utilize the strengths of the free-enterprise market system as it affects the reading aid field. Hence, incentives should be introduced to harness the resources of industry in such projects as the development of an OCR system suitable for systems-based reading services.

To end a paper on this note, with a recital of needs, inevitably risks leaving the somewhat negative impression of an endeavor fraught with many insuperable problems. This is, in many respects, untrue and to set the balance straight some additional observations deserve to be made. For example, it should be noted that for none of the suggested needs is progress barred by fundamental problems and none require the making of a financial commitment that we, as a society, cannot afford or should deny.

Indeed most of the needs can be met by preparing plans, establishing priorities and applying the organizational ability that this country has in abundance. The facts are that there is now, as at no other time since the invention of sound recording, the opportunity to introduce by the end of this decade a group of reading aids and services which cannot fail to significantly broaden the vocational and recreational horizons of the blind. We can make that final push. The choice is ours.

4 The work will be by no means complete with deployment of the aids described in this paper. Many new ideas yet to be examined have been listed in the reports of various committees, notably reference 42.

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Dr.P.W. Nye
Haskins Laboratories
270 Crown Street
New Haven, CT 06511
USA