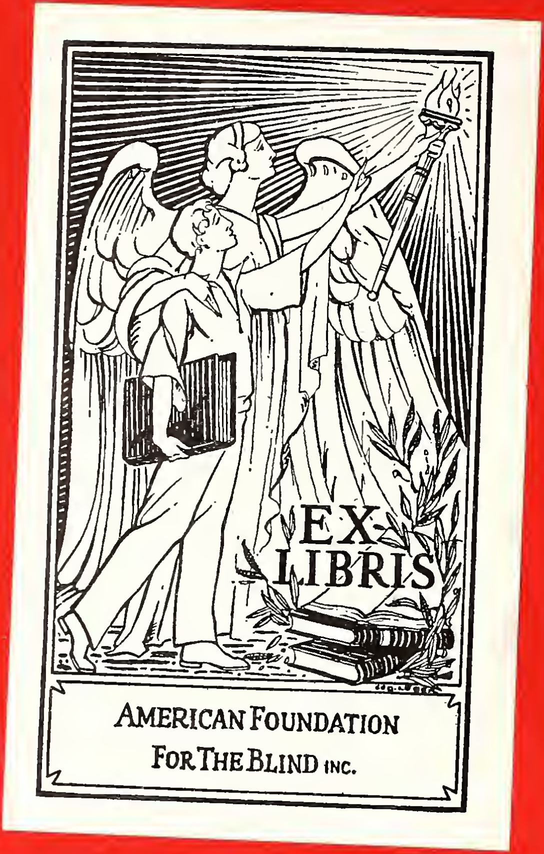
RESEARCH BULLETIN

NUMBER 21 AUGUST 1970



THE RESEARCH BULLETIN
is a publication of
The American Foundation for the Blind
15 West 16 Street
New York, New York 10011

Leslie L. Clark, Editor
International Research
Information Service

One-year subscription: $6
Single copies: $1.50

TABLE OF CONTENTS

FEASIBILITY OF ELECTROCORTICAL VISUAL PROSTHESIS

Herbert G. Vaughan, Jr. and Herbert Schimmel
Saul R. Korey Department of Neurology
Albert Einstein College of Medicine

A systematic review of the feasibility of an electrocortical visual prosthesis was begun by our research group in January 1965. The progress of this work is detailed in research proposals and progress reports to the Department of Health, Education and Welfare (Vaughan and Schimmel, 1965, 1966, 1967, 1968, 1969). In the first part of this review, we discuss the psychophysiological aspects of a useful visual prosthesis. In the second part, we consider some of the relevant biophysical factors in cortical stimulation and outline some aspects of the system we have evolved.

PSYCHOPHYSIOLOGY OF VISUAL PROSTHESIS

Information concerning the environment is available to the totally blind primarily through the alternative channels of somesthesis and hearing. Conventional approaches to the development of sensory aids have concentrated on these alternative pathways. Though useful to some extent, these aids have been rather specialized in purpose and also limited in the type and amount of information that can be conveyed to the user. The devices have been designed either as reading aids or as mobility aids. For reading, it has been necessary to transform the inkprint materials into sound recordings, or into some tactile representation such as braille. The direct translation of inkprint into some auditory analogue has not proven useful, since the burden of learning complex and essentially unnatural sound patterns has been very great for the user. At the present time, despite the development of reading machines and of ingenious mobility aids, braille remains as the major mode of access to printed materials, and the long cane remains as the most effective mobility aid.

The limitations of sensory aids depending on touch or hearing have prompted suggestions for some kind of artificial visual input achieved through electrical stimulation of the eye or the central visual structures (1), (2). Such proposals are based on the fact that electrical stimuli are capable of inducing elementary visual experiences (known as phosphenes) even in totally blind individuals. But the feasibility of this approach has been questioned on the grounds of the apparent lack of physiological and technical knowledge to provide a sufficiently complex pattern of electrical stimulation to the eye or brain (3), (4). Even so, the attractive features of a visual prosthesis have sufficiently outweighed the difficulties, maintaining interest among some researchers who believe that in this way it is possible to improve the capability of the blind to achieve optimum contact with the environment. An impetus was given to this interest by efforts to increase the vocational scope of blind individuals through training in new technical fields such as computer programming. Here, the continued participation of blind persons may be jeopardized by the increasing use of visual displays. In addition, major advances in micro-electronics have brought the fabrication of the complex and compact sensing and stimulating components required for a compact visual prosthetic within the realm of possibility.

These considerations have prompted vision scientists and others concerned with the problem to re-examine the potentialities of a prosthesis employing direct stimulation of the visual system. There are now at least two current efforts to design and implement electrocortical prosthetic systems, Brindley and Lewin, and Vaughan and Schimmel (5), (6), (7), (8), (9).

The unique feature of a visual prosthesis employing direct stimulation of the central nervous system is the possibility of providing a spatial display having the essential characteristics of a visual experience. This is done by using the portion of the nervous system specialized for that purpose. This kind of prosthesis also avoids the problem of information interference and overloading which occurs in the use of the alternative sensory channels due to preemption of the ordinary tasks of audition and somesthesis by a sensory aid. Even a relatively crude visual representation of space would substantially increase the ability of a blind person to move about in his environment. Moreover, the possibility of perceiving written and printed material directly would eliminate the major barrier to free participation in many vocational activities--or, indeed, in many of the common activities of daily life. A successful visual prosthesis could free the blind user from dependence on the several forms of human and technical assistance required now, even by those who have achieved a reasonably successful adaptation to their deficit of visual input.

However, the specific potential and the limitations of a prosthetic approach utilizing electrical stimulation of the visual apparatus must be clearly understood. Normal vision cannot be achieved through any methods now known or foreseen. If it is successful, the prosthesis as now planned will be applicable to only a fraction of the blind population, and it will not replace other complementary techniques for improving the communication of visual information to the blind.

The degree to which the potential of a visual prosthesis can be realized in practice depends on a number of interrelated physiological, psychological, and technological factors. Among them are the following:

1. Physiological and biophysical requirements to establish a suitable visual display through stimulation of the brain.
2. The design and fabrication of the electro-optical and micro-electronic components of the system: camera, encoder/transmitter, receiver/stimulator, and multiple-contact electrode.
3. Psychological variables in the selection and participation of blind volunteers.

It can be seen that the development of a functioning prosthesis presents a unique and difficult challenge, since each of these requirements must be satisfied concurrently. In the past, a number of ingenious sensory aids have failed in practice; partly because of an emphasis on technological development without serious consideration of the requirements of the user. In developing an extraordinarily complex visual prosthetic, it would be easy to repeat the same error. The failure to reach a successful result could arise from but a single problem, which would render useless a substantial expenditure of effort and resources. Because this is so, a rational approach to the development of a prosthetic system demands the most careful analysis of every factor that might effect its design and implementation.

PSYCHOPHYSIOLOGICAL ASPECTS OF VISUAL PROSTHESIS

The basis of a visual prosthesis is found in the electrical excitability of neural tissue. This excitability permits visual sensations (phosphenes) to be elicited by stimulation of the retina or those portions of the brain which receive visual input. Although the phosphene phenomenon has been known for a long time, not until the demonstration by Brindley and Lewin did we have direct evidence that a stable visual display could be achieved by stimulation of multiple points of the visual cortex. This type of display could correspond to patterns of light and dark in the environment thus fulfilling the fundamental requirement of a visual prosthesis. The lack of such evidence before Brindley and Lewin's experiment was the single greatest deterrent to acceptance of the feasibility of the approach. The enormous complexity of the visual system, and our fragmentary knowledge of its mechanisms, had convinced many physiologists that crude electrical stimulation could hardly produce a stable spatial display. Yet there did exist a substantial body of anatomical, physiological, and behavioral evidence which encouraged a more optimistic view, even prior to Brindley and Lewin's report of success.

The spatial representation of the external world in the visual system begins in the retina, with a reversed and inverted image projected on the photoreceptors. Each of these elements, 2.5μ or more in diameter, responds to light from an external source approximately 0.5 minutes in angular dimension. This is also the maximum visual acuity in the center of the retina, which is occupied solely by cones. Due to the increasing convergence of receptors on the retinal ganglion cells, visual acuity diminishes progressively from fovea to periphery. At the retinal level, neural interactions play an important role in determining the sharpness and other features of the visual image. These complexities make the perceptual effects to be obtained from an array of stimulating electrodes problematical; but at the retinal level the dimensions are so small that an electrode spacing close enough to test the limits at perceptual resolution appears to be beyond technical feasibility. Indeed, even if one were prepared to accept a distance between electrodes ten times the diameter of the cone, the technical difficulties in the way of developing a suitable electrode for chronic implantation appear insuperable. The retina is therefore not a particularly suitable site for an artificial input to the visual system. In addition, it is true that for a substantial portion of the blind population their pathology of vision involves the neural elements of the retina and the optic nerve.

It has also been proposed that micro-electrodes be implanted subcortically or intracortically. These suggestions are also unsatisfactory. Although successful experimental stimulation by micro-electrodes has been achieved, there are possibly insuperable technical difficulties in implementing a high-density electrode array. No techniques are available to place a large number of closely spaced stimulating electrodes within the brain for an indefinite period without significant damage to surrounding tissue. Yet is is clear that intracortical stimulation, were it feasible, could achieve substantially more localized neural activation with much weaker stimuli than stimulation of the cortical surface (10), (11). For this reason, animal experiments employing chronic depth microstimulation are of great interest.

We now turn to the possibilities for stimulation of the visual cortex itself. Despite the existence of complex mechanisms in the retina and visual cortex specialized for signaling information on contours, wavelength, and movement,the basic spatial arrangement of the retina is preserved throughout the visual pathways. This fact was precisely established in experimental animals by anatomical and physiological investigations prior to Brindley and Lewin's work. Similar evidence in man was based upon the analysis of the visual field defects resulting from localized brain lesions following penetrating missile wounds. A few observations were made on the localization of phosphenes elicited by cortical stimulation by neurosurgeons such as Foerster (12), Krause (13), and Penfield (14). These confirmed in general the topographic representation indicated by other methods. But these early studies failed to provide critical information on stimulus parameters, phosphene size, or on the perceptual resolution which might be achieved by stimulation of adjacent cortical points. Lacking direct data from man, it was necessary to seek clues about what might be achieved by patterned stimulation of cortex from animal studies.

An analysis of the neural response in cortex to punctuate light stimulation of the retina by Daniel and Whitteridge (15) established that projections of the central ten degrees of the visual field occupy one-half of the striate cortex. The rod-free foveal region, although less than two degrees in angular diameter, is represented in one-fourth of the cortical projection area. This is a magnification from retina to cortex greater than 1000 times the foveal representation. This fact provides an important advantage for a prosthetic system employing cortical stimulation, since the minimal spacing of electrodes for maximum theoretical perceptual resolution would be about 100μ. Electrode separations approaching this figure can be achieved by present day microcircuit technology.

The graduation in magnification of the retinal image in the striate cortex should also affect the perceived size of phosphenes, since for a constant current density the electrodes overlaying the foveal projection will activate zones corresponding to a smaller proportion of the visual field than the more peripheral ones. Phosphene size should therefore vary inversely with the magnification factor. Hence, a prosthetic system employing an array of equally-spaced electrodes could mimic to some extent the normally occurring gradation of visual acuity from fovea to peripheral regions.

The gross anatomical features of the visual cortex must also be taken into account in designing a cortical prosthetic. The visual projections occupy a small region of cortex, roughly 25 square centimeters in total area, situated at the posterior or occipital lobe of the brain, and extending anteriorly for a few centimeters along the mesial surface of each hemisphere. About half of the mesial cortex is buried within the calcarine fissure; it is thus not available to surface stimulation. Fortunately, the important foveal projections are situated in the most exposed location, at the occipital pole. The superior visual field projects on to the lower half of striate cortex, within and below the calcarine fissure, while the inferior fields occupy the superior position. The convolution of visual cortex presents a problem for a prosthetic system, for if stimulation is limited to surface cortex, some areas of discontinuity will exist in the perceived spatial matrix. These gaps would involve primarily the portions of the field along the horizontal meridian which correspond to the projections situated within the calcarine fissure. The extent of scotoma, and the degree of spatial distribution will undoubtedly vary widely from person to person, due to the marked individual differences in convolutional pattern of the cortex. These differences also require us to map carefully the extent of striate cortex by stimulation at the time of implantation. Only in this way can we achieve an optimal placement of the electrode.

Doty's (16) success in training monkeys to discriminate stimuli delivered to the striate cortex at distances less than a millimeter apart suggested that adjacent cortical stimuli could be perceptually differentiated. But the interpretation of these results is difficult, because there is no way to establish with certainty the cues employed by the monkey to make the discrimination. The only really adequate observations would be those made by human subjects, observations which could determine precisely the subjective character of the sensations elicited by cortical stimulation. Indeed, the observations made in Brindley and Lewin's initial experiment provide the key evidence for the feasibility of a visual prosthesis through cortical stimulation. Their initial system comprised an electrode of 80 contacts inserted over the mesial striate cortex of one hemisphere; of the 80 contacts, only 39 produced phosphenes. The phosphenes were white in color, and stable in position, size, and brightness, for constant stimulus values over many months. With some exceptions, the location of phosphenes corresponded well with what was expected from the human retinocortical relationships (Fig. 1). Unfortunately, none of them fell within the fovea; most of them did, however, occupy the central 20° of the field. As expected, there was a gap extending roughly 45° on either side of the horizontal meridian, with the phosphenes occupying pie-shaped sectors superiorly and inferiorily, adjacent to the vertical meridian. Those less than 15° from fixation were small and round, while of those more peripheral, some were elongated with axes displaying various orientations. Others were "cloud-like" with ill-defined boundaries. A regular gradation of phosphene size was not reported, but the findings are not incompatible with that prediction, since the most peripheral phosphenes were larger and less well-defined than those in the parafoveal field. Indeed, the "cloud-like" phosphenes appear to us to be similar to the sensation elicited by a small dim light presented to the periphery of the dark-adapted eye. Further observations will be required to define the range of phosphene size, including those within the foveal field. The elongated phosphenes at 10° to 20° from fixation also seem reminiscent of the characteristic neural receptive field shapes described by Hubel and Wiesel (17) in striate cortex of cat and monkey. These phosphenes might represent a selective activation of neurones representing particular receptive field orientations. The absence of elongated phosphenes more centrally, might arise from the representation within a given cortical area of a larger number of smaller receptive fields which, when activated together, produce a round phosphene. Since surface cortical stimulation must activate

Figure 1. Computer Simulation of the Phosphene Size and Position Reported by Brindley and Lewin's Patient. Photograph by George Tames. Courtesy of Medical World News.

a very large number of underlying neurones all at once, the observation of anything possessing properties similar to those of single neurones is of interest.

Brindley's electrodes were no closer than 2.4 mm apart, and the minimum spatial separation of the phosphenes appeared to be about one degree of visual angle. We do not know the minimum electrode spacing which still allows spatial discrimination. But the small size of the phosphenes, and the absence of marked perceptual interaction between adjacent, simultaneously delivered stimuli encourage us to believe that spacings of less than one millimeter could be used to produce a considerable improvement in spatial resolution. The closest possible spacing of electrodes is desirable, for two reasons: first, improvement in visual detail, and second, improvement of the topography of the spatial display. Cortical enfolding produces discontinuities in the array, and also other topological distortions of the retinocortical projections. These will be reflected in perceptual effects. Hence, arrays of electrodes stimulating adjacent points of a single gyrus should produce the most satisfactory spatial map. With Brindley's electrode it is not likely that more than a few contacts lie upon a single continuous gyral surface. But a thin-film electrode conforming closely to the cortical surface, with spacing of 0.5 mm or less should lie upon a single gyrus and thus be able to create a continguous field of about 400 points. We think that success in achieving an accurate topographic spatial array would significantly reduce the requirement for perceptual adaptation, or for difficult and elaborate technological manipulations to improve the spatial array. Even so, the well-known adaptation of the visual system to inversion lenses, and to other major distortions of the visual field, suggests that relying on the learning capability of the central nervous system may be more effective than complex topological manipulations with hardware.

For accurate localization of external objects, an artificial visual array must be correctly oriented to the position of the user's body. This is accomplished normally by neural mechanisms which integrate information concerning head and eye position and the perceived visual image. The mechanism is readily experienced. The spatial image appears to move in a direction opposite to passive movements of the eyeball, corresponding to the shift of the image on the retina. When the eyes are actively moved, no movement of the retinal image is perceived. Since input to striate cortex is topographically determined by the retinal image, it seems likely that the spatial correlation associated with eye movements occurs further on within the visual system. This inference is supported by the observation of Brindley's patient that the phosphenes elicited by direct cortical stimulation appeared to shift in conformity with movements of the eyes. It will be desirable, therefore, to link the sensor of the proposed prosthesis to the oculomotor system. This might be done by incorporating the camera directly within an artificial globe surgically attached to the extra-ocular musculature. This procedure is already done for cosmetic purposes, and cameras smaller than the eye are already in the offing, so the suggestion seems feasible.

One of the most critical aspects of prosthetic system development is the determining of optimal stimulus parameters. Brindley's observations established that variation either in pulse frequency or in charge-delivered-per-pulse were effective in modulating the brightness of the phosphenes. To apply this observation successfully to the generation of a visual array corresponding accurately to the continuously changing patterns of light and dark in the environment sensed by a camera, requires us to master a variety of physiological and biophysical problems. Under normal circumstances, for example, it is the temporal pattern of neural discharge which signals variations in stimulus intensity. We think it probable that modulation of stimulus frequency will also prove best in a prosthetic system. We do know that increases in signal strength are associated with an increase in the neural population subjected to suprathreshold stimulation. It would therefore seem likely that maximum spatial resolution will be obtained by the minimum effective charge-per-pulse. Increases in pulse intensity are associated with undesirable electrochemical effects at the electrode-tissue interface, and there is the risk of tissue damage through heat generation. Thus, it is clear that achieving optimal temporal patterning of stimulation will not be a simple matter; it will require extensive experimental study during the initial stages of prosthesis development.

The brain does not receive a steady neural signal, so the regular trains of electrical stimuli favored in former studies of direct cortical stimulation are not the optimal means of evoking a perceptual response. In normal vision, the image is shifted about on the retina by saccadic eye movements occurring at the rate of 2 to 4 per second. During eye movements, input to the brain is suppressed, so that the perception of the moving image is prevented as it is shifted across the retina. A burst of neural activity follows at the beginning of each fixational pause. Maximum discharge persists for no more than 50 msec; with progressive falling-off in activity during the rest of the fixational pause. In experiments with animals it has been shown that pattern shifts at a rate of approximately 3-per-second, produce maximal neural response in the striate cortex. These results suggest to us that cortical stimulation should be delivered in brief trains of pulses lasting less than 100 msec, repeated at intervals of 300 msec or so. In this way, we can mimic the normally discontinuous pattern of input to the brain. The mimicry could be further improved, by a system with a camera linked to eye movements, which gated the stimulation at each fixational pause.

We are sure that a human observer will be required to determine the optimal stimulus characteristics of the prosthetic system. The variety and complexity of the tests to be made, as well as the need for subjective evaluation of the perceptual effects obtained, effectively remove the task from the realm of animal behavioral analysis. In spite of this, the fears of unwarranted human experimentation have led some critics of our direct approach to demand a demonstration of feasibility in experimental animals before starting studies in man. Brindley's demonstration has diminished the force of these criticisms. After careful consideration of all the aspects of the problem, we are convinced that aside from the required studies of the safety of specific designs, further animal experimentation is not needed for the development of a cortical visual prosthesis.

SYSTEM CONSIDERATIONS

In considering the information which can be transmitted by spatiotemporal arrays, three different approaches can be identified. In these displays the number of points in the matrix is the critical factor in defining the type and mode of information delivery. The first approach is appropriate for a matrix of 100 points or less; the second for 400 to 1000 points; while the third needs at least 4000 points. Although all could be produced by cortical stimulation, the first and second might make effective use of a cutaneous input. The main features of each approach are outlined below:

Small Matrix -- Coded Information. Due to the small matrix size, 10 x 10 or less, information must be categorized and encoded to maximize information delivery. This system cannot effectively provide a direct two-dimensional representation of space, but must abstract the significant environmental features and present them in a coded format. This approach places a heavy demand upon the development of optimal coding and display, as well as upon the learning capacity of the user. These problems are already well known in the sensory aids field and have limited the acceptance of a number of techniques for information delivery to the blind, including braille. The intrinsic limitations of this approach are severe, and it is hard to see how it could be utilized in motility to provide more than the most elementary information concerning the presence, position, and size of environmental features. Such encoded inputs would hardly be considered suitable for a cortical device, since the limited information provided can be readily transmitted through alternate sensory channels. None of the special advantages of the visual cortex for spatial display would be exploited by this approach.

Intermediate Matrix -- Preprocessed Input. With a matrix size of between 20 x 20 (400 points) and 32 x 32 (1024 points), an effective two-dimensional display can be achieved. On the basis of simulation experiments carried out in sighted persons (18), Brindley estimated that a phosphene matrix containing 600 points would be sufficient to permit a reading speed of 120 words-per-minute with ordinary printed material or careful handwriting. These experiments involved a special device which presented ten letters at a time to his subjects. It is almost certain that the use of matrices containing 1000 points or less will require devices to adapt the input either for reading or for motility. Indeed, problems similar to those encountered with the coding technique appear in contemplating the adaptation of an intermediate-sized matrix to motility applications. The combination of a suitable field range for detection of peripheral hazards with adequate central resolution for useful object identification presents a severe challenge at this matrix size. It should be noted that results of comparable effectiveness might be achieved equally at this level by either cortical or cutaneous stimulation. If the matrix size were limited by technological factors to 1000 points or less, an effort to define the limits of cutaneous stimulation might be preferable to early exploration of a cortical system.

Maximum Density Matrix -- Direct Spatial Display. With a 4000-point display of intensity-modulated points an image subtending a visual angle as large as 10° can provide a fairly good image of a face (Fig. 2). The effects of a cortical-phosphene matrix may be simulated, as shown by the technique of half-tone photography, which permits an experimental evaluation of the effects of matrix size on object resolution. As previously noted, the observations on cortical phosphene characteristics made by Brindley suggest that a simulation of this nature is a valid one. This display size is also adequate for reading of fine print with suitable optical adjustment of field size. Even expansion of the field to the extent necessary for guidance in mobility is compatible with identification of gross objects such as persons, automobiles, curbs, and fire hydrants.

The upper limit of achievable matrix size and density with cortical stimulation is determined by physiological as well as technological considerations. We have estimated that an 0.5-mm electrode spacing would provide both adequate phosphene resolution and be technically feasible. This would correspond to a density of 400/cm^2. A further increase to 1000/cm^2 may be possible. If an electrode with the lower density were implanted over 10/cm^2 of striate cortex, a matrix size of 4000 would be achieved. It must be recognized, however, that electrode failures and cortical discontinuities might degrade the matrix from the ideal array. It is anticipated on the basis of experiences of patients with defects in the field of vision that a reasonable adaptation to field discontinuities will occur (19), (20).

The information transmitted by a spatial electrode matrix of any size can be substantially increased by taking advantage of the capacity of the visual system to utilize information presented in rapid sequence as if it were simultaneous. Thus, by the technique

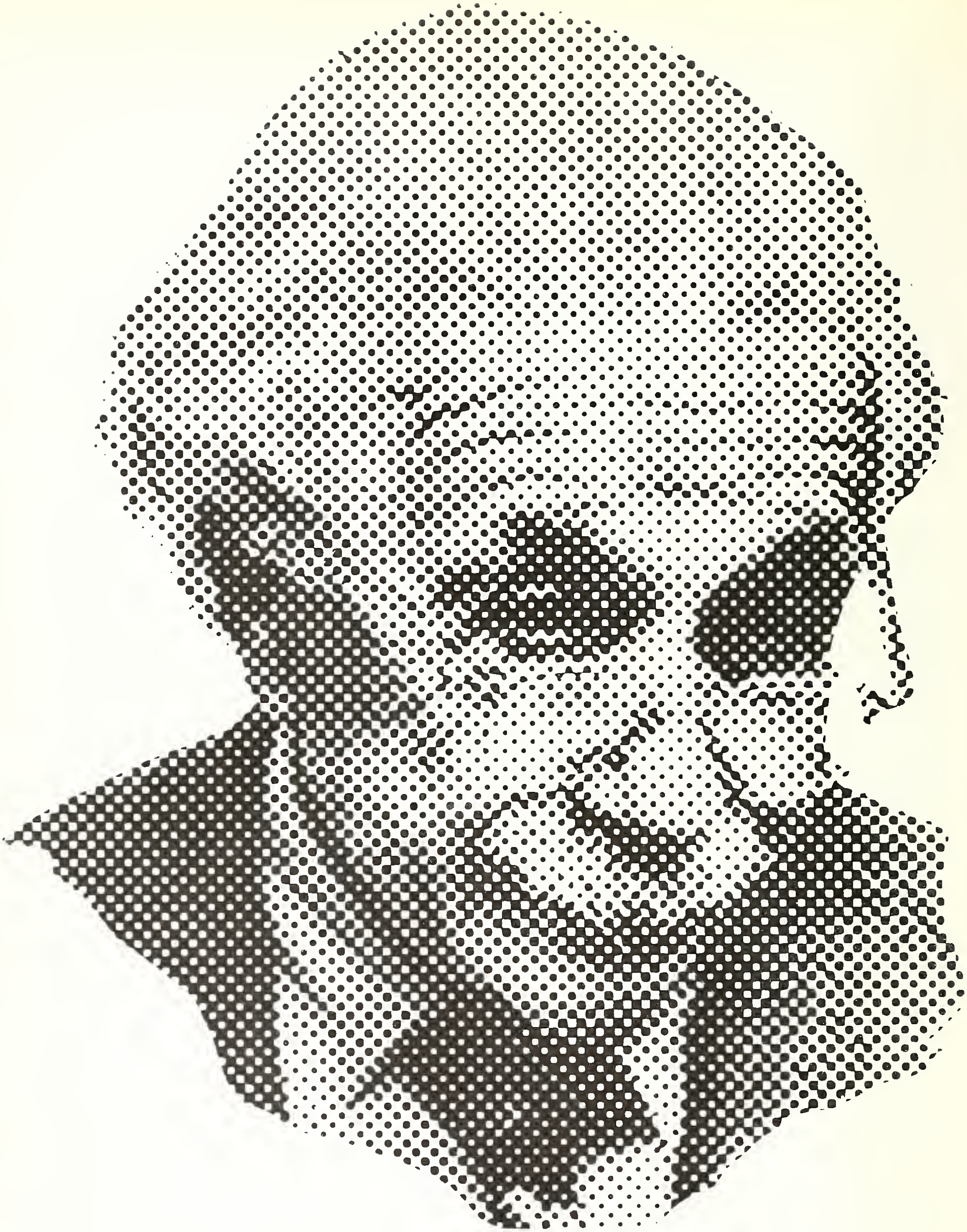


Figure 2. Half-tone Photograph Simulating a 4000-point Phosphene Matrix.

of *microscanning* at least a four-fold increase in the effective matrix size may be achieved. The procedure would be of greatest utility for intermediate and large matrix sizes, and in the latter case would permit a 4000-point array to provide an image quality not substantially inferior to that of an acceptable television image (Figs. 3a and 3b). The effect of microscanning can be demonstrated by placing a perforated sheet over a photograph. While the photograph cannot be adequately resolved with the overlying grid held stationary, by rapidly oscillating it with an excursion slightly less than the space between holes, the picture can be made out.

In considering the technological factors in implementing a prosthetic system of this dimension, it is clear that neither feasibility nor cost now limits the maximum matrix size and density. Recent advances in integrated microcircuit technology permit the fabrication of a system, including camera, which could be fully incorporated within the confines of the head (Fig. 4). Although an ultimate system with camera placed within the orbit may well be a decade or more in the offing, a functioning prosthesis with head-mounted camera could be produced within a three year period. The cost of system development could be surprisingly low, considering its complexity, if available components developed primarily for military, space, and computer applications could be made available and efficiently adapted for the prosthesis application. Present indications suggest that this is possible. One point is quite clear. Increase in matrix size does not entail a proportionate increase in cost. Once a modular component design is achieved, a ten-fold increase in matrix size would barely double system cost, taking into account prototype development. In production, costs would be very much lower. The conclusion to be drawn from the technological situation is that, once miniaturization of system components is attempted, no significant saving either in complexity of system design or of cost is achieved by reducing the number of points in the matrix. An optimal strategy in prosthesis development would be to aim for the maximum possible matrix size for electrocortical application. Since the approaches to prosthesis employing smaller matrices might still prove quite useful in patients not appropriate for a cortical prosthesis, the same technology could be applied with only minor modification to an electrocutaneous system. Since these approaches may well prove to be complementary to one another in approaching the overall problem of sensory aid to the blind, we feel that a coordinated program to develop and evaluate both of these systems would be most effective and economical.

A decision to proceed with this development, using blind human volunteers, raises critical human and ethical issues which themselves affect the strategy one employs. The early phases of most radical advances in medical treatment are also those which are accompanied by risk of harm to the recipient. The risk has not, at times in the past, been properly weighed and minimized,

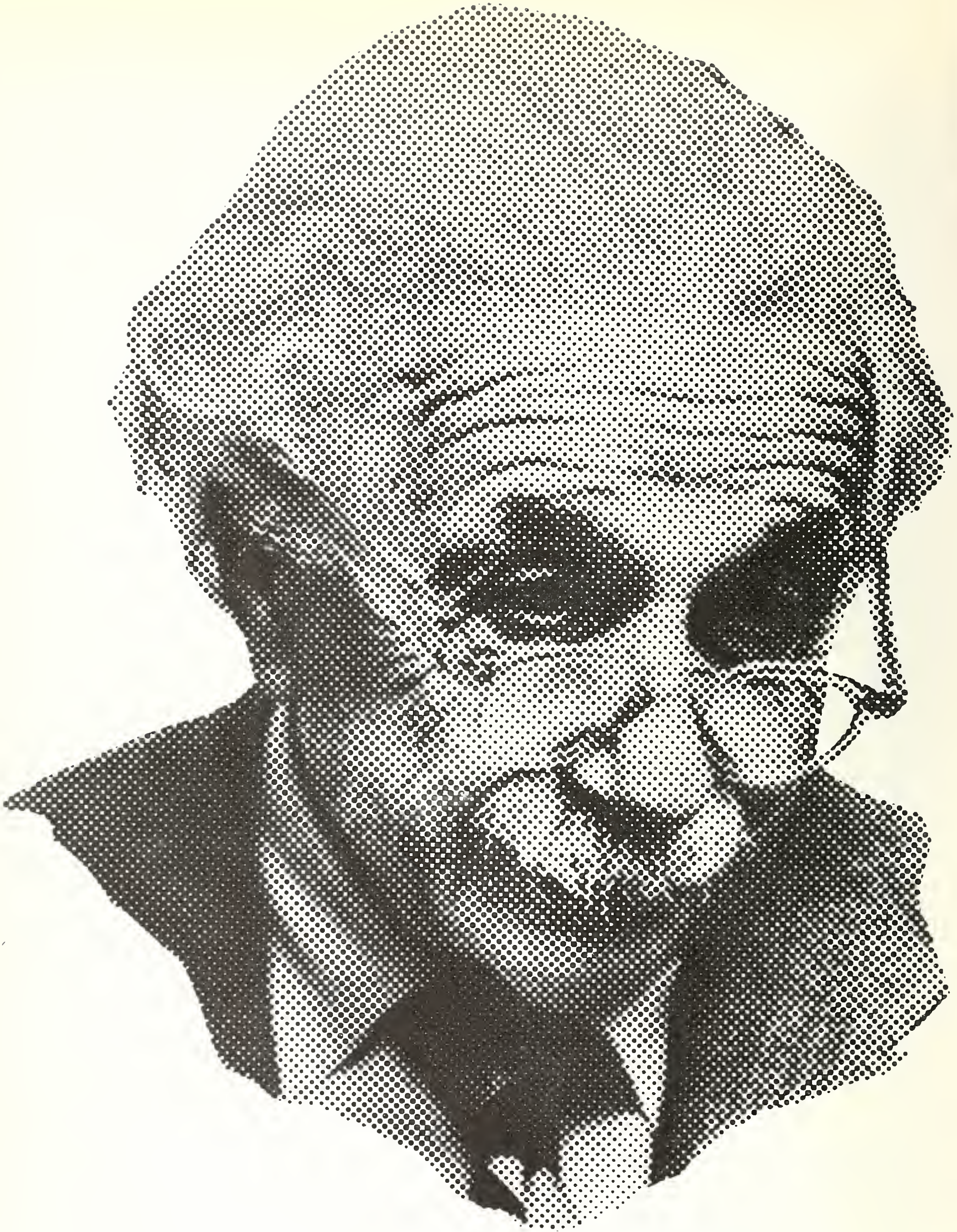


Figure 3a. Photograph of Figure 2 Represented by a 20,000-point Matrix as Might be Achieved by Microscanning Technique.

Figure 3b. A Scene Occupying a Field Size Appropriate for Mobility Application Represented by a 20,000-point Matrix. Each face contains about 200 points.

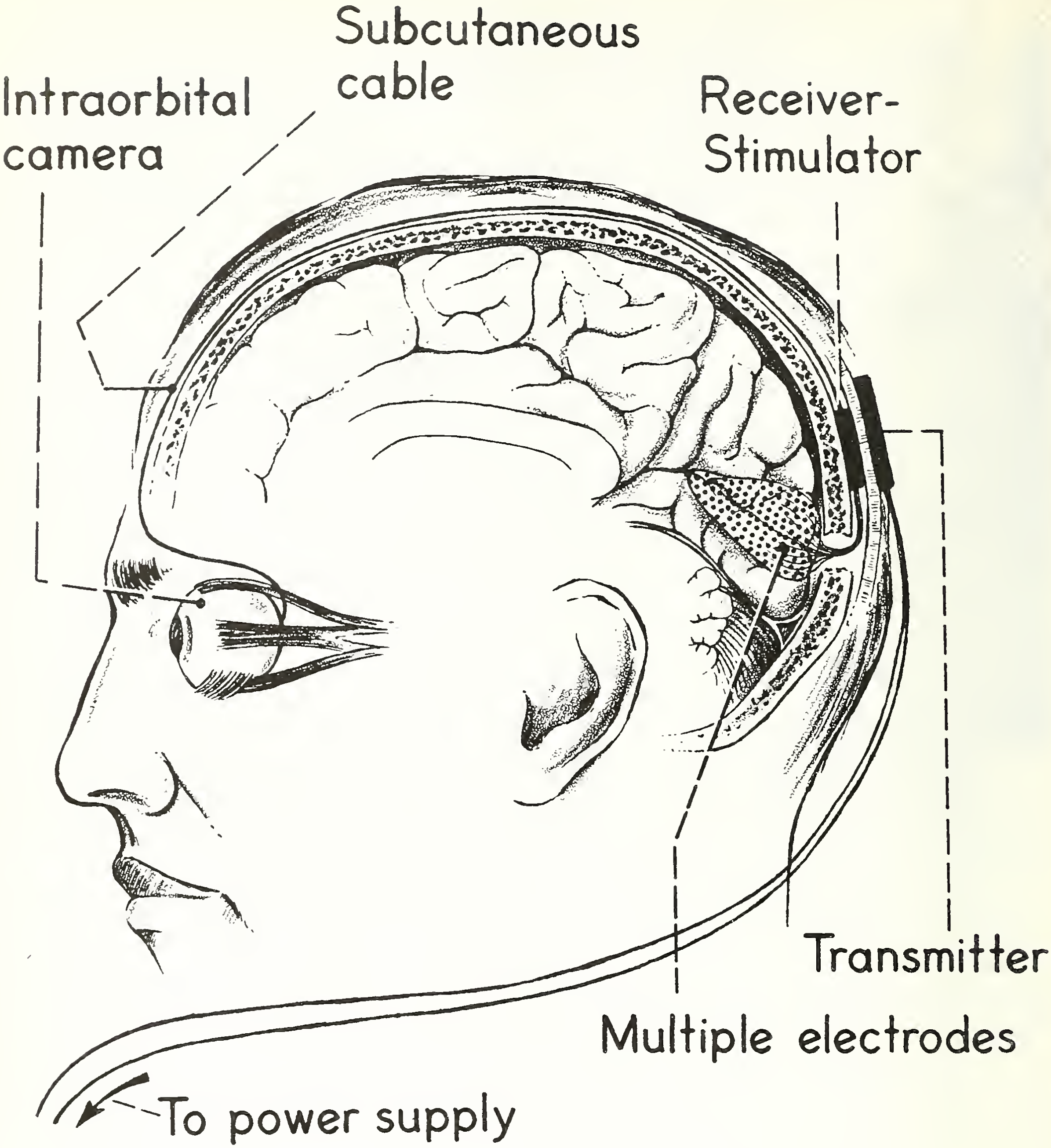


Figure 4. Schematic Representation of an Ultimate Prosthetic System Employing an Intraocular Camera. All control circuitry is implanted. Only the power required for operation of the system is transmitted through the skin.

particularly in areas requiring clinical trial early in the course of development. We hope that such lapses will not mar the implementation of a visual prosthesis. Although one would want the swiftest accomplishment of a functioning device, premature or unnecessary human experimentation cannot be permitted. Fortunately, the material risks to which the human subject will be exposed are slight. With proper tests of implanted materials and optimal stimulus parameters in experimental animals, the risk of damage to the human subject's brain is minimal. Nevertheless, the psychological implications of the prosthesis cannot be taken lightly, despite the safety of its implantation. Every participant should be provided the opportunity to benefit from the best possible prosthetic, and not regarded merely as the stepping stone to later improvements.

This decision is underlined by the substantial costs and effort of prosthesis development. There is a considerable temptation to proceed by developing simpler and less expensive devices, progressing gradually to an optimal design. These pressures should be resisted strenuously, for the crucial questions about optimal spatial resolution can only be answered with a highly sophisticated system. It is true that limited objectives would be achieved sooner, but there is a considerable danger that the development of an optimal prosthesis might actually be impeded by half-way measures. This is due to the fact that low-density systems with a relatively small matrix size can be built and tested using conventional electronic components and a hand-made multiple-stimulating electrode. These techniques are not applicable, however, to the high-density system required for an adequate general purpose prosthesis. It would be necessary, therefore, to develop a completely new system design using integrated-circuit techniques in moving from a low to a high-density system. Furthermore, as we have pointed out, the necessity for some sort of specialized preprocessing in a lower-density matrix requires additional effort and experimentation to define optimal techniques. This problem is completely circumvented in the high-density system. There is a place, we assume, for various well-conceived approaches to prosthesis implementation, provided that there is adequate financial support. But the complex of physiological and biophysical demands imposed by an electronic link with the brain leave little room for error. In the absence of a radically different approach to a visual prosthesis, the basic features of an optimal system can be quite well defined by the appropriate experimental observations whose nature we have already outlined. What now remains is the development of a system capable of defining these variables as well as functioning as an effective prosthetic.

DESIGN OF A PROSTHETIC SYSTEM

Our earliest studies of the feasibility of a prosthetic system, completed in 1965 and 1966, convinced us that the balance of anatomic and electrophysiological data favored the investment of a substantial effort in the development of a prototype. The system which we concentrated upon is fundamentally similar to that employed by Brindley, but it is far more sophisticated. For reasons we have already given, we decided that we would have to complete a system which, if our basic hypotheses regarding cortical stimulation were correct, could serve as a working prosthesis for the first volunteer human subject.

In this review of our work to date, we shall first describe the basic system and its components. We shall include here some information on earlier designs, partly because the history of the experience may become important, and partly because it may still prove necessary to return to some of these earlier designs. Next we shall summarize a number of experimental and theoretical studies which have guided our design. In conclusion, the present status of system and component development and plans for further work will be described.

THE BASIC SYSTEM AND ITS COMPONENTS

The definition and evaluation of the prosthesis to be developed was given as follows in our report on 1966:

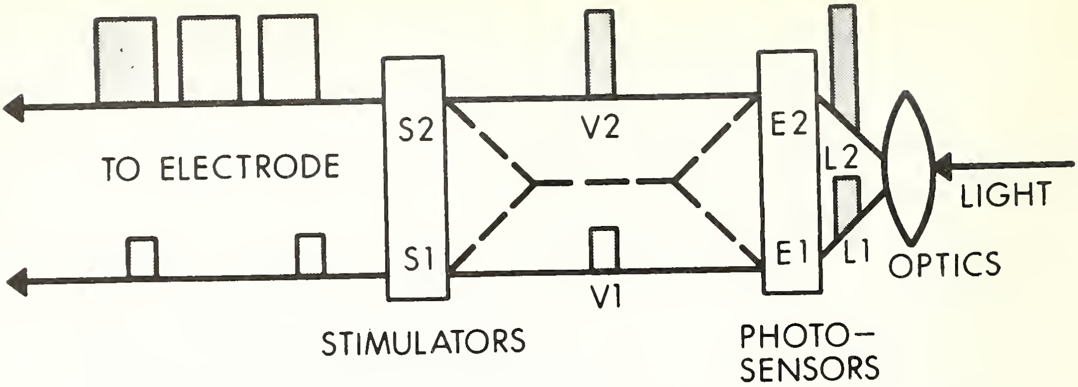
> "The function of the prosthesis is to deliver spatially and temporally differentiated electrical patterns to the visual cortex of a blind human subject. The development of a compact prosthetic device involves a complex optical-electronic system capable of meeting the electrophysiological requirements, still unknown, of visual perception. In its essentials, such a prosthetic device can be envisioned as consisting of three major system components:
>
> 1. An optical-electronic camera in which a visual scene would be projected onto 1000 to 10,000 light sensitive elements;
>
> 2. An electronic stimulus encoding-generator system which would use the information contained in the light sensitive elements to deliver a pattern of stimulation to the human visual cortex;
>
> 3. A multiple electrode permanently implanted in the occipital region overlying striate cortex. This electrode would contain as many leads as there were

> photo-sensitive elements (1,000 to 10,000) and would reproduce in an appropriate electrical stimulus pattern the light pattern observed in the camera.
>
> In evaluating the technological feasibility of the project, these three major system components were considered in the order of their apparent difficulty. Thus, the multiple electrode with its requirements for biological compatability and effectiveness clearly presented the major problem upon whose solution rested the entire project. The next component, the stimulus encoder, although complex, requiring more knowledge of physiological stimulus parameters than is currently available, is clearly a development within the current state of micro-electronics. The photo-electronic camera was known to be under development in similar form to that required for prosthetic application by several NASA contractors, and was therefore not necessary to consider as a unique problem."

It was also planned that the prosthesis would provide for a simple topological transformation of elements in the visual field to corresponding electrodes implanted over the cortex. Different light values would be translated into different patterns of electrical pulses. Figure 5 shows the transformation and explains the action of transformation.

Our conceptualization contemplated some interaction between the light values in adjacent fields. For example, the limitation of the total amount of current flowing into adjacent areas is considered (see section "A Review of Physiological Stimulus Results"). We also considered the transformation of light values to enhance edge effects (Fig. 6). Macro- and micro-scanning features would be included, either mechanically or electronically. Although we realized that some major topological transformations might be necessary, and eventually included in the encoding system, we placed principal reliance on the learning capability of the user to correct for field distortions. To quote our 1966 report:

> "Requirements for stimulus encoding will be further defined during the course of the human studies, which are envisaged in three stages.
>
> 1. The effects of systematic variation of stimulus parameters on perceptual experiences of the subject will be determined. The effects of basic stimulus parameters such as pulse amplitude, duration, and repetition rate upon intensity and other aspects of the percepts; the spatial projection and extensity of the percept as a function of stimulus position and number of contacts activated; and the effects of simple patterned stimulation with and without attempts to enhance edge effects will be evaluated. The computer



Two different small areas of the visual field are sensed by elements E1 and E2. The light values L1 and L2 at these elements are converted to voltage V1 and V2 which are transmitted to separate stimulators S1 and S2. The values V1 and V2 determine the parameters of the stimuli which are generated. In this simplified case the higher light value L2 is converted to a voltage signal V2 higher than V1. These are passed on to the stimulators S1 and S2 where they control the stimulus pattern. In this hypothetical case the larger voltage V2 has resulted in a stimulus of higher voltage, longer duration and faster repetition rate.

Note the joined dotted lines over which V1 and V2 can be transmitted. This is to indicate that it is not necessary to have 4,000 separate leads from the photo-sensing field to the stimulators. The light values might be scanned serially and then transmitted serially to the 4,000 stimulators instead of in parallel. Each stimulator then must include storage so as to correct for the different times of appearance of the voltage signals if the stimulus system is to act independently of the temporal scanning pattern of the visual field.

Figure 5. Transformation of Light Pattern to Electrical Stimulus Pattern-Figure.

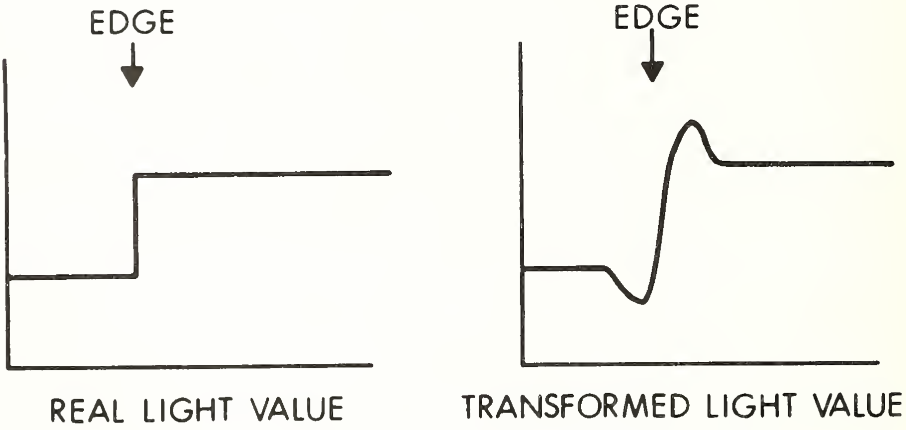


Figure 6. Transformation to Enhance Edges

will be employed to control the sequence of each experiment series of stimulation and to produce the required stimulus transformations.

2. While the first stage may yield substantial guides as to what is effective stimulation, it is possible that the subject will not be able to develop percepts for even elementary geometric figures without some form of learning. In the second stage the subject will control stimulus presentation for elementary objects. Tactile and kinesthetic feedback will be provided so that learning may take place (21). The visual experiences resulting from electrical stimulation may thus be consolidated into stable visual percepts. Although stimulation will be controlled by the subject during this stage, the effects of systematic variation of stimulus parameters will continue to be studied.

3. In the third stage it is expected that the stimulus pattern will be controlled by a real visual field. The subject will be ambulatory and the electronic stimulus pattern will be based on the optical input of the electronic camera and encoded on the basis of the knowledge gained during the first two stages. This stage will still involve learning and may guide further adjustment of stimulus parameters to yield more effective stimulation."

Though our basic design provides for a passive multiple electrode with 4000 separate leads, we recognized that a great simplification in design is offered by a combined parallel-serial approach. In our 1966 report we put it this way:

> "The complexity and cost of the stimulus encoder would be substantially reduced if it were possible to address each of the stimulating electrodes serially rather than simultaneously. A serial address system could activate each electrode utilizing column by row scanning, thus requiring only 128 inputs to the electrode. It is not believed that serial scanning of the entire array is feasible due to the required pulse durations and repetition rates. Thus, with 100-μsec. pulses, scanning of the entire array would require 6.4 msec. whereas it is likely that repetition rates as high as 1000/sec. may be required. It would therefore be necessary to reduce the pulse duration by a factor of ten, with a concurrent ten-fold increase in stimulus current, which would be undesirable. By subdividing the electrode into 16 x 16 arrays, the desired pulse duration and repetition rate could be achieved and the total number of stimulators reduced from 4096 to 256. If this type of operation proves feasible in the experimental prototype system, then subsequent electrode designs could be substantially simplified by reducing very substantially the number of leads passing

through the skull and connecting the electrode to the stimulating circuitry. Certain other design simplifications might also be achieved since the photoelectric camera systems considered for the prosthesis also employ scanning for transmission of the sensed photic information."

The major features of the design at present remain the same as those of 1966. As we anticipated, serious problems were encountered in making the high-density thin-film platinum/Teflon electrode of 4000 points. Success in this has eluded us, in spite of industrial assistance and what seemed like imminent solution of the problems involved in its fabrication.

Our initial electrode design was made with the assumption that adhesion of the electrode to the cortex due to scar tissue formation would occur, and that this would not permit removal of the original electrode. This assumption led us to a specification of extraordinarily high reliability and long life for it. These requirements also virtually eliminated the possibility of incorporating any active circuit elements within the electrode array. The design also stipulated leads passing through the skull and skin to a stimulator. Rapid progress in microcircuitry led us to explore again the possibilities of incorporating the stimulating circuitry into the electrode array. In our talks prior to 1967 with Westinghouse Corporation, we were told that the device we planned should not be seriously contemplated for two to three years; and that the specification of ". . . indefinite life with failure rate of less than 2 percent per year. . . " was not likely to be achieved for a period considerably longer than that. But we understood that the progress anticipated at that time would permit us to consider installing the stimulator under the skin, and to expect to replace it in a few years.

A system design based on this thinking is shown in Figure 7. We had decided, before Brindley and Lewin's report, that the stimulus code would be transmitted either serially or by a multiplex technique through the skin via one or more antannae. How to transmit sufficient power safely through the skin to operate the required number of stimulators is still under study.

Brindley has shown that in chronically implanted baboons, adhesions do not develop between the electrode and the brain. Instead, a membrane less than 80μ thick grows over the electrode surface, adhering to it, but not to the brain. This finding makes it possible to consider removal of the electrode when it wears out and/or fails, and to consider replacement by an improved version. If we can accept a more limited life expectancy of some two to five years, we can then consider the use of active microcircuitry in the electrode. We are now exploring this option again (see "Present Status of System and Component Development and Plans for Further Work"), in view of the difficulties encountered with the

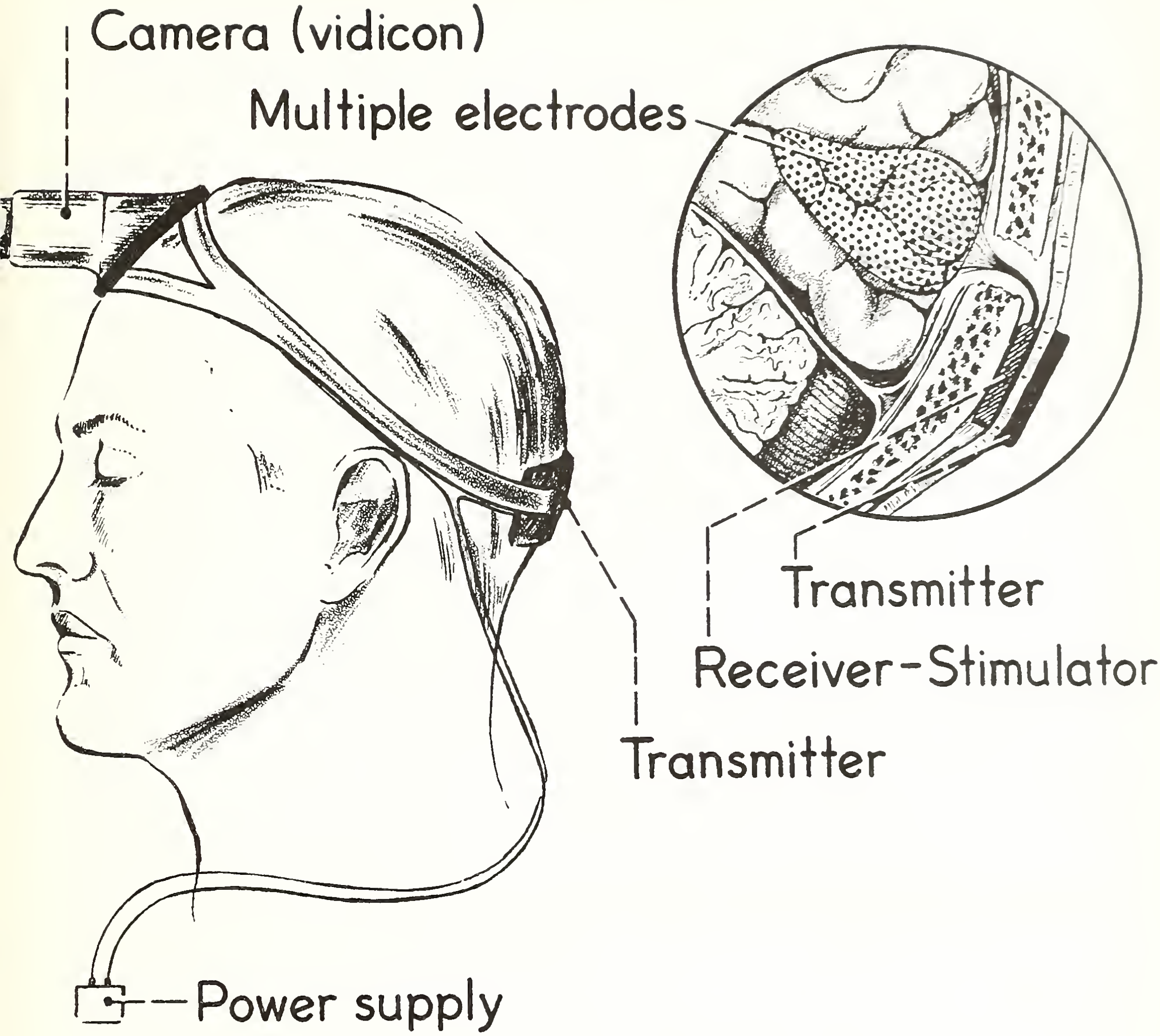


Figure 7. Diagram of the Prototype Visual Prosthesis. The miniature camera and encoding circuitry are external to the body and can be readily removed. Receiving and stimulating circuitry are implanted beneath the skin and the multiple contact electrode overlies the visual cortex.

passive electrode and its large number of leads. It appears now that if one is prepared to accept a combination of serial/parallel stimulation, as described above, the required electrode density can be reached. This is particularly so since we require only that transistor switches and isolation diodes will be included along with the multiple electrode. The number of stimulators required is relatively small and can be placed either directly with the electrode or remotely (see Fig. 7).

We have reviewed the question of the multiple electrode at the outset because from the beginning it provided us with the greatest difficulty and with one major focus of our work. In contrast to this, our efforts regarding the optical component (an electronic camera) have been limited to following the substantial progress made by the electronics industry.

A miniature Vidicon, equivalent to a matrix of 100 x 100, or 10,000 points, is capable of repetitive scanning at a rate of several hundred frames-per-second. This appears to be a more than adequate frame rate. Its output information is delivered through a wire pair. This stands in sharp contrast to the 4000 electrode points that must be separately activated by this output. Since we began our studies, there has been great progress in the development of photosensitive matrix devices by the American Telephone and Telegraph Company, Westinghouse Corporation, and Radio Corporation of America. These efforts are likely to yield a miniature electronic camera suitable for the final prosthesis, and with a small number of leads (for an N x N matrix, only $2N$ leads are required, that is, 200 for a 10,000-point matrix). Its possible additional features, including adjustment of the visual field, macro- and microscanning movement, mechanical or electronic, and utilization of oculomotor information, are relatively modest problems compared to the development of the other elements of the prosthetic system: the implanted multiple electrode and the encoding-stimulating system.

MATHEMATICAL AND PHYSICAL STUDIES

The design of components and of systems is highly dependent on the size and number of electrodes in them, and on the range of stimulus parameters to be taken into account (e.g., voltage or current, duration, and time pattern). It is therefore necessary for us to anticipate the effects of changing the ranges of parameters. For example, from the beginning we have been concerned about the possibility of excessive temperature rises due to current flow. Preliminary calculations, based on what we thought were suitable variations in parameters, showed that temperature rises would not be excessive. Brindley and Lewin's subject, they reckoned, required currents and voltages three to five times larger than our calculated values. These larger values would result in temperature rises 10 to 25 times greater than we had anticipated.

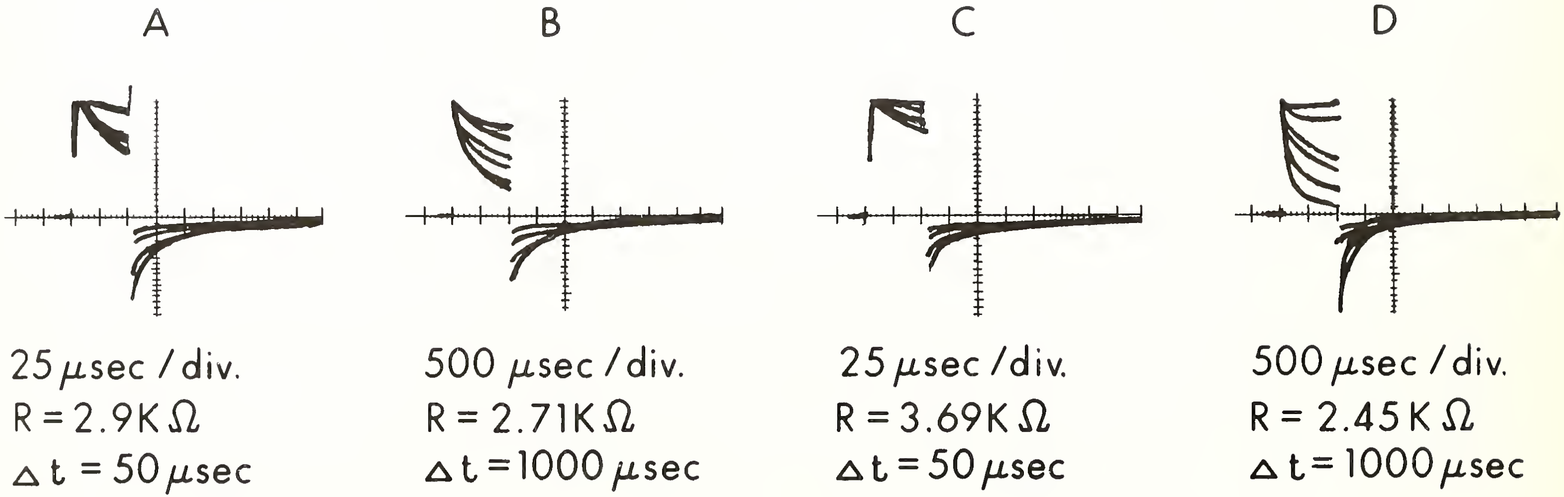
We have had to review our original temperature study with care, and we shall present our results below. First, however, we would like to consider some of Brindley and Lewin's results, and other physiological data, which are relevant to stimulus parameters (7).

The Platinum-Saline Interface. The platinum-saline interface is extremely complex. Its nature depends on local metallurgical or chemical conditions with their own prior history. Experimental study also gives varying results depending on the surface conditions at the moment of examination. It cannot be described by passive linear electrical circuitry, particularly at low voltage levels. The interface has been studied for us over a wide range of voltages, durations, saline concentrations, and electrode sizes that one might consider in a prosthetic design, by Mr. Victor Klig of Albert Einstein Medical College, and by Dr. Robert Schoenfeld of Rockefeller University. Figure 8 gives some typical data from their study. It shows data for a 5.0-mil (0.125 mm) diameter electrode immersed in a 0.05 normal sodium-chloride solution; the other electrode is large, remote, and made of platinum. There are six curves for each of the four slides; these correspond to pulse voltages of 0.1, 0.5, 1.0, 5.0, and 10.0 volts. The curves are in corresponding ascending order. They indicate that the lower the voltage, the more rapid the decay, and the greater the overshoot. In Figures 8(a) and 8(b) the current enters the cathodal electrode; in Figures 8(c) and 8(d) the current leaves the electrode.

We can readily see from Figure 8 that the data cannot be interpreted in terms of passive linear circuitry. Consider, for example, Figure 8(a): at the end of 50 μsec, the current of an 0.1-volt pulse has been reduced by half. Now an examination of Figure 8(b) will show that at the end of 1000 μsec it has been reduced to about 0.25. Under the assumption of passive linear circuitry, the current would have been expected to be reduced to 10^{-7}.

Anodal stimuli behave somewhat differently, but still not linearly. Curves taken at concentrations of up to 0.2 normal concentrations, for the same size electrode, cathodal current, and anodal current, all show similar patterns.

These data conform to the results of Le Blanc's classical experiments, showing that using large platinum electrodes the voltage must exceed approximately 1.7 volts before direct current will flow. The largest part of the difference observed can be accounted for by the EMF required to dissociate hydrogen and oxygen (i.e., 1.2 volts), the balance used for rate-limiting processes or equivalent counter EMF generated at the electrode surface. The rate of development, and the size, of the counter EMF varies with the condition of the electrode, current density, salt concentration, and polarity. The error introduced by considering only the



A: 25 μsec / div. R = 2.9 KΩ Δt = 50 μsec

B: 500 μsec / div. R = 2.71 KΩ Δt = 1000 μsec

C: 25 μsec / div. R = 3.69 KΩ Δt = 50 μsec

D: 500 μsec / div. R = 2.45 KΩ Δt = 1000 μsec

Figure 8. Variation of Normalized Electrode Current (i/i peak) as a Function of Time and Pulse Voltage and Duration.

passive resistance involved is smaller for short pulses and high voltages and for durations under 50 μsec, and intensities over 5.0 volts, the error is less than 10 percent. For long durations and higher voltages the current can be estimated by subtracting one to two volts from the impressed voltage.

Electrode Size, Electrode Density, and Field Penetration. One of our earliest studies dealt with the question of the depth of the cortex which would be penetrated by a differential field pattern. If we put aside the complex questions of timing and phase effects, the question can be put simply: if a multicontact electrode is placed at the surface of a homogeneous conducting volume, at what distance from the surface will the effect of individual electrodes disappear so that the currents would seem to be due to a single continuous surface electrode? And, to what extent will the result be influenced by the size of the electrode?

A good estimate can be had by inferring from the case of an infinite two-dimensional equally-spaced array of square electrodes, positioned in the $z = 0$ plane, and centered at all positive and negative integral values of x and y. This arrangement corresponds to a rectangular array with an interelectrode distance of unity. Table 1, reproduced from our report of 1966, gives the field intensity values at depths of 0.5 and 1.0 interelectrode distances, respectively; and for electrode edge sizes of 0.1 and 0.5 of the interelectrode distance. The two points chosen for computation of field intensity are (1) $x = 0$ and $y = 0$; this is directly under an electrode, where field intensity will be a maximum at a given depth; (2) $x = 0.5$ and $y = 0.5$, which is a point equally centered between four neighboring electrodes. It is also the point for which the field is a minimum at the same depth. The field intensity is normalized to 1 for z = infinity, that is, to the field intensity value at which the multi-electrode appears as a single continuous plane electrode.

TABLE 1

Maximum and Minimum Field Intensity as a Function of Depth and Electrode Size; Infinite Rectangular Electrode Array

Depth	Edge size = 0.5		Edge size = 0.1	
	$z = 0.5$	$z = 1.0$	$z = 0.5$	$z = 1.0$
$x = 0$; $y = 0$	1.129	1.005	1.230	1.008
$x = 0.5$	0.909	0.995	0.876	0.993

The computation in Table 1 shows that for an electrode whose edge size is half an interelectrode distance, at a depth of half an interelectrode distance, there is about a 20 percent difference between maximum and minimum field intensities. At a depth of one interelectrode distance the difference is less than 2 percent. At the latter depth, in fact, the grid has become degraded to a single planar electrode. When the edge size is decreased by a factor of 5, and electrode area decreased by a factor of 25, the results turn out to be substantially the same: the difference between maximum and minimum intensity is about 25 percent at a depth of half an interelectrode distance, and about 1 percent at a depth of one interelectrode distance. We also calculated the outcome when the electrode size was reduced by a factor of 10 and the electrode area by a factor of 100. There was little change from the results just presented.

These calculations of field penetration are useful in helping us decide on an acceptable minimum electrode density. Thus, for a density of 400 per square centimeter, the interelectrode distance is 0.5 mm. If the cortex is considered homogeneous, then the differential field effects should penetrate 0.2 to 0.3 mm, the distance from the surface at which the nearest neuronal bodies are located. But the cortex is not homogeneous, and inhomogeneities which provide special paths between electrodes and electrically excitable regions like dendrites or cell bodies would permit a greater density to be still more effective. Not all inhomogeneities are favorable, of course, and surface fluids and blood vessels will tend to pool signals from a number of electrodes, making a higher density less effective.

The finding that the area of an electrode is not critical for depth penetration is an important one. It suggests that for a given interelectrode distance the size of the electrode disc be large, that is, that it have a diameter equal to about half the interelectrode distance. The reason is that smaller electrodes will have higher resistances, require higher voltages, and will tend to give higher rises in local temperature, than larger electrodes. And the smaller electrodes will have stronger, possibly deleterious, electrochemical effects. Higher voltages also impose more difficult system and component design specifications.

One interesting calculation which illustrates the results of the depth penetrations studies just described is given in Fig. 9, drawn from our 1966 report. Here, field intensity is shown as a function of depth when 20 selected electrodes of the infinite array are stimulated. The stimulated electrodes are organized in two 2 x 5 (bar) arrays. For Figure 9(a) the two-bar arrays are next to each other. Figure 9(b) and 9(c) show them moved away from one another by 1 and 2 interelectrode distances, respectively.

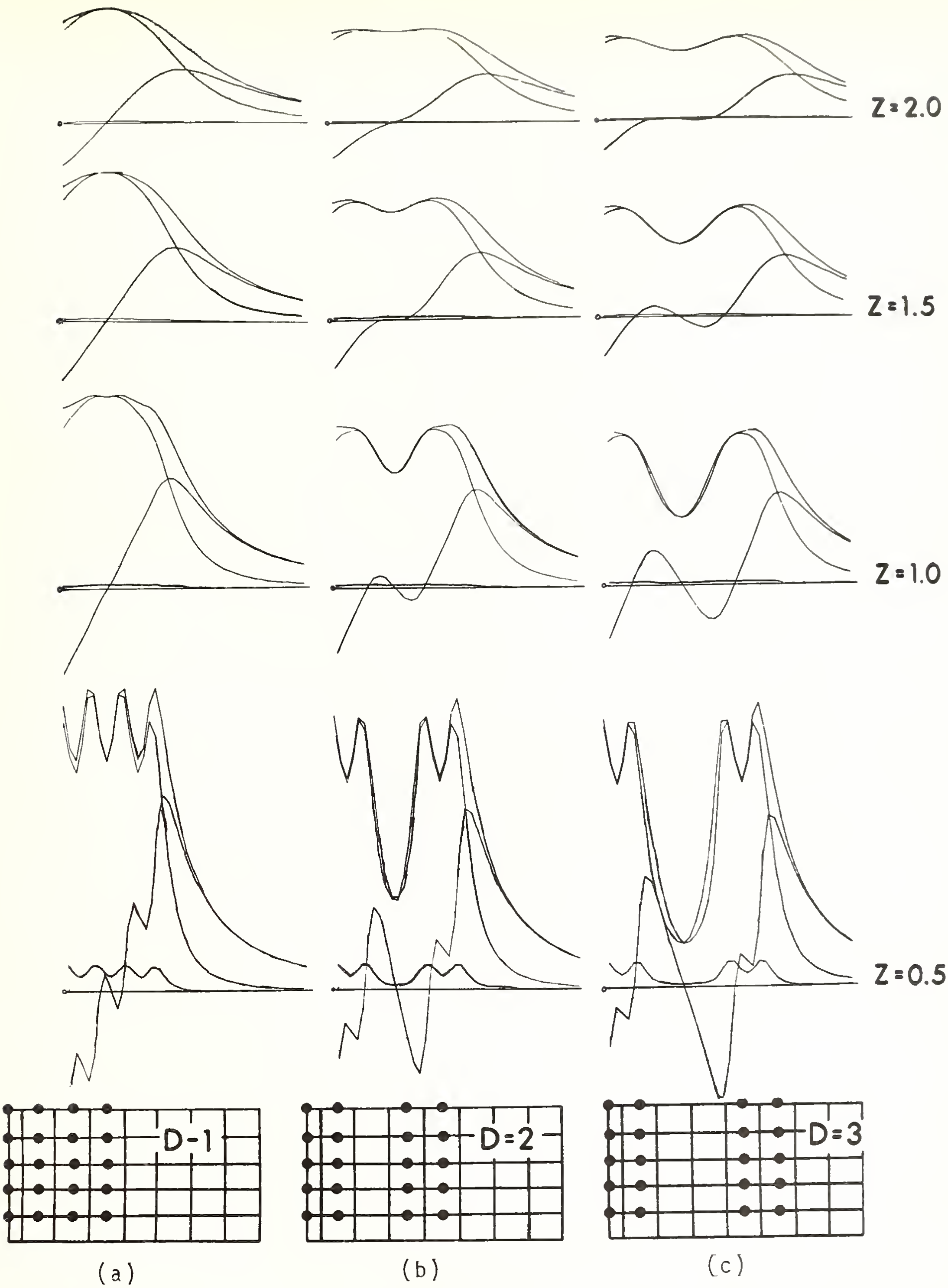


Figure 9. Computations of Current Density as a Function of Electrode Arrangement.

The charts in Fig. 9 show the variation of the scalar value of the field intensity and its x, y, and z components along a line parallel to the x axis and almost at the midline ($y = 0.1$). Computations were made for the four different depths shown. The electrodes are assumed to be point sources. The effect of individual electrodes is apparent at a depth of 0.5-interelectrode distance, but it disappears at a depth of 1.0. The separation of the bars at a depth of $z = 2$ effectively disappears when their sides are separated by a distance of 2; but it is clearly visible once again when the separation rises to 4.

A Review of Physiological Stimulus Parameters. Brindley and Lewin's report (5) gives systematic observations of threshold voltages for stimulation of the human visual cortex over a range of stimuli varying in frequency and duration. We can compare these with the data obtained by Libet, et al. (22), for stimulation of human somatosensory cortex. Figure 10 is a reproduction of Libet's Fig. 4, on which we have superimposed computed data from Brindley's paper for comparison purposes. Note that the estimate of threshold currents in the Brindley experiment is obtained by dividing the voltage by the passive resistance of 3000 ohms. The counter EMF generated in the platinum saline interface could lead one to overestimate the currents involved by as much as 10 percent for the longest pulses (1000 μsec), and 5 percent for the shorter pulses (100 μsec). The stimulus rate for the Brindley experiment is 30 pulses-per-second, which would tend to give larger values than the 60 pps of Libet's subjects. According to Libet's data, this difference could increase currents by as much as 50 percent, whereas in Brindley's data the increase would be limited to about 10 percent. Brindley has also indicated in a private conversation that the stimulus train durations are about 0.5 second, which contrasts sharply with Libet's train duration of 5.0 seconds. (This alone could account for an increase of 10 to 25 percent.) A final difference is found in the electrode size: 0.8 mm for Brindley, 1.0 mm for Libet. This factor would tend to reduce the currents in Brindley's experiment by a few percent; perhaps by as much as 10 percent (but see the discussion below of Libet's results). All in all, it would seem that differences in experimental methods could account for an increase from as little as 10 percent to as much as 100 percent from Brindley's to Libet's data. One of Libet's subjects required about twice the current of the other two; Brindley's results give values after corrections of about this same high level. Figure 11 (Fig. 3 of Libet's paper, upon which we have superimposed some data computed from Table 2 in Brindley's paper) shows that for the atypical Libet subject, the level is more than twice that of other subjects for a comparable stimulus at 60 pulses/second of 0.5-second duration (2.6 mA versus a range of 0.6 to 1.2 mA for seven other subjects). Brindley's data thus tend to be higher than Libet's data by a factor of 3 to 4. We can note the large variation in individual responses among Libet's subjects, but we

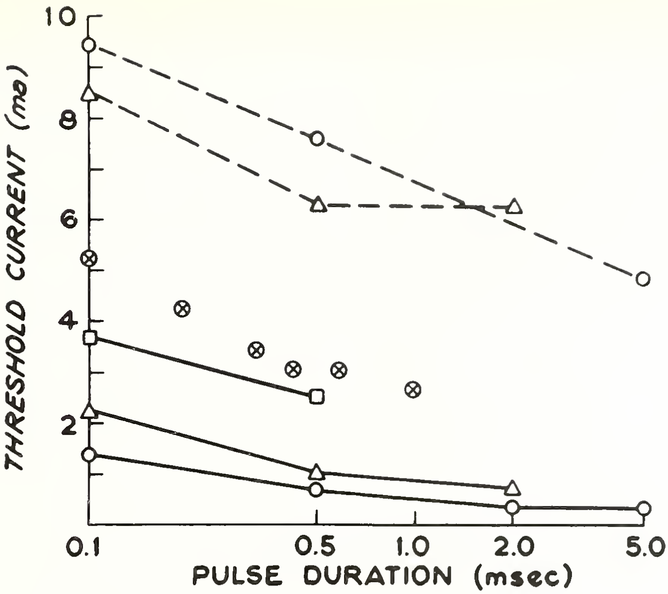


Figure 10. Libet's Figure 4 with Superimposed Data Computed from Brindley and Lewin.

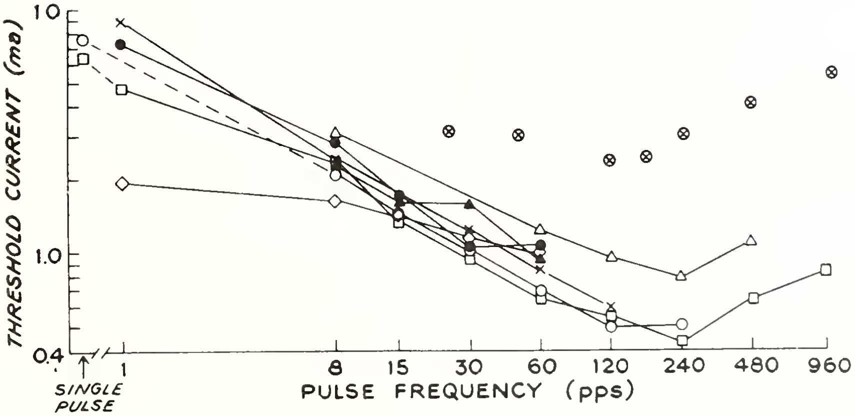


Figure 11. Libet's Figure 3 with Superimposed Data Computed from Brindley and Lewin.

cannot tell whether the difference between Brindley and Libet's results is due to individual variability or to differences between the visual and somatosensory cortex.

Larger values are also suggested for Brindley's subject in Fig. 11. The computed Brindley points are based on a passive resistance of 3000 ohms, and a reduction of his reported values for 30 μsec by a factor of 9/28 (this is the ratio of voltages for 500-μsec to 30-μsec pulses in Brindley's Table 1. This correction was made for comparison with Libet's data, which are for 500-μsec pulses.).

The decline in threshold stimulus as the pulse frequency was increased for Brindley's subject from 25 to 100 pps is not as large as the decline for Libet's three subjects from 30 to 120 pps, namely from 30 percent to 50 percent. But Brindley's data are consistent with Libet's data if we take into account substantial subject variability, already noted for Libet's subjects.

Libet's experiments generated some data on the effect of varying the number of stimuli in a pulse train. The threshold current required for single stimuli in two subjects required only about 9 mA for 100-μsec pulses, and about 7 mA for 500-μsec pulses (Fig. 11). In one experiment, in which the pulse frequency was 30 and pulse duration 500 μsec, when the number of pulses was increased for this subject from 2 to 4, the threshold current was reduced from 3.8 mA to 2.4 mA, or close to 40 percent. For still longer trains, the threshold current was gradually reduced to 1.5 mA. In a second subject who had higher thresholds, when the frequency was increased from 10 to 30 pps, the current threshold reduced from 4.3 to 1.9 mA. This large difference between the two subjects makes inference difficult, but the data suggests that for a limited range of values the threshold current may be reduced in inverse proportion to the number of stimuli.

Figure 12 contains some estimated parameters of minimal threshold stimuli as a function of pulse duration for long trains, computed from both Brindley and Libet's data. Brindley's results have been used for the relation between stimulus duration and peak current, for the long trains of pulses at 30 and 120 pps; Libet's data have been used for the absolute values. Since we recognize that Brindley's current values were three to four times higher than the values from Libet's experiments (used in constructing this figure) these data were labeled as *minimal threshold parameters*.

The data on peak and mean power, and heat-generated-per-pulse ($i^2 R \Delta t$) were computed by assuming a 2000-ohm resistance for the 1.0-mm diameter electrode that Libet used. The value of the resistance R of a circular disc electrode is 0.25 ρr^{-1}, in

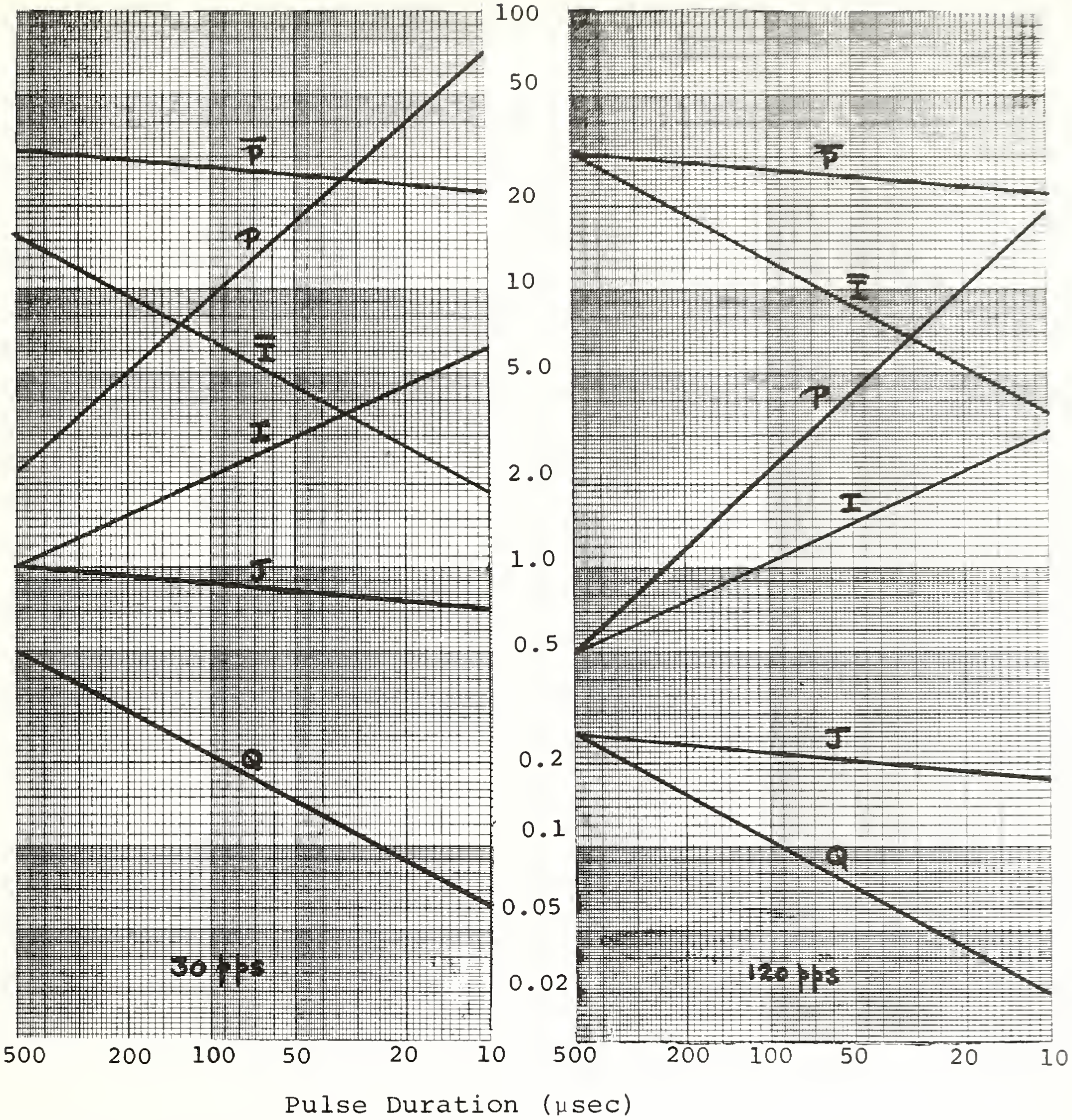


Figure 12. Estimated Parameters of Minimal Threshold Stimuli as a Function of Pulse Duration for 30 pps and 120 pps Long Trains.

Peak current (mA, milliamperes) = I

Mean current (μA, microamperes) = $\overline{I}$

Peak power (mW, milliwatts) = P

Mean power (μW, microwatts) = $\overline{P}$

Microcoulombs-per-pulse = Q

Microjoules-per-pulse = J

which ρ is the resistivity and r is the radius. If we use a commonly accepted value of 300 ohms cm for cortical tissue, this would have given a value of 1500 ohms. The same value of ρ would give a resistance of 1875 ohms for the electrode Brindley used, but his measurements give a value almost twice as high as this. We do not know whether this difference is due to added membrane resistance in a chronic implantation, or to some defect in electrical measurements. In any event, we used the higher figure, rounded off to 2000 ohms, instead of 1500 ohms, for the computations based on Libet's data.

Figure 12 shows some facts useful for system design. For long trains, peak current and peak power increase sharply as pulse duration is increased. Yet the mean current is sharply reduced, and this would correspond, for trains of similar duration, to the quantity of electricity per stimulus.

It is also significant, as these data lead us to infer, that both mean power and mean energy-per-pulse are affected very little when pulse duration is changed by a factor of 50. Still more interesting is that mean power is not affected by pulse frequency, although the energy-per-pulse is substantially higher at the lower frequencies. In fact, the energy-per-pulse would be inversely proportional to frequency, in the range of 8 to 240 pps, according to Libet's data. Peak currents are increased as the pulse rate is reduced from 120 to 30 pps; the mean current is increased.

Figure 12 also suggests that a mean power of 20 to 30 μW is minimal for threshold parameters. If the pulse currents actually required were three to four times higher than this, mean power could then be increased by a factor of about 10 to 15. This would bring the total requirement within the range of 0.2 to 0.5 mW. We have included estimates on single pulses, derived from Libet's data, which suggest that in conjunction with his limited data on stimulus train-length effect, it may be possible to reorganize stimuli into shorter pulse trains with the same mean power requirements. For example, the mean energy-per-pulse for single pulse stimuli of 100 μsec duration is about 15 microjoules. If three such pulses were delivered per second, the mean power would be about twice that of longer trains. We noted earlier that one of Libet's subjects required only four pulses of 2.4-mA current for threshold stimulation. This implies a requirement of 25 microjoules for four 500-μsec pulses, with the likelihood that still less would be required for 100-μsec pulses. Note that the single pulse stimulus of 500-μsec duration required 50 microjoules.

Neither Libet nor Brindley has published current or voltage requirements for suprathreshold stimulation, but it is quite likely that both groups have data bearing on the question. It is not clear from the literature on animal experiments just what the appropriate stimulus parameters are that should be modified to increase subjective intensity. The central nervous system, commonly responds to increased external stimuli by the peripheral sensory neurons grouping their action potentials into high-frequency trains without substantially altering the mean firing rate. How this affects the appropriate cortical cells is not certain, although synchronous firing by a number of peripheral neurons could result in a similar pattern of firing of a group of cortical cells. Here, the work of Landgren, Philips, and Porter (23) is particularly relevant. In baboon, they showed that single stimuli of 200-μsec duration and 0.4-mA current, delivered by a cortical surface electrode, could stimulate neurons immediately under the electrode; and that increases in current to 1 to 2 mA would stimulate cortical neurons in a disc roughly one centimeter in diameter. Their result suggests that subjective conscious sensation requires the synchronous firing of a population of neurons, probably repetitively (because of the much larger currents, of about 8 mA for single pulse stimulation, required in Libet's studies). Libet's subjects also reported clearly different sensations produced by single stimuli and short trains, as compared to long trains. Libet's work pointed to the larger currents required for conscious sensation in observing that subthreshold stimuli in the sensory cortex could produce motor responses. It thus appears unlikely that intense sensations would require currents more than three to five times larger than threshold stimuli, or mean power more than 10 to 20 times greater than threshold. It is also possible that much smaller increases might be satisfactory. Hypothetically, if a train of two 100-μsec pulses at 10-mA current, with a frequency of 120 pps, might represent threshold; then a train of 10 pulses might represent maximal stimulation. In this example, there is an increase of five times in the mean power required. It is also quite possible that one might obtain increased light intensity through minimal changes in mean power, merely by changes in the train frequency.

So far, we have discussed stimuli delivered through a single electrode. When many electrodes are involved, the current-per-electrode is likely to be much smaller. Libet reported the effect on threshold currents of increasing the size of the electrode from 1 mm to 10 mm diameter. Although the area increased 100-fold, current increases range only from 1.5 to 9 times, with a mean of 4.1; currents ranged from 3.3 to 10.8 mA. One would expect the resistance to decrease inversely to radius here, by a factor of 10. But the power consumption (which is proportional to I^2R) actually decreased substantially, for two cases, when currents were increased by a factor less than 2. In fact, for the mean 4.1-mA increase in current, the increase in power consumption would amount only to 65 percent.

The explanation for these results is not immediately clear. It might be that the most sensitive local group of neurons responded within the larger area. Or, there may be an effect due to spread of the electric field, reported by Landgren, Phillips, and Porter. We might also suggest a spatial-integration effect in the cortex due to stimulation of many neuronal processes.

Whatever the explanation might be in detail, it appears that total current required to stimulate an area of one square centimeter at threshold level in the visual cortex might be only four times that of a single electrode. If this current were divided among 400 electrodes, the current-per-electrode would be 1/100 that of a single electrode. For 4000 electrodes and an area of 10 square centimeters, the threshold current might be only six times that for one square centimeter. Maximal stimulation might require perhaps a further four-fold increase in current. It is therefore possible that simultaneous maximal stimulation through all 4000 electrodes would require no more than 100 times that current required for threshold stimulation of a single electrode. In the section which follows, on temperature rise, we shall discuss further the implications for power requirements.

Some Volume, Current, Resistance, and Heat Relationships: Single Electrode. Consider the case of a single electrode at the surface of a medium assumed to be homogeneous, which has a resistivity ρ_o of 500-Ωcm^{-1} (after Brindley), a heat conductivity k_o assumed to be 5 x 10^{-3} watts $^oC^{-1}$ cm^{-1}, a heat capacity c_o the same as water (c_o = 4.2 watts x sec x cm^{-3} x $^oC^{-1}$). Finally, assume a heat absorption factor a_o, due to blood circulation, in which a_o = 4.2 x 10^{-2} watts cm^{-3} $^oC^{-1}$.

The basic heat flow equation has the form:

$$k_o \Delta 2T + i^2 \rho_o - a_o T = c_o \frac{\partial T}{\partial t}; \tag{1}$$

where $k_o,\ \rho_o,\ a_o,\ c_o$

are parameters of the medium previously defined and estimated, T is temperature, and i is local current density.

To simplify discussion and solutions, assume a half-sphere electrode of radius r_o instead of a disc of radius r_1, where $r_o = 2r_1/\pi$, so that the disc and half-sphere electrode have the same resistance R_o, with an area 20 percent less for the latter than that of the disc electrode. If V_o is the electrode voltage and I_o the total current, then we have the following useful relations:

$$R_o = V_o I_o^{-1} = \rho_o (2\pi r_o)^{-1} = \rho_o (4r_1)^{-1};$$

$$i^2 \rho_o = I_o^2 \rho_o (2\pi r^2)^{-2} = I_o V_o r_o (2\pi r^4)^{-1}; \; i = I_o (2\pi r^2)^{-1}.$$

Assuming spherical symmetry, Equation 1 can be put in the form:

$$(2) \qquad k\frac{\partial^2 U}{1\partial x^2} + b_o x^{-3} - a_o U = c_o \frac{\partial U}{\partial t}$$

where

$$k_1 = k_o r_o^{-2} = 1.2 \times 10^{-2} r_1^{-2};$$

$$b_o = P_o (2\pi r_o^3)^{-1} = 0.63\ P_o r_1^{-3};$$

$$P_o = I_o V_o = I_o^2 R_o = V_o^2 R_o^{-1};$$

$$U = Tx;\ x = r/r_o.$$

In the above equation, the spatial dimension has been referred to the electrode radius; at the surface of the electrode, $x = 1$. We note that as the radius gets smaller, heat conduction gets more important in terms of this space unit. This is as expected. P_o is seen to be power.

Estimates of various effects can be obtained easily from Equation 2. First, consider temperature rise ΔT during a short pulse of duration Δt. For very short pulses a satisfactory estimate can be obtained by ignoring both conduction and absorption; then the range of validity of such an estimate can be checked if necessary. Thus,

$$(3) \quad \Delta T = b_o\ \Delta t\ c_o^{-1}\ x^{-4};\ \Delta T_{\max} = 0.15\ P_o\ t\ r_1^{-3} \text{ for } x = 1.$$

It had been noted previously that $P_o \Delta t$ (the J of Fig.12) is approximately independent of pulse duration at a fixed frequency. For 120 pps stimuli, $J = P_o \Delta t \simeq 0.2\mu$joules. For an $r_1 = 4 \times 10^{-2}$ cm (after Brindley), Equation 3 gives T max $\simeq 5 \times 10^{-4}$° C. Even with a forty-fold increase in stimulating current, the temperature would rise less than 1° C. It is, therefore, unnecessary to examine the offset effected by taking into account absorption or conduction.

In the case of continued stimulation, an estimate of the maximum temperature rise can be obtained by examining the steady state solution $T/\partial = 0$ of Equation 2. As a first step, absorption will be ignored. Also, in place of the coefficient b_o, one must use a $\overline{b_o}$ based on a mean power, $\overline{P_o}$, which is equal to $D_o P_o$, where D_o is the duty cycle.

Equation 2 is readily integrated under these assumptions and the result is:

$$(4)\quad T = \overline{b_o}\,k^{-1}\,(x^{-1} - 0.5x^{-2});\; T_{\max} = 25\,\overline{P_o}/r_1 \text{ for } x = 1.$$

From Fig. 12, we note that $\overline{P_o}$ is independent of pulse frequency and duration in the range 30 to 120 pps, and it is approximately equal to 25 μW. For a radius $r_1 = 4 \times 10^{-2}$ cm, we find T max ≈ 1.5×10^{-2}° C.

Thus, if current levels were increased by a factor of 10 and power accordingly by a factor of 100, the maximum temperature rise would be about 1.5° C. What is the effectiveness of absorption? To estimate it, consider the ratio of the heat absorbed to the heat being generated (i.e., of the third term to the second). It is:

$$(5)\qquad 3.5\, r_1^{\,2}\,(x^3 - 0.5x^2) \simeq 3.5\, r_1^{\,2}\, x^3 \text{ if } x > 2.$$

For $x = 3$ and $r_1 = 4 \times 10^{-2}$, the ratio equals about 0.5, indicating that absorption would tend to dominate at about this distance. Since the temperature at this distance is about 60 percent of the surface maximum according to Equation 4, then to a first rough approximation it is seen that absorption will tend to cut the maximum temperature by a factor of about 0.5. In fact, if one takes into account only absorption, the steady state solution for Equation 2 is:

$$T = 0.63\,\overline{P_o}\,a_o^{-1}\,r_1^{-3}\,x^{-4}.$$

For the example previously cited, the temperature at $x = 4$ would be only 10^{-3}° C, justifying that absorption would reduce T max by about half.

It is difficult to generalize these results to the case of electrodes of smaller radii, because there are no clear guides to the current and power requirements for stimulation by smaller electrodes. If neuronal bodies or processes to be affected are at a distance of the same order of magnitude as, or less than, the electrode diameter, we can expect Libet's basic finding to hold, and less power would be required as the radius of the electrode is decreased--but only slightly. Thus, if P_o and $\overline{P_o}$ were decreased by a factor of 0.9, while r_1 was decreased by a factor of 0.3, then ΔT max and T max would increase by factors of 33 and 3, respectively. This would give quite a considerable range of stimulus levels, but the range is far more restricted than for larger electrodes, particularly regarding the temperature rise during the pulse. We might then try to examine the estimate given for ΔT in Equation 3, and ask whether it is seriously reduced by taking into account heat conduction and/or absorption. If we compare the first and third terms with the second term in Equation 2, for heat generation, we find that for a radius $r_1 = 1.3 \times 10^{-2}$ cm, conduction would begin to remove only about 10 percent of the heat at the surface after a pulse duration of 2 msec, while absorption becomes effective even more slowly. In the range of pulses which we have been considering, neither of these factors affects our estimates.

Temperature Rise: Multiple Electrodes. We shall use Libet's data to estimate the temperature rise for simultaneous stimulation of the entire area A, of 10 square centimeters. In a first-order estimate, the problem can be divided into two parts. First, we shall deal with current flows and temperature rises up to the surface of the electrode as though the electrode were continuous. Second, we shall add an additional temperature rise due to the local currents from individual electrodes.

This situation can be approximated by considering the continuous electrode to correspond to a disc of $r_1 \simeq 1.8$ cm. To this approximation we add local effects in the immediate neighborhood of the electrode. The concave curvature would tend to give higher values of current density and temperature, but this will be offset by an irregular shape and, for a first approximation, appears adequate.

In accordance with our discussion earlier of Libet's results, we shall assume that approximately 60 times as much current is required for minimal threshold stimulation as in the case of a single electrode. For a 100-μsec pulse duration and 120-pps frequency, this would require 60-mA current flow from the entire electrode (see Fig. 12). For a tissue resistivity of 300 ohm/cm, this means an electrode resistance $R_o' \simeq 40$ ohms, and a driving voltage $V_o' \simeq 2.5$ V. Peak power would be about 150 mW, mean power about 2 mW. Inserting these values into Equation 3, we find that ΔT max is less than 10^{-6}° C. This temperature rise is insignificant unless currents are increased by a factor of 1000.

Regarding the steady state temperature rise under conditions of continued stimulation, only the effect of absorption appears important. Integrating Equation 2 gives

$$(6) \qquad T = \overline{b_o'}\, a_o^{-1} \times{}^{-4}; \quad T \text{ max} \simeq 5 \times 10^{-3}$$

Current levels could therefore be increased by a factor of 15, for a temperature rise of about 1° C.

Individual electrode currents would have been reduced by a factor of 0.01 for the case of the multiple electrode versus the single electrode stimulation condition. Peak and mean power would be reduced, accordingly, by a factor of 10^{-4}. We can thus infer from the earlier computations for single electrodes that corrections for local heating effects are negligible.

PRESENT STATUS OF SYSTEM AND COMPONENT DEVELOPMENT AND PLANS FOR FURTHER WORK

For reasons already set forth, it appears to us that only a high-density electrocortical prosthesis should be attempted, since low- and medium-density systems may function well enough by mechanical or electrical stimulation of the skin. It appears that given adequate funding and necessary cooperation from industrial facilities, it will be possible to build a high-density prototype prosthesis within two to three years. At the present time a figure of between 4,000 and 10,000 points appears to be the practical limit of a prototype prosthesis which could be constructed within three years. Technological limitations of matrix size have been significantly reduced by advances in integrated microcircuitry and further improvements are to be anticipated. The fact that cost of production does not increase in proportion to matrix size is of great significance. Thus, on the basis of present estimates from industry, a ten-fold increase in number of stimulus circuits (from 250 to 2500) would not quite double the cost. This is an estimate based on a modular prototype development. Actual production costs in quantity would be far lower. It may be concluded that there is no advantage to be gained either in cost or simplicity in reducing matrix size in a prototype system involving integrated circuitry. Thus, once the decision has been made to proceed with the development of suitable components, the prosthetic system may be designed to provide the maximum number of points which can be physiologically utilized, which is estimated to be 4,000 on each half of visual cortex.

The discussion of system and component development which follows is limited to the two most difficult components: the thin-film multiple electrode containing 4,000 platinum electrodes insulated by Teflon which will have the flexibility to follow the surface contours of the cortex; and the decoder-stimulator microcircuit which is to be implanted outside the skull, but beneath the skin, and will receive code and power by induction.

Stimulating Multiple Thin-Film Electrode. Over a year ago Westinghouse (Baltimore) had succeeded, in collaboration with us, in preparing printed circuit thin-film electrodes with platinum-plated gold sandwiched between Teflon. They had not then devised a method for effective exposure of the electrode contacts on a large scale basis. At that time they found it impossible to provide support for this project out of company funds and estimated that completion of a satisfactory electrode would cost in the order of $100,000.

In addition to the above work, other approaches to thin-film platinum-Teflon electrodes are being explored as possibly cheaper than the effort involved in completing the Westinghouse project, either manually exposing electrode contacts one by one, or perfecting technology for exposing the electrodes automatically. In any event, the work to date shows that for a sum of up to $100,000, and possibly substantially less, sufficient electrodes and thin-film circuits to construct at least three 4,000-point prototype systems can be fabricated. All electrode designs which have been developed or are still being considered are modular. Electrodes are organized from 32 to 64 contacts on 0.5-mm (20-mil) spacings at the end of a flexible Teflon tape. At the other end of the lead tape, the leads are spaced on 3-mil or larger centers, depending on requirements for bonding to microcircuitry. The corners of the tapes of the electrode ends which have been designed, both as squares and as triangles, can be welded together to cover an irregularly shaped cortical surface.

Decoder Design and Fabrication. Our basic designs depend upon serial transmission of a code to a separate switch for each electrode. In the simplest design each switch is either closed or open. A pattern of switch closures can be set within 0.5 to 8 msec for all 4,000 switches. All switches within a microcircuit module are connected to a common stimulating source. From a combined analysis of the Brindley and Libet data, it would appear that pulses of 100 μsec duration, presented at a frequency of 100-200/sec., would provide optimal stimulation. On the basis of our calculations given previously maximal stimulation on a single electrode may require a peak power of 200 mW and mean power of 2 mW. If the Libet effect is fully present, a group of 500 electrodes will require no more than 400 mW and 4 mW for peak and mean power respectively. If spatial summation effects are minimal, these values should not exceed 2 W and 20 mW for 500 electrodes.

One company has developed a preliminary proposal based on this approach, providing for a separate MOS flip-flop at each switch. Their proposal envisions a microcircuit module containing 128 points and connected to two 64-lead, or four 32-lead platinum-Teflon electrode tapes. The mean switching power required by this design would be between 50 to 100 mW for 4,000 points. Peak power would be 20 to 150 times higher, depending upon switching speeds. Preliminary estimates for this design show that modules for three prototype systems of 4,000 points each would cost on the order of $500,000. Other designs are being explored which are not only likely to cost less, but also allow separate modulation of the amplitude at each switch point.

One of the factors leading to higher costs of microcircuitry has been the necessity, as a result of Dr. Brindley's experiment with his first subject, to provide for higher currents than originally contemplated. We have been discussing with Dr. Brindley the possibility of his performing additional experiments oriented particularly toward establishing those maximum stimulus parameters which most affect system costs, e.g., the requirement of up to 40 volts stimulation per point.

Combined Electrode and Switching Microcircuitry. We have from the beginning of the study examined periodically the feasibility of incorporating the switching microcircuitry directly with the cortical electrode. Within the past two years, progress in MOS/FET circuit technology has permitted the preparation of small enough chips to incorporate the required decoder-stimulator circuitry within a package less than 0.5 mm thick. While such an electrode would lose the advantage of flexibility, each chip could be small enough to contact the cortex underlying it, and curvature of the electrode would be obtained at the junctions among chips. The advantage of such a design is great, since the conversion from serial input of the code to the parallel switching pattern would occur within the electrode, thus sharply reducing the number of leads required, from receivers to intracranial electrode, which would pass through the skull. Until recently these circuits have been packaged in steel and ceramic cases which could not be implanted intracranially, although they could have been coated with Silastic for subcutaneous implantation, due to their size. Recently, however, there have been apparently successful experiments in packaging these circuits in a new plastic material, which when coated with Silastic, would permit development of encapsulated chips of the required size for cortical implantation. This work has not reached the commercial stage, but has been sufficiently promising to be considered as a serious possibility for our initial prototype system. Accordingly, we are pursuing a design which would provide Silastic electrode tapes with platinum electrodes protruding from microcircuits embedded therein. Each tape would contain approximately 500 contacts and would require only six input leads. For the 4,000-contact system less than 50 wires would have to be brought through the skull to the subcutaneous code and power receivers. If this design can be implemented within the time schedule set for the thin-film system it would be preferable, due to its relative simplicity and the likelihood of substantially lower cost.

Other components present no major challenge. A prototype transmitter-receiver set has been constructed for measuring temperature rise of intervening tissue as a result of transmission of stimulus power through the skin. Estimated power requirements are high, and the results of these studies will be employed to insure safety of the system. Other safety studies now under way include a check on the theoretical temperature rise studies previously summarized. Under the worst conditions, unacceptable temperature rises might occur in a high-density system, although the possibility of spatial summation of stimulating current (the "Libet effect"--see below) would substantially ameliorate this problem by reducing the total power requirements. The theoretical analysis is now being checked empirically in animals, employing a special platinum platinum-alloy stimulating-thermocouple electrode which has been developed for this purpose. The experiments, both acute and chronic, are employing rat cortex, and stimulus parameters equalling and exceeding the values predicted from the human data obtained by Brindley will be evaluated.

Final selection and adaptation of the camera and design of the encoder are awaiting decisions about the thin-film electrode and decoder design. During the past four years there has been substantial progress in miniature Vidicon camera (Sony) and matrix-type sensing devices (Westinghouse, R.C.A., and A.T. & T.). The relative merits and availability of the various sensing devices at the estimated date for prototype system completion (about two years) are being continually evaluated. Selection can be deferred for at least a year, and depends upon the rate of development of other more critical system components.

The detailed design of the encoder which will translate output from the camera into the pulse code to be transmitted through the skin (to set up the pattern of cortical stimuli) awaits final decision on decoder design. The prototype will be fabricated from existing microcircuit components rather than employing specially designed integrated circuitry, as is required for the intracranial components. This will permit maximum flexibility at relatively low cost, but will comprise a larger extracranial package than will ultimately be possible. Special microcircuitry will be fabricated only after the initial studies on the prototype prosthesis have been carried out with a human recipient.

Financial Requirements and Time Schedules. We have presented our designs and specifications to a number of the leading electronic companies. It would appear that the total project could be completed within five years, of which the first three would be required for fabrication of components and assembly and testing of the entire system. The financial requirement is of the order of one million dollars. A provisional schedule based on separate electrode and microcircuit components follows. If the electrodes can be directly integrated with the decoder-stimulating microcircuits, then camera fabrication would be advanced and a separate and simpler prototype prosthetic would be developed for skin stimulation tests (see Fig. 13).

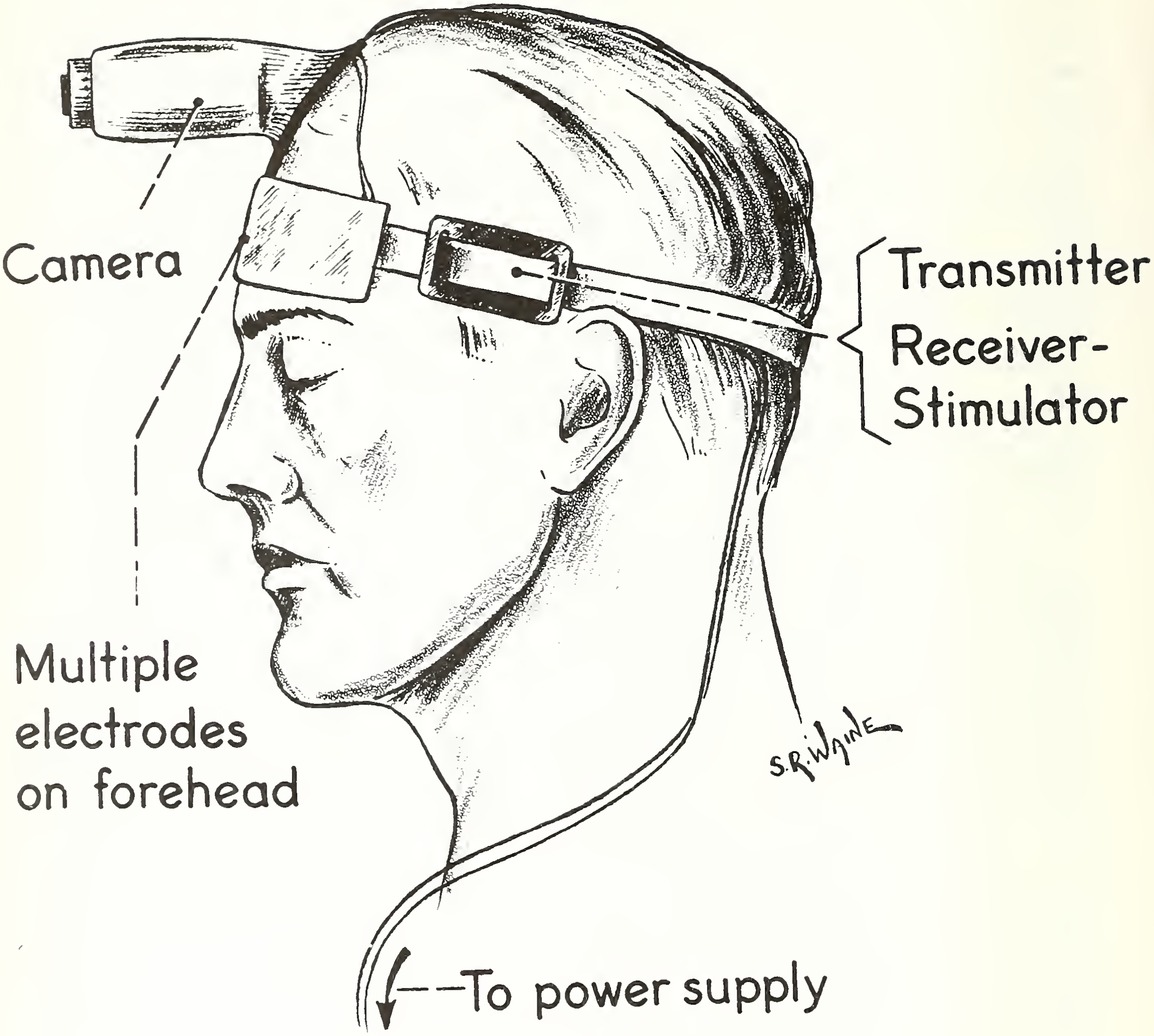


Figure 13. An Electrocutaneous Prosthesis Employing an Electrode Matrix Overlying the Forehead. The camera and encoding system utilize components required for the cortical prosthesis.

Electrocortical Visual Prosthesis System

Schedule of Fabrication and Evaluation

	Fabrication Program			Evaluation Program
	Completion and review of all designs for cortical system			Elementary skin experiments
1970	Letting of subcontracts	Safety tests of components and assembled cortical system in animals	Special designs and fabrication for skin experiments	Test and use of primitive skin prototype systems
1971	Fabrication of all major components--electrode-decoder-stimulator, camera, encoder, transmitter-receiver sets, and power supplies			
1972				Test and use of sophisticated skin prototype system
	Assembly of system			
1973	Refinement of external systems and development of new designs			Test and use of cortical system with human recipient(s)
1974				

REFERENCES

1. W. J. S. Krieg. *Functional Neuroanatomy.* New York: Blakiston, 1953.

2. J. Button, and T. Putnam. "Visual Responses to Cortical Stimulation in the Blind," *Journal Iowa Medical Society*, Vol. 52, pp. 17-21, 1962.

3. T. Shipley. "Cortiogenic Vision: A False Hope for the Blind," *American Journal of Ophthalmology*, Vol. 47, pp. 358-63, 1959.

4. T. Shipley. "Conceptual Difficulties in the Application of Direct Coded Input Signals to the Brain," in L. L. Clark, (ed.) *Proceedings of the International Congress on Technology and Blindness.* New York: American Foundation for the Blind, Vol. II, pp. 247-65, 1963.

5. G. S. Brindley and W. S. Lewin. "The Sensations Produced by Electrical Stimulation of the Visual Cortex," *Journal of Physiology*, London, Vol. 196, pp. 479-93, May 1968.

6. H. G. Vaughan, Jr. and H. Schimmel. *Preliminary Study of the Feasibility of Electrocortical Prosthesis.* Progress Report. VRA Grant No. RD-2064-S. New York: Albert Einstein College of Medicine, 1965.

7. H. G. Vaughan, Jr. and H. Schimmel. *Preliminary Study of the Feasibility of Electrocortical Prosthesis.* Progress Report. VRA Grant No. RD-2064-S. New York: Albert Einstein College of Medicine, 1966.

8. H. G. Vaughan, Jr. and H. Schimmel. *Preliminary Study of the Feasibility of Electrocortical Prosthesis.* Progress Report. VRA Grant No. RD-2064-S. New York: Albert Einstein College of Medicine, 1967.

9. H. G. Vaughan, Jr. and H. Schimmel. *Preliminary Study of the Feasibility of Electrocortical Prosthesis.* Progress Report. VRA Grant No. RD-2667-S. New York: Albert Einstein College of Medicine, 1968.

10. H. Asanuma and H. Sakata. "Functional Organization of a Cortical Efferent System Examined with Focal Depth Stimulation in Cats," *Journal of Neurophysiology*, Vol. 30, pp. 35-54, 1967.

11. S. D. Stoney, Jr., W. D. Thompson and H. Asanuma. "Excitation of Pyramidal Tract Cells by Intracortical Microstimulation: Effective Extent of Stimulating Current," *Journal of Neurophysiology*, Vol. 31, pp. 659-69, 1968.

12. O. Foerster. "Beiträge zur Pathophysiologie der Sehbar und der Sehsphäre," *Journal of Physiological Neurology* (Lpz), Vol. 39, pp. 463-85, 1929.

13. F. Krause and H. Schum. *Neue Deutsche Chirurgie.* H. Kutter, ed., Stuttgart: Enke, Vol. 49a, pp. 482-86, 1937.

14. W. Penfield and H. Jasper. *Epilepsy and the Functional Anatomy of the Human Brain.* Boston: Little Brown and Company, 1954.

15. P. M. Daniel and D. Whittenridge. "The Representation of the Visual Field in the Cerebral Cortex in Monkeys," *Journal of Physiology*, Vol. 159, pp. 203-21, 1961.

16. R. W. Doty. "Ability of Monkeys to Discriminate Electrical Stimulation of the Brain," *Physiologist*, Vol. 3, p. 171, 1963.

17. D. H. Hubel and T. N. Wiesel. "Receptive Fields and Functional Architecture of Monkey Striate Cortex," *Journal of Physiology*, Vol. 165, pp. 215-43, 1968.

18. G. S. Brindley. "The Number of Information Channels Needed for Efficient Reading," *Journal of Physiology*, Vol. 177, p. 46, 1964.

19. K. S. Lashley. "Patterns of Cerebral Integration Indicated by the Scotomas of Migraine," *Archives of Neurology and Psychiatry*, Chicago, Vol. 46, pp. 331-39, 1941.

20. H. L. Teuber, W. S. Battersby and M. B. Bender. *Visual Field Defects after Penetrating Missile Wounds of the Brain.* Cambridge: Harvard University Press, 1960.

21. A. Hein. "Recovering Spatial-Motor Coordination after Visual Cortex Lesions," in *Proceedings of ARNMD*, p. 47, 1969.

22. B. Libet, W. W. Alberts, E. W. Wright, Jr., L. D. DeLattre, G. Levin, and B. Feinstein. "Production of Threshold Levels of Conscious Sensation by Electrical Stimulation of Human Somatosensory Cortex," *Journal of Neurophysiology*, Vol. 27, pp. 546-78, 1964.

23. S. Landgren, C. G. Phillips and R. Porter. "Cortical Fields of the Monosynaptic Pyramidal Pathways to Some Alpha Motoneurones of the Baboon's Hand and Forearm," *Journal of Physiology*, Vol. 161, pp. 112-25, 1962.

HOW TO BUILD A CLOSED-CIRCUIT TELEVISION READING AID

John H. Kuck

INTRODUCTION

This is a description of a closed-circuit television reading aid which the writer has built for his own use and which might be of interest to some other visually handicapped persons. The television equipment is the same in principle as that used in other closed-circuit magnifiers that have been described in the literature by Genensky et. al. (1, 2), Weed (3), and Potts et. al. (4). The present article discusses selection of television equipment and describes in detail the writer's design for a camera stand. The stand may be advantageous for many people, because it can be easily built at low cost. Dimensional drawings are included from which the stand can be duplicated. Ideas for possible improvements in television reading aids are also discussed.

The equipment picks up the image of a printed page and presents a highly magnified picture of the page on the television screen. As has been pointed out in the aforementioned references, the main advantage of closed-circuit television over direct optical projection of the light reflected from an opaque page is that one can obtain a bright, high-contrast image. Direct optical projection from an opaque page is very inefficient, because a high percentage of the reflected light is lost, and there is a loss of contrast due to the scattering of light from bright to dark areas within the viewing screen. There is also loss of contrast due to stray light reflected from internal surfaces of the projector or from ambient room light. With the television method, on the other hand, printed material can actually have its contrast enhanced. Other subsidiary advantages are that less heat is generated by the television equipment and more flexibility is afforded for the arrangement of the reading aid setup, because the location of the reading material is not fixed by the location of the viewing screen.

One might well ask whether there is a significant advantage in using a projected image instead of a highly magnifying pair of eyeglasses or a reading glass. There is a subtle advantage in the increased visual depth of field that the reader enjoys, when he views a large projected image at a distance. It was this potential advantage that motivated the writer to try the television approach. Reading had become sufficiently difficult so that highly magnifying glasses were required. Reading with them was very tiring, apparently because the small visual depth of field made it necessary to hold the material at precisely the right distance away. It was necessary to stop reading frequently in order to move the page in and out to find the focal plane. These difficulties resulted in considerable eyestrain. In addition, some material having thin lines, small print, or low contrast, was impossible to handle.

Several ophthalmologists and optical-aids people were questioned about the possibilities of opaque optical projectors, but the writer was advised that none of these devices would be satisfactory for him because of low brightness, poor contrast, and inadequate provisions for moving the work. Consideration of the first two difficulties led the writer to the conclusion that some form of light amplification was needed. Possibilities that seemed interesting were: image intensifiers, light-amplifier panels (5), and closed-circuit television. The latter appeared to be the most attractive, because the equipment was commercially available and had been in quantity production long enough so that prices were beginning to come down to reasonable levels.

Considerable thought was given to the design of a camera stand that would have provisions for moving the work and would be convenient to use. The camera is mounted vertically and can be moved horizontally in two directions, by means of cranks, for gross positioning over any part of a large page. (Gross positioning by camera movement rather than by movement of the work was chosen to conserve table space.) In addition, the work tray can be moved back and forth through a distance of two and one-half inches by means of an easy-moving lever. When a column of print is too wide for full display on the screen at the magnification the reader wishes to use, this lever is moved back and forth, as the reader scans each line of print. The two cranks and the scanning lever are located so that they can be reached by the reader, while he is seated in an easy chair. Figure 1 shows the equipment in use.

The construction of the stand is simple enough so that it can be duplicated by a cabinetmaker using ordinary woodworking tools plus a crude metal-cutting tool such as the abrasive-impregnated cloth blade inserted in place of a woodcutting blade on a power saw. It is a stand that one might have built at low cost, if demand for such a device does not justify production by a manufacturing concern.

SELECTION OF THE TV EQUIPMENT

The closed-circuit television system consists of a television camera and a monitor. The monitor may be an ordinary television receiver or a specially designed, high-quality display unit. If an ordinary TV receiver is to be used, some minor modifications may be necessary or desirable. These modifications will be discussed later.

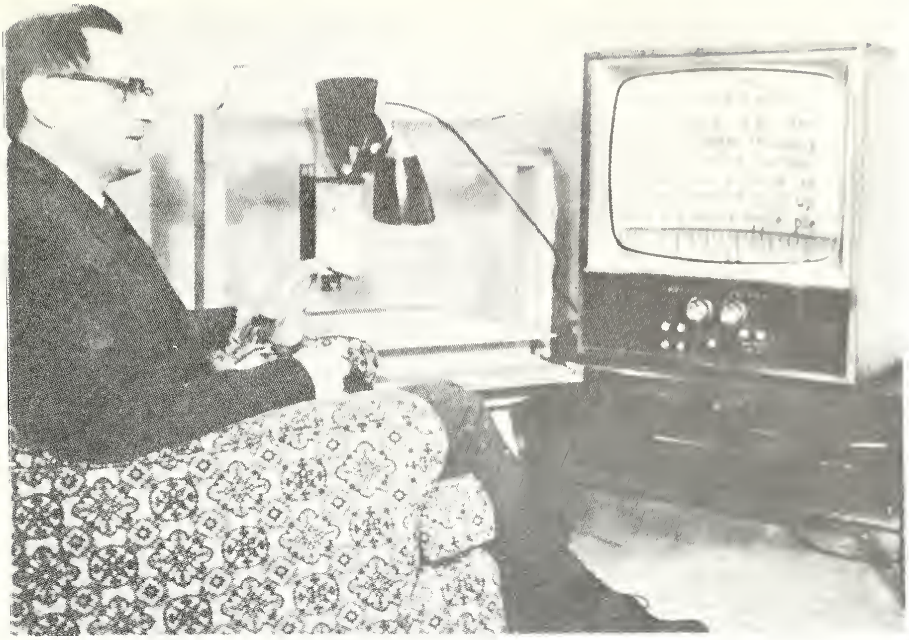


Figure 1. Television Reader in Operation

Before any equipment is purchased, the visually handicapped person who plans to use it should have a demonstration to determine whether or not he can read printed material easily when it is displayed on the television screen. It is a simple matter for a salesman to set up such a demonstration, if he understands the requirements. He will probably need to have a set of lens-extender tubes on hand. (A set can be purchased at a nominal cost.)

For the demonstration, the TV camera can be placed on a table, and a box with printed material (a typical newspaper column about two inches wide) taped to its side is set in front of the camera. The magnification of the system is adjusted so that the picture of the newspaper column just fills the TV screen. To adjust the magnification, the distance from the box to the camera is changed and the camera is refocused. Reducing the distance increases the magnification. My camera required that a five millimeter lens-extender tube be inserted between the camera and the lens barrel in order to bring the camera into focus at the correct distance. When the reading material is uniformly illuminated, careful attention should be paid to uniformity of picture brightness. The controls for good picture quality on both camera and monitor should be easy to adjust. No purchase should be made until the correct combination of camera and monitor or receiver has been demonstrated.

Closed-circuit TV equipment can be supplied by many different manufacturers in a wide range of models and prices. Apparently some low-cost systems can be used effectively for reading aids.

In 1968 the cost of a television camera ranged from about $300 to several thousand dollars. The writer was advised by a distributor that a high-quality system (camera and monitor) satisfactory for the reading aid application would cost approximately $2400. However, careful consideration of the resolution requirements suggested that a much lower-cost system might do an adequate job. Since that time lower cost cameras have become available. Douglas B. Miron, a visually handicapped student at the University of Connecticut is using an Olson Electronics camera as a reading aid. Its cost was $180.00.

The cost of a closed-circuit television system is strongly influenced by the resolution of the system. Paradoxically, if the magnification requirement is increased while the size of the display screen remains fixed, the resolution requirements and the cost of the system go down. This is because the resolution required is proportional to the number of letters (and spaces) that can be displayed in a line of print extending all the way across the screen. This number decreases as the magnification is increased.

The resolution of a TV camera or a monitor is generally specified on the manufacturer's data sheets by a number which indicates the fineness of detail that can be displayed in a television picture.

For example, if a picture being viewed by a TV system were composed of a large number of parallel white lines separated by black lines of equal width, the TV resolution is the maximum number of lines (counting both black and white) that can be seen on the viewing screen in a distance equal to the height of the picture. The horizontal resolution would be determined by counting vertical lines while moving across the picture in the horizontal direction. For vertical resolution, horizontal lines would be counted in a vertical direction. Resolution is sometimes quoted in two ways, at the center of the picture where it is highest, and at the corners where it is lowest. In practice, resolution is measured with the aid of a standard television test pattern. If this pattern is displayed so that it just fills the screen, then one simply looks along a set of converging lines to find the point at which the lines merge. A numbered scale beside the lines indicates the resolution to which this point corresponds.

Of course, if such measurements are to be meaningful, they must be carried out under carefully controlled and standardized lighting conditions. The Electronic Industries Association

(EIA) (6), a standards body of the television industry, has specified how these measurements should be made.

It has been determined that good legibility of letters and numbers on computer displays can be obtained if there are seven resolution elements-per-character in the horizontal direction and nine in the vertical direction (7). Since resolution measurements may not be very accurate and depend on a large number of variable factors, it seems wise to allow a wide safety factor when estimating the resolution that will be required for a reading aid. Thus, if we assume ten resolution elements-per-letter in the horizontal direction, it would take about 300 horizontal resolution elements to display approximately thirty letters and spaces. This is the requirement for a typical newspaper column. About twice that number of resolution lines (600) would be needed to display the full width of the page of a typical book. (It would be well to display a full line of print, and if this results in a magnification that is acceptable to the reader at a comfortable viewing distance, the need for continuous movement of the work or the camera as the reader scans each line of print could be eliminated.) Since the height of a TV picture is about 75 percent of its width, the resolution required, expressed as "TV lines," might be expected to be about 75 percent of these numbers, i.e., 225 lines for the newspaper column and 450 for the book page. Table 1 shows the resolution, price, and some other characteristics, as specified by the manufacturer of a number of TV cameras that were investigated during 1968.

Vertical and horizontal resolution are affected by the quality of the components in the camera and the monitor, i.e., the camera lenses, the vidicon tube, the electronic circuitry in the camera and the monitor, and the cathode-ray display tube in the monitor. One dominant factor determining horizontal resolution is the bandwidth of the video signal circuits in the camera and the receiver. The wider the bandwidth, the higher the resolution, other things being equal. Table 1 includes the specified bandwidths of the cameras.

Vertical resolution is limited by the number of horizontal scanning lines which are generated by the camera. The standard broadcast TV picture has 525 horizontal scan lines of which about 40 are lost (blanked out during vertical retrace) leaving about 485 useful lines. The common, inexpensive TV cameras are nominally specified to give this number of scan lines. However, the vertical resolution implied by this number is not realized, because the inexpensive cameras do not have a feature known as *locked synchronization* or *2:1 interlace*, a feature which is required in broadcast-type equipment. Instead, their method of scanning is characterized by the term *random synchronization*. This method of operation results in a loss of vertical resolution, which is variable. Random synchronization can easily cut the effective vertical resolution in half for a large percentage of the operating time. When

TABLE 1

Comparison of Various Closed-Circuit TV Cameras

Manufacturer	Model No.	Resolution No. of lines	Bandwidth (Megacycles)	Has 2:1 Interlace	1968 Price
Ampex	CC-6007	550 center 350 corners	10	No	$ 400
Ampex	CC-6400	600 center 400 corners	10	No	$ 550
Ampex	CC-324	550 center 400 corners	10	No	$ 995
Ampex	CC-326-10	700 center 500 corners	12	No	$1795
Ampex	CC-326-20	700 center 500 corners	12	Yes	$1995
Concord	MTC-15	550	6	No	$ 375
Sony	VCK-2000	350		No	$ 350
GE	TE-23A	500 center 300 corners		No	$ 495

one observes a randomly-synchronized picture closely on the TV screen he can see that there appear to be approximately half the expected number of scanning lines and the lines are moving slowly up or down instead of standing still as in a normal broadcast TV picture. (Because of the smaller number of scanning lines in a randomly-synchronized picture, these lines can be annoying to the reader, if he is too close to the screen.

Explicitly, there is a fixed relationship in broadcast TV between the starting times and frequencies of the vertical and horizontal deflection-coil currents which deflects the electron beam in the vidicon tube of the camera and the beam in the cathode-ray display tube of the monitor. This relationship is such that the scanning beam sweeps across the full picture area during one field and lays down half of the total number of scan lines. The beam then covers the same area again during the next field and lays down the remaining lines interleaved halfway between those in the first field. In random-synchronization, a very slight drift in the frequencies of the vertical- or horizontal-scan generating circuits can easily cause the one set of lines to be superimposed on the other so that there are, effectively, only half as many lines in the picture.

Table 1 indicates whether or not each camera has the desirable 2:1 interlace feature, which eliminates this difficulty. It will be noted that only one expensive camera had this feature.

In addition to all of the aforementioned factors, resolution is strongly affected by the adjustments of focus and shutter opening (f-number) on the camera, and the brightness and contrast controls on the receiver. Consequently, when purchasing a system for a reading aid, it would be well to spend considerable time at the controls to see how hard it is to obtain a good picture. A good way to rate different systems as reading aids is to adjust the magnification to determine the maximum number of letters of some standard print that can be displayed across the screen and be easily legible to a person with normal vision. Magnification is varied by changing the distance of the reading material from the camera and adjusting the focus, and adding lens-extender tubes if necessary.

CAMERA SELECTION

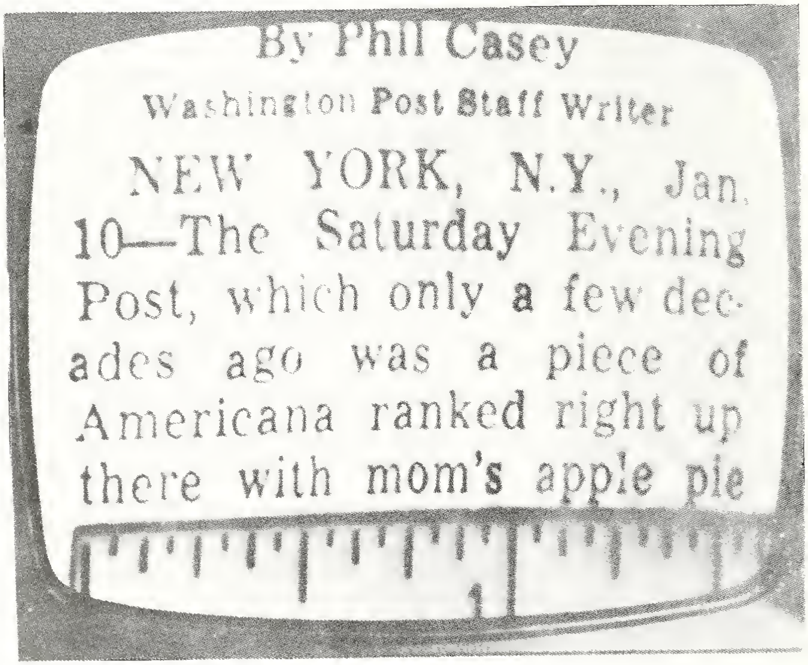
An inspection of the specifications in Table 1 indicated that there was a good chance of obtaining sufficient resolution in an inexpensive camera so that the full width of a typical newspaper column could be displayed, despite the expected loss in vertical resolution due to random synchronization. However, to get sufficient resolution to display the full width of a book page reliably might require a much more expensive camera having 2:1 interlace and at least 600 lines horizontal resolution over the whole picture area. Therefore, the writer decided to settle for a low-cost camera and to accept the necessity of line scanning book pages.

When an attempt was made to obtain a demonstration of various cameras, it was found that, because this was an unusual request, the salesmen in retail outlets did not know how to set up the lenses for their cameras so that the cameras would focus at close enough range to obtain the desired magnification. Better luck was encountered at engineering type outlets specializing in custom television setups for institutions and broadcast studios.

It turned out to be a simple matter to obtain the desired result with the standard lens assembly that is normally supplied with the camera. All that is needed is to increase slightly the spacing between the vidicon tube and the lens assembly. This can be done easily by the use of a spacer called a *lens-extender tube.* A set of these providing a variety of spacings can be purchased at a nominal cost. The smallest lens extender in the set (5mm spacing) gave the magnification required to blow up the picture of a two-inch wide newspaper column to the full width of the TV screen. (A special lens which eliminates the need for the lens-extender tube can be purchased as an accessory for Ampex cameras for $98.)

A nice feature in a reading aid would be a single knob to vary the magnification. The idea of using a zoom lens for this purpose naturally comes to mind. However, it turns out that a zoom lens will not work, because it is not designed to function properly at the short ranges required. Even though the material is brought into focus at short range by use of a lens-extender tube, it will not remain in focus when the magnification is varied by means of the zoom control. Even if one is willing to accept the inconvenience of readjusting the focus, the range of magnification control that can be achieved is much too small to be useful.

The Ampex CC-6007 was selected for purchase on the grounds that it appeared to offer a little wider bandwidth and resolution than the least expensive cameras listed in Table 1, for a modest increase in cost. The specifications of this camera indicated that the full width of a newspaper column could be easily accommodated (Fig. 2), and there appeared to be a chance that the full width



By Phil Casey

Washington Post Staff Writer

NEW YORK, N.Y., Jan. 10—The Saturday Evening Post, which only a few decades ago was a piece of Americana ranked right up there with mom's apple pie

Figure 2. Newspaper Column Displayed on Television Screen

of a book page could be displayed. As it turned out the legibility of a book page seems a bit marginal. Sometimes it can be read by the writer and sometimes not. It may be that this variability is due to random synchronization. At any rate, even if sufficient resolution had been available to display the full width of a book page reliably, it is not clear that this would have been useful, because the smaller magnification might require the reader to sit uncomfortably close to the TV screen.

MONITOR SELECTION

It is possible to use either an ordinary television receiver or a specially designed unit (a monitor) to display the picture that is received from the camera. If an ordinary TV receiver is used, some minor modification may or may not be required, depending on the design of the camera. The reason for the modification may be understood by reference to Fig. 3. This indicates the major sections of circuitry that the electrical signal carrying picture information (the video signal) passes through on its way from the camera pick-up tube (the vidicon) to the cathode-ray display tube in the receiver. Some cameras contain only the video amplifier, while others contain in addition a radio-frequency transmitter. In the latter case one need only connect a suitable cable from the output of the transmitter to the antenna terminals of the receiver. The signal will then follow the path shown by the dotted line labeled *alternate signal path.* Alternatively, one can arrange to have the signal take the "short-cut" path from the video output of the camera to the input of the video amplifier in the receiver. This path is labeled the *preferred path.* To use the preferred connection with an ordinary home TV receiver, it would be desirable to wire in terminals or a jack to facilitate this connection and to disable the RF amplifier section. If it is desired that the receiver do double duty and function as a broadcast receiver, in addition to its use as a reading aid, then some sort of a convenient switching arrangement should be provided to change functions. These changes would have to be custom designed for each manufacturer's receiver and checked out by experienced personnel. Some TV receivers do not contain power transformers. Connection of a camera to the video amplifier of such a receiver may create a shock hazard.

It may seem simpler to use the longer signal path through the RF amplifiers, but, technically, this is a less satisfactory solution because some resolution is inevitably lost in taking the signal through the extra circuitry. There may be a need for evaluation of various types of equipment to determine if this loss is significant in the reading aid application.

In a receiver that is designed to be a monitor, the required modifications for using the video output of the camera are already installed. The Ampex camera that was purchased had no RF

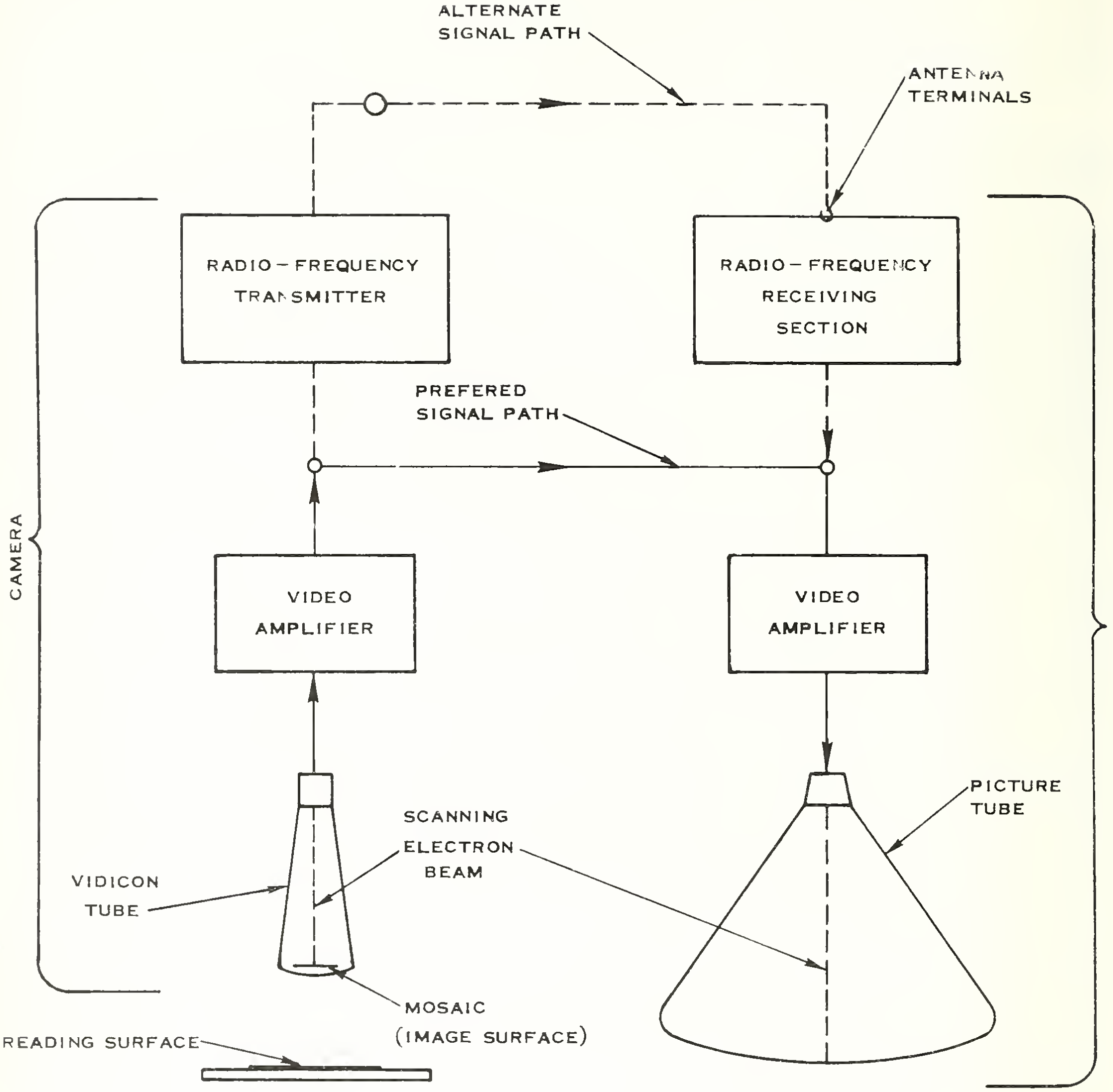


Figure 3. Diagram Showing Alternate Paths of Picture Signal Through Television Camera and Receiver

section and, therefore, only a video output was available. Thus, it was necessary to have the aforementioned modifications in the receiver. The Setchel-Carson *Educator* model receiver/monitor which was purchased, is normally supplied with the necessary video-input jack and monitor switch. This unit has a specified resolution of 600 lines, which more than matches the capability of the Ampex camera. The Setchel-Carlson monitor can be changed to function as a broadcast receiver by merely flipping the monitor switch. This receiver has a 20-inch wide screen and a high enough accelerating voltage (17,000 volts) to give a bright, high-contrast picture. The large screen size was felt to be highly desirable in order to permit comfortable viewing at a distance, maximizing the reader's depth of visual field. It is interesting to note that Genensky uses a small screen and a very short viewing distance, whereas the writer prefers a large screen in order to make the viewing distance as large as possible. Perhaps the difference between the two setups results from the nature of the visual difficulties. If so, this would indicate that each reader should try out different screen sizes and determine for himself what screen size and viewing distance is best for him. If a short viewing distance is required, then the monitor would have to be mounted on a projecting shelf, as in Genesky's arrangement.

COST OF EQUIPMENT

The cost of the television equipment, excluding the home-made camera stand, was as follows when purchased in the Fall of 1968:

Ampex, Model CC-6007 TV camera	$400
Set of lens-extender tubes	16
Setchel-Carlson Receiver/Monitor, Model No. 2100-SD	233
Total	$649 (plus tax)

CONSTRUCTION OF THE CAMERA STAND

Figure 4 is a rear view of the stand showing the mounting of the camera and Fig. 5 is a front view. Fiqure 6 is a rear view showing a special tray for books, and Figs. 7, 8, 9 and 10 are dimensioned drawings of the assembly and major parts of the camera stand. The camera stand consists of three major parts: the base, the carriage, and a slide which carries the camera.

The base is a 24 x 30-inch piece of 3/4-inch plywood. Mounted on this base are two sets of tracks of aluminum angle

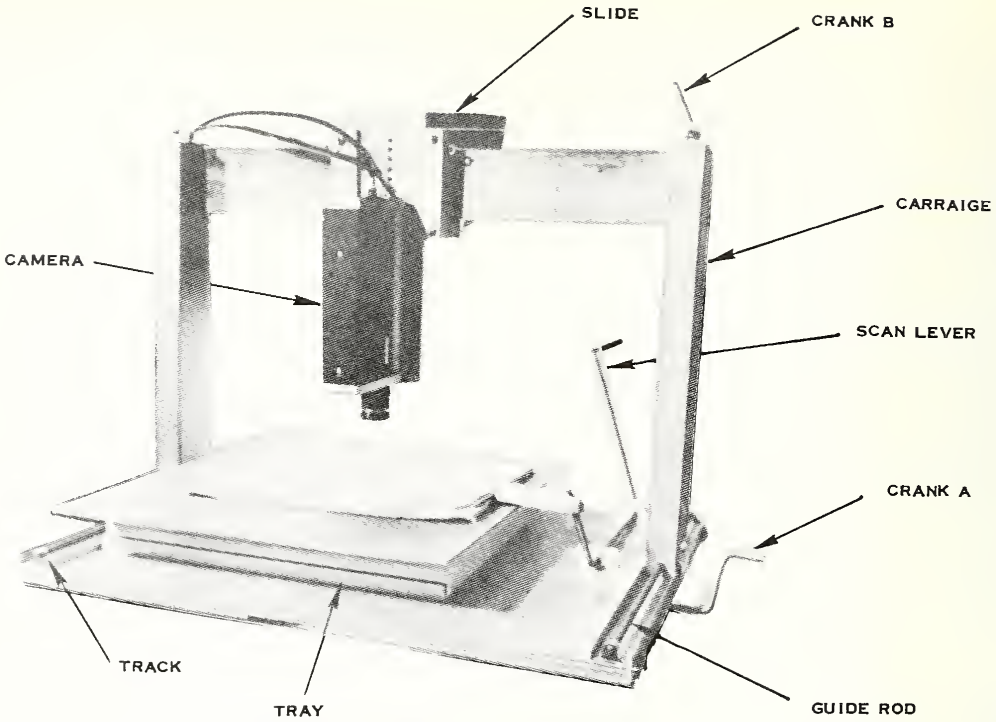


Figure 4. Rear View of Camera Stand Showing Camera Mounted Vertically

stock plus two round, 3/8-inch diameter guide rods. The tracks, which are shown in Fig. 7, carry the load transmitted to them by two vertical carriage legs. The guide rods, which pass through loosely fitting holes in these legs, serve to prevent the carriage from tipping over. The guide rods, which were solid steel curtain rods in the prototype, were fastened to the base by means of curtain rod brackets. These hold the rods a short distance above the base. The holes in the legs for the guide rods were carefully drilled on a drill press to assure good alignment, and the distance from the bottom of the leg to the center of the hole was adjusted so that the guide rod fitted loosely and did not bind or carry any of the load. A 3/8-inch drill was used to make an oversized hole in the wooden leg, so that a loose fit was obtained.

The base can be mounted on legs if it is to sit low on the floor beside an easy chair. Or the legs can be omitted if it is to sit on a desk or table for use in an office. In the latter case it might also be used as a writing aid such as Genensky has done with his equipment. A rectangular wooden frame of one-by-fours or one-by-twos a few inches smaller in outside dimensions than the base, can be added underneath to raise the base high

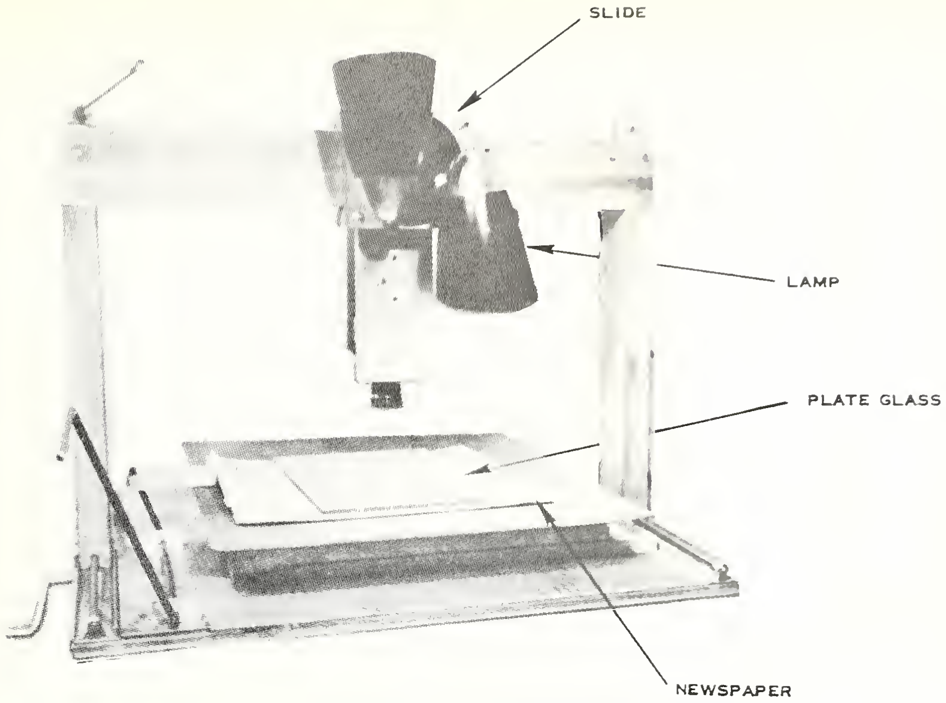


Figure 5. Front View of Camera Showing Lamp Carried on Slide Which Carries Camera

enough above a table to provide clearance for the crank and cable mechanism which moves the carriage (crank A in Fig. 4). If, for reasons of comfort it is desired to reduce this clearance to a minimum when the stand is mounted on a table, then the height of the frame can be reduced if one allows the crank handle to hang over one end of the table.

The carriage consists of two vertical two-by-four legs fastened to a horizontal one-by-four cross-bar at the top. Riding on this bar is the aforementioned slide. This slide (see Fig. 9) is a "sandwich" made up of a number of pieces, which are bolted together with four long carriage bolts to form a loosely fitting sleeve around the carriage bar. The slide provides a support for the camera. The camera is mounted on a mounting board by means of a screw which fits the threaded mounting hole in the bottom of the camera. The mounting board slips down into vertical grooves in the slide structure. The vertical position of the mounting board can be changed if one wishes to raise and lower the camera. The desired height is maintained by means of a peg that can be inserted in one of a series of holes in the mounting board. A stop is provided to set a lower limit on the height of the mounting board. The camera and board assembly can easily be lifted out as one unit.

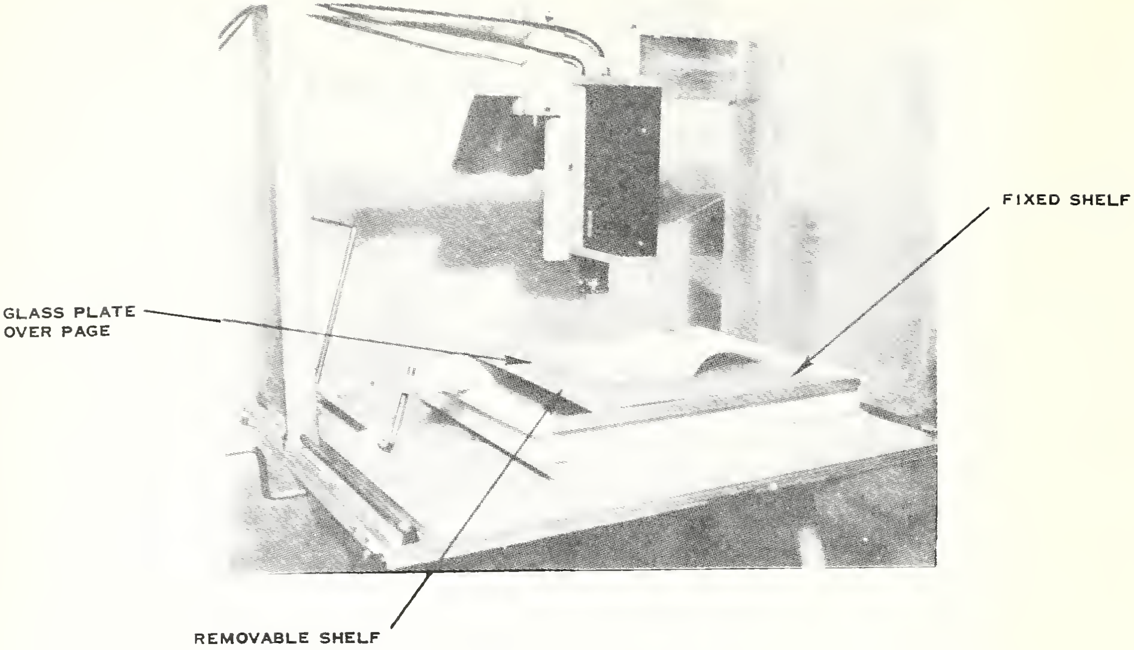


Figure 6. Rear View of Camera Stand Showing Book Tray

The two cranks and the scan lever were all formed from 3/8-inch diameter steel rod (curtain rod). If the rod is notched on the inside of the bend it can be bent easily in a vise. Four small holes were drilled in crank A and two in crank B to form anchor points for the cables. The spacing between each pair of holes was about one and one-half inches. Holes were positioned so that the midpoint between holes would be in the natural plane of the cable.

Bearings to carry the two cranks and the scan lever were simply pieces of 1 x 1 x 1/16-inch aluminum angle stock. It appears that there has been noticeable wear in these bearings which has caused some jerkiness to develop in the motion of the carriage and slide. Therefore, in the drawings these bearings are shown modified to heavier-gauge brass angle stock.

Figure 7 shows the crank, cable, and pulley arrangements. Crank A moves the carriage along its tracks. Before the carriage was assembled to the base there was some doubt that a smooth motion could be obtained with this mechanism. Indeed, before the

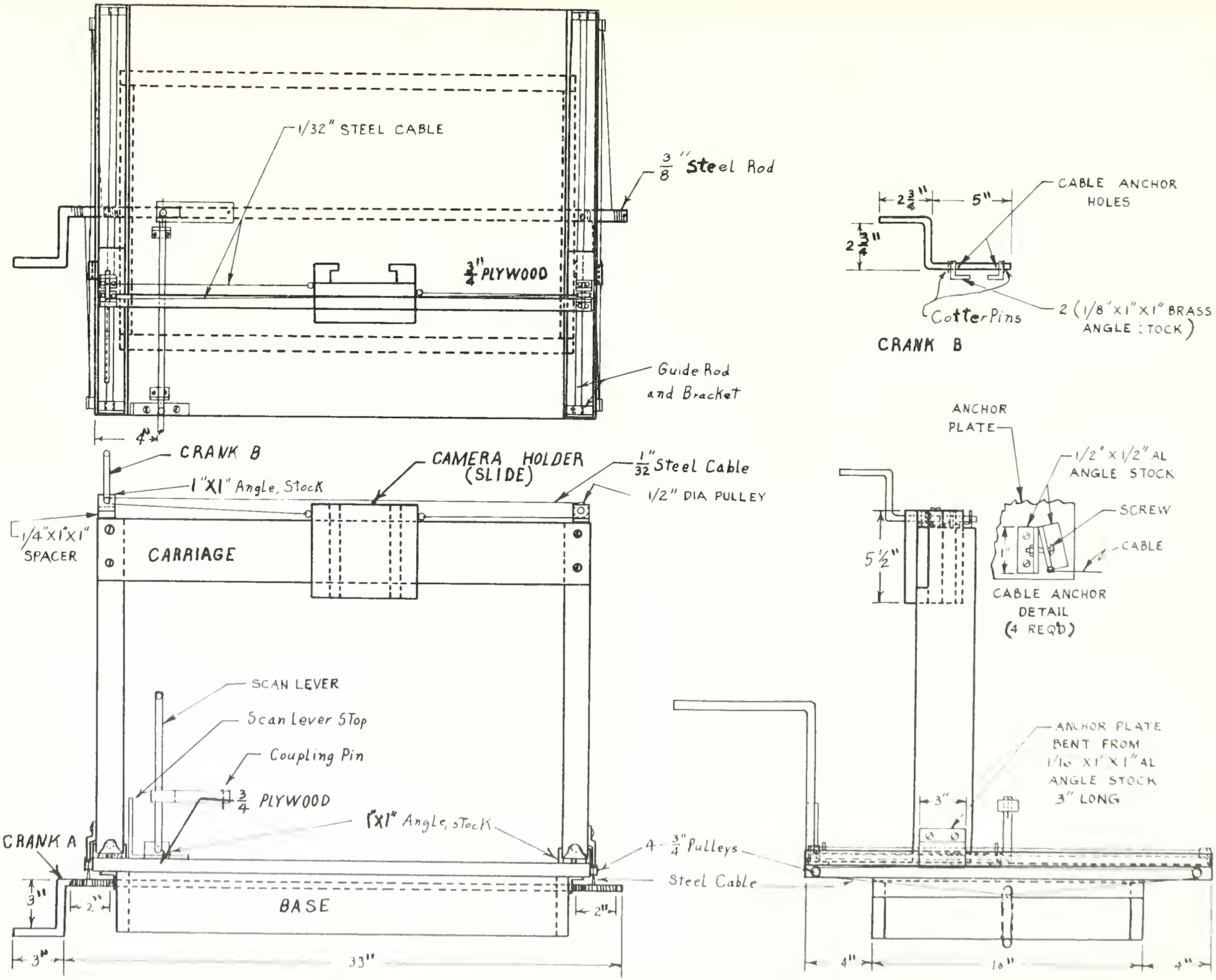


Figure 7. Assembly Drawing of Camera Stand

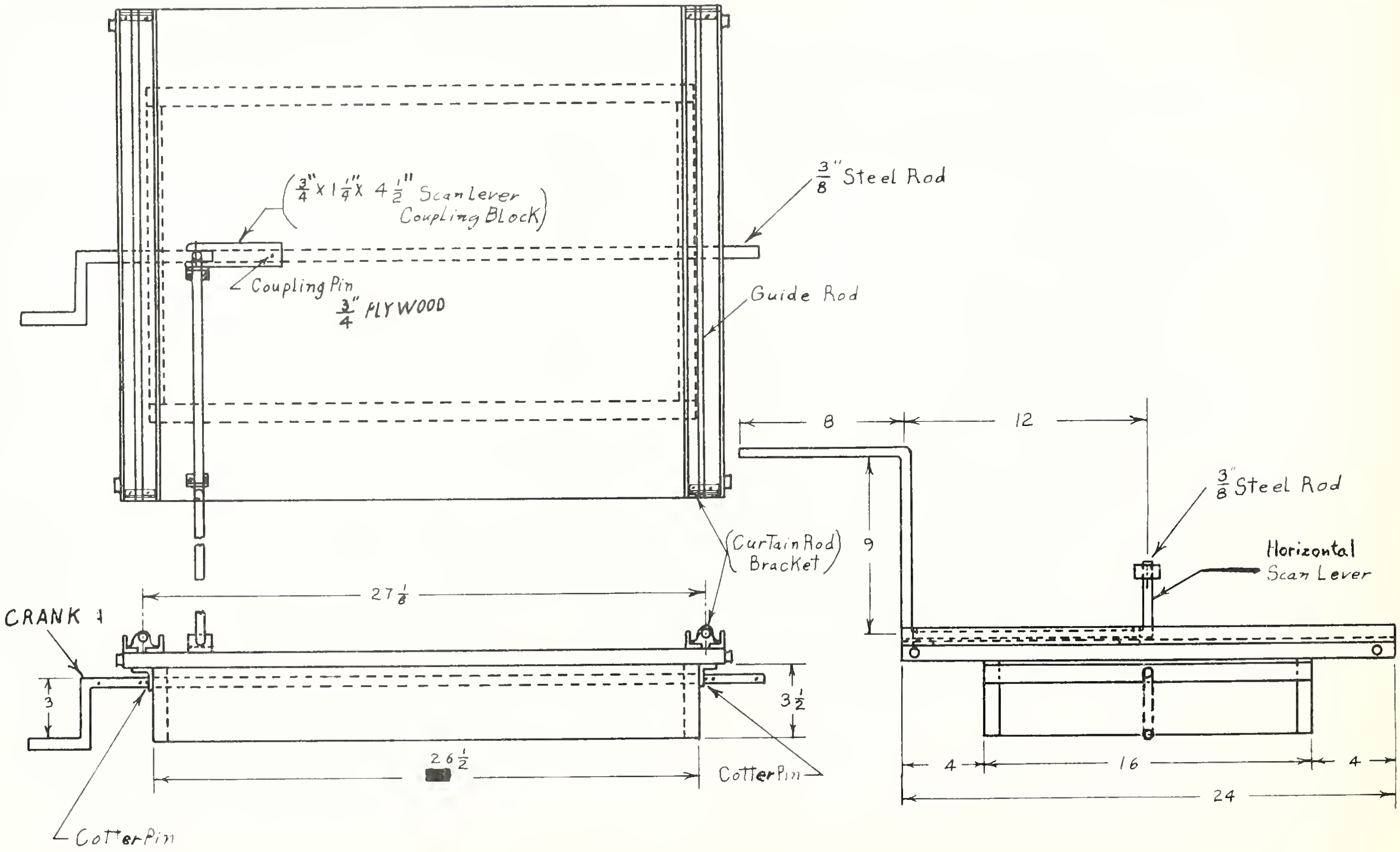


Figure 8. Base

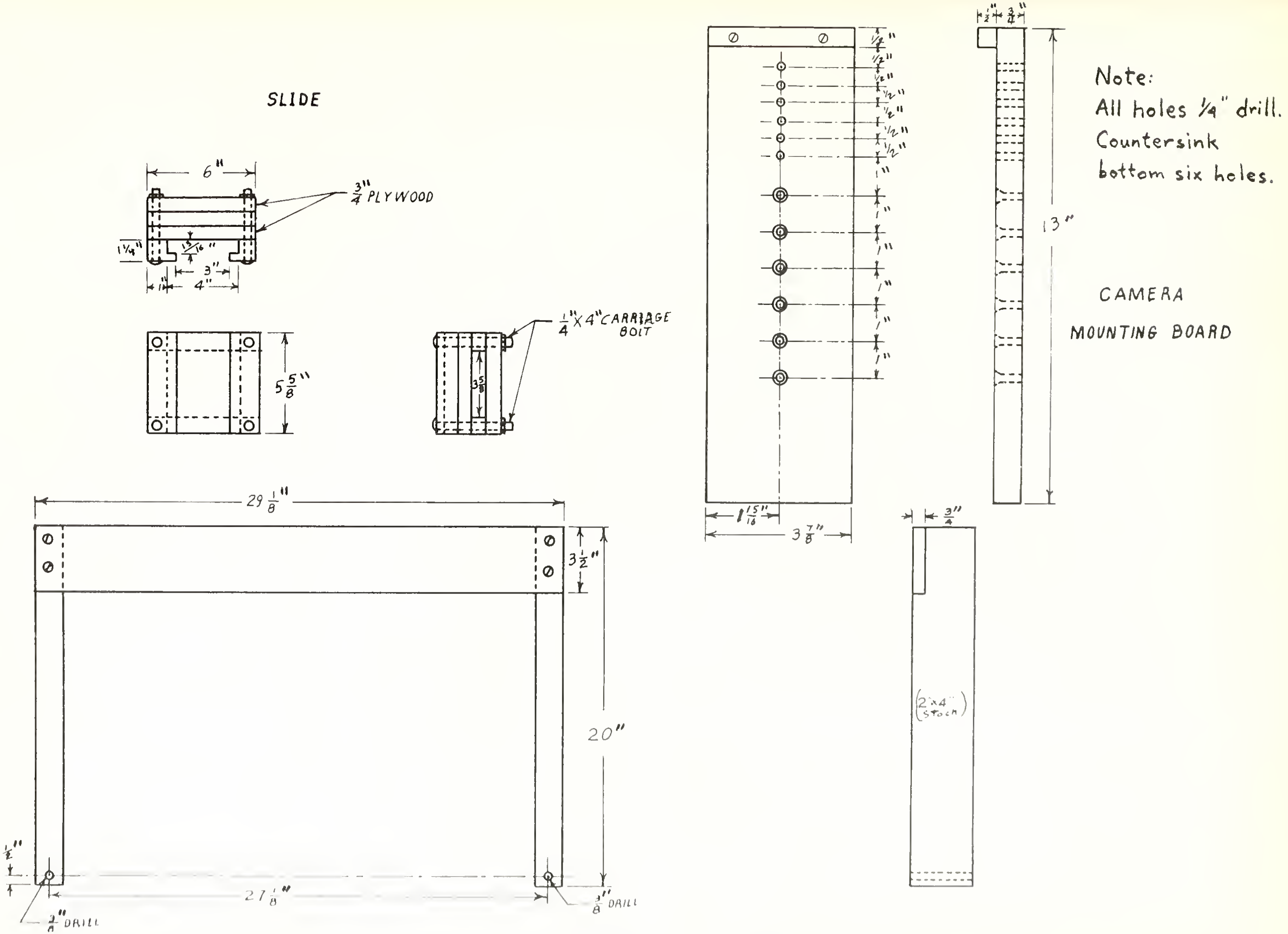


Figure 9. Carriage

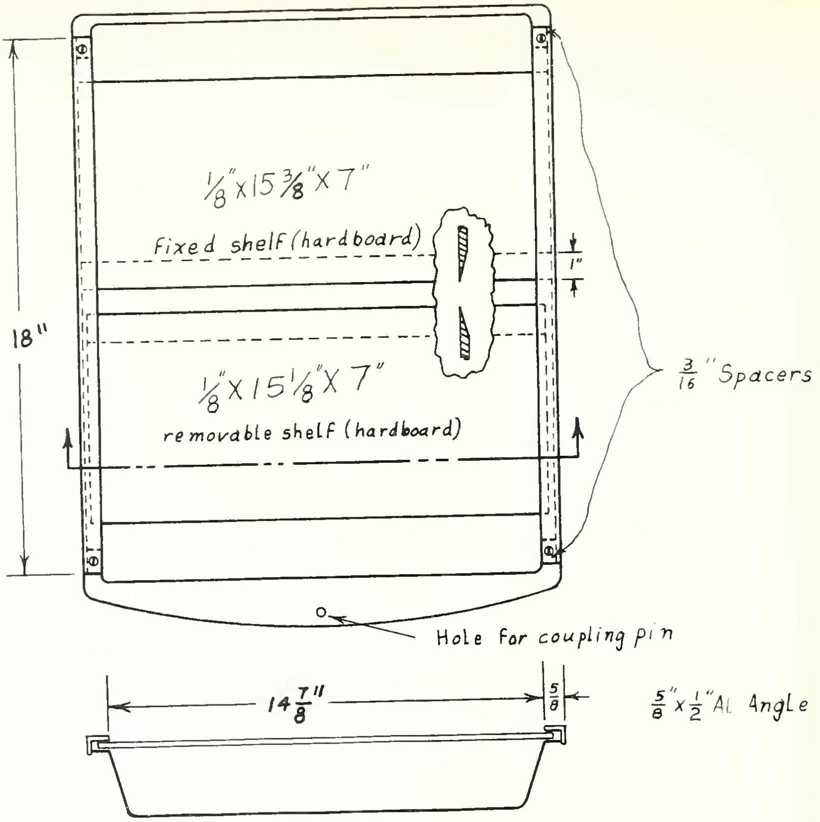


Figure 10. Book Tray
Rubbermaid Tray No. 2811-16
(16" x 19")

crank and cable were added, it was not possible to push the carriage by hand without having it bind, because in using two hands, one could not move the two legs at exactly the same rate. However, after the crank and pulley assembly were added and the cables had been tightened and adjusted in position to eliminate any twist on the carriage, a smooth and easy motion was obtained.

Crank B moves the slide which carries the camera along the horizontal carriage bar. This crank is located at the left end of the carriage, where it can be easily reached from the easy chair. One piece of cable runs directly from its anchor point on the crank to the slide, and another piece of cable runs from a second anchor point in the crank to a pulley at the other end of the carriage bar and thence to the slide.

The cable used was obtained from a hobby shop and is a small, flexible, steel cable about 1/32-inch diameter. It is used for model airplane controls. Also available are pieces of small metal tubing used for crimping around a loop of the cable for fastening to brackets or screw eyes. At any point in a crank where the cable was to be anchored, a small hole was drilled through the crank rod. The hole was large enough so that the cable could be threaded through two or three times and looped under itself. (It may be desirable to devise a better cable anchoring method, as there appears to have been some loosening of the cable with use.)

It had originally been planned that the slide would be moved by hand, but it was found that after crank B was added, the crank was definitely a worthwhile convenience because it gave better control and was easier to reach than the slide.

The friction between the slide and the carriage bar was somewhat greater than had been anticipated after the load of the camera was added. This was due to the twist exerted by the unbalanced load of the camera. Another contributing factor was the fact that the writer made the mistake of finishing the wood with shellac. This gave a tacky finish with a high starting friction that resulted in a jerky motion. (One knowledgeable person advised that a better finish would result if the wood were soaked in boiled linseed oil until it was saturated. He assured that once the excess was wiped off, the surface would not collect dust.)

The friction problem was overcome with the aid of lubrication. An orderless silicone grease, Amphenol No. 53-307 Silicone Compound, gave good results. This lubricant can also be applied to the tracks which support the carriage legs.

When the carriage, tracks, and guide rod are assembled to the base, care should be taken to insure that the tracks and guide-rod brackets are accurately located so that the carriage legs will not bind. The tracks are held in place by round-head wood screws at each end. These screws also fasten down the guide-rod brackets which rest on top of the bearing surface of the tracks. If the holes for these screws in the track and guide-rod bracket are slightly oversized, it will facilitate minor adjustments of position as the screws are tightened. These screws should not be installed until the carriage has been set in place on the tracks so that the track spacing may be adjusted to compensate for any small dimensional error in the carriage. Reasonable care should be taken to insure that the carriage construction is accurate, since this may determine whether or not the carriage will bind.

The final items to be assembled are the scan lever and tracks for the work tray. The work tray, which carries the reading material, is an easy-sliding plastic tray, which rides in plastic tracks. The tray and track assembly, Rubbermaid No. 2811-16 (Rubbermaid, Inc., Wooster, Ohio), are a commercial item and can be purchased at a hardware store. The tray dimensions are 16 x 19 x 2-3/4 inches, and it moves in the long direction. The writer uses two interchangeable trays. One, which is used for magazines and newspapers, is completely covered with a 1/4-inch thick sheet of Masonite measuring 20 x 22 inches. The other tray, which is designed for books has two smaller shelves, one of which is fixed and the other easily removable by a short, slide-and-lift movement, which frees one end from an overhanging lip of aluminum angle stock. Figure 10 is a drawing of the tray and shelves. The book lies in the tray beneath the shelves with a few pages brought up through the crack between the two shelves, as shown in Figure 6. This small group of pages can be turned one at a time by hand. It is necessary to force some foam rubber under the book to hold the heel of the book up against the crack. (Several pieces of foam rubber of various thicknesses are kept on hand for this purpose. They have plastic jackets to prevent dust collection.) The shelves are tapered to a feather edge where they meet at this crack, so that the heel of the book can be pushed up as far as possible. The shelves are made of hardboard panelling, which is stiff enough not to bend too much.

A 6 x 9-inch piece of plate glass with beveled edges is used to weight the page down and hold it flat while it is being read. A larger piece is also on hand for use with newspapers and magazines. While the glass may not be absolutely necessary, the picture will be in better focus if the reading surface can be kept flat. With the arrangement of equipment shown in Fig. 1, it would be awkward to have to lean forward and hold the work flat by hand. If the camera is not refocused, the height of the reading surface can be varied about 1/4 inch without serious degradation of the picture at ten times magnification. Variation of the focus adjustment permits the height for best focus to be varied about 1 inch (i.e., from five to six inches below the camera body or about 2-1/2 to 3-1/2 inches below the end of the lens barrel).

The reading tray can be moved back and forth approximately two and one-half inches for line scanning. This is accomplished by means of the scan lever, which gives a mechanical advantage of a factor of three. This arrangement gives good control and easy movement.

ILLUMINATION

The lamp that illuminates the reading surface travels with the camera. Light is supplied by a single 75-watt bulb in a wall-lamp fixture mounted on the slide. This arrangement has the advantage over fixed illumination in that less light is required, because only the small viewing area directly under the camera needs to be illuminated.

OPERATING EXPERIENCE

The equipment has been in operation about one year. It has been used frequently for light reading and the writer has found it very helpful. It is possible to read for one or two hours without tiring. The writer is able to achieve a reading speed of about 75 to 90 words-per-minute (five-letter average word-size assumed). Larger print material can sometimes be read directly, or with magnifying glasses, when the pupil of the one good eye has been dilated with drops in order to reduce the distortion caused by a small cataract. In these cases the speed may be slightly higher, depending on the type of material. (The sight of one eye was lost due to injury. Other factors which may contribute to the writer's reading difficulties are near sightedness, a narrow visual field, and low visual sensitivity.)

When reading directly or with magnifying glasses, the writer must hold his reading distance to within a fraction of an inch of the optimum distance. With a large magnifying glass supported in front of a reading stand the permissible variation is somewhat greater, typically plus or minus an inch from the optimum. But even this seems very confining. In addition, reading of magazine print with this setup is not always possible when the pupil dilation is not optimum.

TV reading seems to be much less critical. Reading is possible at any time and, when wearing his distance glasses, the writer can vary the reading distance from one and one-half to three or four feet without having the print get out of focus. Thus it is possible to shift body position and move the head about in a relaxed fashion, contributing greatly to reading comfort.

Reading books which require line scanning, does not appear to be appreciably slower than reading newspaper columns that require no line scanning. However, the elimination of movement of the display and operation of the scan lever seems to make reading a bit more relaxing.

During the one year period of operation of the system the picture has remained sharp and clear. There have been some operational problems with the camera, i.e. picture nonuniformity (the right side tends to be dark), and a tendency for picture quality to degrade after an hour or two of operation, apparently due to internal heating.

The camera has been checked by the distributor, the Ampex Service Center, and the Engineering Department at the factory. After they had done their best to cure the problem of picture darkening on the right-hand side, the writer was informed that this characteristic was inherent in the design and that the camera was judged to be within specifications for this "bottom of the line" model.

This problem, while somewhat annoying, is not disastrous. It can be overcome in large part if one simply points the lamp to the right to brighten the right-hand side of the picture, or throws a shadow on the left side of the reading material with a cardboard vane attached to the camera slide, as was done when the picture shown in Figure 2 was taken. Some change in these adjustments may be required from time to time while the camera is operating. The writer has been informed that other cameras of this same model might darken different parts of the picture and thus require different treatments of the illumination.

The writer recently had an opportunity to inspect an experimental reading aid setup at the Eye Research Foundation in Bethesda, Maryland, and was informed by them that difficulties had not been encountered in their equipment, which consisted of a Concord Model MTC-15 camera and a Sony Model CVM-51VWP receiver. This equipment was able to produce a sharp, legible display of a two-inch wide newspaper column on its eight-inch wide screen, with higher magnification (e.g., x 10). Only a few words of the column width is displayed.

Recently some modifications in the camera stand have been made to overcome mechanical problems that developed after long use; jerky movement of the carriage and the camera slide. These modifications are as follows:

1. Screw adjustments have been devised to permit each of the four cables which move the carriage to be tightened individually. Each of the cables is adjusted by means of a pair of short pieces of aluminum angle stock which are brought together by a screw in a scissor action. One piece is fixed to the anchor bracket on the carriage leg at each anchor point and the other is moveable to tighten the cable (see detail in Fig. 7). The carriage motion became smooth again after these devices were installed and properly adjusted.

2. A similar type of screw adjustment (not shown in the drawings) was also devised to tighten the cable which moves the camera slide.

FURTHER IMPROVEMENTS IN READING AIDS

There are some interesting possibilities that could be investigated for improvement of the TV reading aid. It would seem that the manufacturers of closed-circuit television equipment might be able to add some features to their line of inexpensive cameras that would be useful for the reading aid application without making major increases in cost. However, before there would be much motivation for such changes, it would have to be shown that there would be a sizeable market. Thus, there is need for information as to the number of people who might benefit.

It has been estimated that the number of visually handicapped persons whose vision is such that they could make use of the device may be in the hundreds of thousands. However, there is some uncertainty as to whether or not there are a significant number of such people who cannot be helped more simply by optical devices. Also, a large percentage of visually handicapped people are elderly people, who are either not strongly motivated or would be easily frustrated by any difficulties with the equipment. On the other hand, the fact that libraries are now beginning to stock large print books for the visually handicapped would seem to indicate that the number who would want to use TV readers might be significant, if the equipment can be made sufficiently reliable and easy to use. A television reader has the obvious advantage over large print books that one's selection of reading material is not restricted.

It would seem that tests on a large number of visually handicapped people should be made with the closed-circuit TV equipment that is now available to determine what percentage of them could profitably make use of television readers. If the number proves to be significant, some obvious improvements that might be incorporated in the TV camera are as follows: (A number of these possibilities also occurred to Genensky et. al. and were mentioned in Reference 1.)

1. Use of higher quality vidicon tubes in the inexpensive cameras to obtain more uniform picture brightness.

2. Installation of circuitry and switch for reversing the polarity of the video signal in the camera. This would give a negative image on the viewing screen; i.e., white print on a black background from ordinary black on white reading material. This would reduce glare from the page and might have a beneficial effect for persons with small cataracts in that there would be less tendency for the pupil to contract. (Pupil contraction can cause a larger percentage of the light which enters the eye to pass through the cataract, if it is at the center of the lens. This can degrade the image.)

3. Installation of circuitry and a switch to permit the reader to change to a mode where the video signal is switched back and forth between two levels from maximum black to maximum white, as the video signal crosses a threshold level. See Genensky's "two-level gray scale" (2). This would give a display of uniform brightness despite some variation in sensitivity of the vidicon. It might be a way of overcoming shading problems so

that less expensive vidicons could be used for the reading application. (However, one would not want to use it for viewing pictures.)

4. Installation of 2:1 interlace. (This feature was discussed in an earlier section.)

5. An old TV camera, the "flying spot scanner" using a fast-phosphor cathode ray tube as the scanner, might be revived. Because of its simplicity it might be a more reliable and lower cost camera than the vidicon camera.

A second change could be introduced in inexpensive cameras by the addition of a trivial amount of additional circuitry. It is already included on some more expensive cameras. A third change should also be simple and inexpensive to install, although some experimentation may be required to find the most effective circuit. A fourth change, which is a standard feature of expensive broadcast-type cameras, requires quite a bit of additional circuitry, but with the possibilities of great savings in space and cost that the new microminiature, integrated-circuit techniques now afford, one may hope that this can become an inexpensive feature.

The camera stand which has been described seems to be quite serviceable as is, although some refinement of the mechanical design details may prove to be desirable. One can always think of luxury features that might be nice to add, such as:

1. Motor drives for the two-camera motions.

2. A variable-speed motor drive with a cam actuator to replace the manual line-scanning mechanism. (These two changes would give more flexibility in placement of the equipment. One could have a remote control box with pushbuttons and a speed control knob to control these functions. Motor drives might be preferred by invalids reading in bed or old people, who might find the operation of the manual controls a bit awkward or tiring.

3. Automatic page turners have been developed to aid invalids. Perhaps this feature could also be incorporated in a TV reader.

4. Changes to reduce bearing wear and friction in the mechanism. The carriage legs might be supported by rollers in tracks or sleeve bearings or ball bushings riding on steel rods. Also, the design of the slide that carries the camera might be modified to include rollers that would be arranged to carry both the downward thrust and the torque due to the unbalanced load of the camera. The

work tray for the reading material could also be carried on rollers. If motor drives are to be used, these changes would be desirable to reduce bearing wear and the size of the motors that would be required.

5. The small glass plate which is used to hold down a book page should have a handle, which would permit it to be lifted out of the way more easily. A mechanism to raise the large glass on the magazine tray is needed.

6. The design of the scan lever could be changed to provide more travel for the book tray. If the scan lever is placed underneath the book tray, it can be arranged to have it swing back and forth in a horizontal plane about a vertical axis. A pin protruding down from the tray into a slot in the scan lever would move the tray. With this arrangement the travel of the tray could be increased from two and one-half to seven inches. This would be useful for reading legal documents and reports.

7. It would be nice to have a quick and easy way of changing the magnification of the TV reader between at least two fixed values, say from five to ten times magnification, without the necessity of raising or lowering the camera and changing lens extender tubes. From a crude test, it appears to be possible to accomplish this in a simple and inexpensive manner. If one suspends a suitable lens, similar to a reading glass lens, on a moving arm attached to the camera slide in such a way that it can be moved into a position between the reading material and the lens barrel of the camera when needed, it should be possible to accomplish such a change in magnification. Some change in focus results, but this appears to be within the range of the focusing adjustment on the camera.

In connection with the second change, some psychological investigation might be made to determine what kind of line-scanning motion is best for the reader.

The questions to be answered are: Should the work be moved slowly at constant speed from right to left and then returned quickly? Or, should it be jumped quickly back and forth between two extreme positions, perhaps at the command of a pushbutton? Should the camera motion down the page be a slow, continuous motion, one line steps, or large steps after a number of lines have been read?

In addition to the above possibilities for improvement, there are a number of other possibilities that might require a considerable amount of research and development that may become technically feasible at some time in the future:

1. Development of new types of cameras; solid state devices to replace the vidicon tube are a future possibility. These are now in the development stage (8).

2. A small device to replace the TV camera that would be light enough to be hand-held in contact with the reading surface, may be within the realm of possibility. If it were designed to pick up only a single line of print, it might turn out to be simpler, less expensive, and more reliable than a TV camera. A small plate containing a micro-miniaturized matrix of photo-diodes or photo transistors might be used as the pick-up device. Current work on such devices is described in the literature (8).

3. Electronic methods of line scanning may be worthy of consideration. It would eliminate the need for moving the work tray, but would require the use of a vidicon tube having high enough resolution to pick up a full page.

4. Magnification might be electronically variable by a single-knob control.

5. An ideal solution to the line-scanning problem would be to eliminate the need for it, by rearranging the relationship between the format of the display and that of the reading material. For example, one might break up the image of a long line of print into two parts and transpose the second half into a position below the first half, when the line is displayed. This could be done optically with mirrors or fiber optics located between the reading surface and the camera. Or, it might be done electronically by operating on the scanning voltages in the camera or the TV receiver. If only a single line of print were to be broken up and displayed, then it would seem that the optical method with mirrors (suggested by J. B. Garrison of the Johns Hopkins Applied Physics Laboratory) might be the simplest implementation. However, with the electronic method it would be possible to sense gaps between words and use this information to break the line between words. Some psychological testing of the effect of the two forms of display on readers might be worthwhile.

6. It is possible that the TV screen in the reading aid can eventually be replaced by a solid-state, light-emitting panel of some sort (e.g., an electroluminescent panel). This would remove the limit on screen width that is imposed by the cathode ray picture tube.

7. Laser displays, which are currently in the research stage, may eventually become available. These promise even higher brightness and contrast than the TV picture tube

can provide. (Reference 9 indicates that contrast ratios of 100-to-1 can be obtained compared with 15-to-1 for the cathode ray tube.)

CONCLUSION

The writer has found the equipment described here to be a comfortable and relaxing method of reading. It seems to be more relaxing than reading with the aid of high-magnifying lenses or large-print books, apparently because there is less eyestrain involved in focusing on larger letters at a greater distance. Also, one does not have to hold up the weight of the book. This becomes a fatigue factor with large-print books if one must hold them at a very precise focal distance for long periods.

The television cameras that are now available at relatively low cost are small, compact, and simple to operate. There are only two controls for the reader to adjust; focus and lens opening, and these perform the same functions as a film camera which millions of people have learned to use. With the television camera, however, one has the big advantage that he can see instantly the effect of his adjustments on the picture.

There are still some inconveniences in television reading having to do with getting the reading material into position, finding one's place, and working the cranks and scan-lever, but these inconveniences are minor to a reader who is strongly motivated.

To encourage readers who are less strongly motivated or more easily discouraged, the TV reading aid must be designed to be as simple and convenient to operate as possible, and it would seem that some design effort along these lines might be in order.

ACKNOWLEDGEMENT

The writer wishes to express appreciation to his son, George Kuck, for assistance in construction of the camera stand and preparation of the drawings, and to his wife, Phoebe, for the photographic illustrations in this article. The writer is also indebted to Dr. William B. Glew, Ophthalmologist, for the encouragement and advice which he gave to this project.

NOTES AND REFERENCES

1. S. M. Genensky, P. Barak, H. L. Moshin, and H. Steingold. "A Closed-Circuit TV System for the Visually Handicapped," Rand Corporation Memorandum RM-5672-PR, August, 1968.

2. S. M. Genensky. *Some Comments on a Closed Circuit TV System,* The Rand Corporation, December, 1968.

3. C. A. Weed, M.D. *Electronic Image Enlargement for the Partially Sighted,* Hartford Hospital Bulletin, March, 1968, Vol. 23, p. 66.

4. A. M. Potts, M.D., D. Volk, M.D., and S. West. "A Television Reader," *American Journal of Ophthalmology*, Vol. 47, April 1959, pp. 580-81.

5. B. Kazan and E. H. Nichols. "An Electroluminescent Light-Amplifier Panel," *Proceedings of the IRE*, Dec. 1955, p. 1888.

6. Electronic Industries Association, 1721 DeSalles Street, Washington, D.C.

7. "Direct View Bistable Storage CRT Resolution," *Tektronix Service Scope,* No. 49, April, 1968, pp. 8-11.

8. P. K. Weimer, et. al. "Multi-element Self-Scanned Mosaic Sensors," *IEEE Spectrum,* Convention Issue, March, 1969, p. 52.

9. C. E. Baker. "Laser Display Technology," *IEEE Spectrum,* Vol. 5, No. 12, December, 1968, p. 49.

PSYCHOLOGICAL TESTING OF BLIND CHILDREN

Herbert Goldman

Very early in the study of human abilities, samples of behavior were related to intelligence or, what might better be called, general mental ability. Binet assembled a number of test questions and tasks into a scale which related mental age (measured by the samples on which the individual succeeded) to chronological age resulting in the computation of an intelligence quotient, or I.Q. Binet and, at a later date, Terman developed some items for lower age levels which involved activity or the use of concrete materials. However, most of the items were verbal.

Even though the Stanford-Binet test was extremely successful, there was a need for a test with less dependence on verbal material to measure the ability of individuals who had not had the opportunity to develop verbal skills, e.g. young children, educationally and culturally deprived persons, those with foreign language background, and deaf and blind individuals. Early workers in this field developed formboards of varying complexity to meet the need for mental measurement of these individuals.

As this early performance testing emerged and progressed, it was realized that such concrete materials could measure abilities not tapped through words, even in a person with normal verbal skills. Lightner Witmer, one of the first individuals to obtain information about these nonverbal abilities, devised and adapted three tests of varying difficulty and developed norms by age and grade for preschool to beginning high school levels. A great variety of performance tests ultimately emerged and many of them sought to evaluate the ability to perceive similarities and differences, to see relationships, to develop concepts, to solve problems, to integrate parts into wholes, to apply rules, to profit by experience and, therefore, the ability to learn. An effort was also made to keep these tests "culture free," by attempting to measure those aspects of mental ability which were not dependent on or affected by schooling. This was far truer for performance tests than it was for various verbal scales which, to a much greater extent, sampled academic subject matter.

PERFORMANCE TESTING OF THE BLIND

The history of the mental measurement of the blind shows that early efforts were completely verbal in form. The Hayes-Binet Test (1) resulted from a deliberate selection of purely verbal items, with omission of all nonverbal content, from forms L and M of the Binet. The verbal section of the Wechsler scales was used with little or no modification, while the performance section remained unused because each of the tests required some vision. Many workers with the blind expressed regret at the completely verbal character of these measuring devices, a regret which was all the greater because there are many reasons why verbal measurements might be less truly representative for blind than for seeing persons. Cutsforth (2) and many others expressed the belief that many blind persons develop a pseudo-verbal skill which can inflate verbal mental measurements; a show of prowess with words which covers very bare and limited concepts. On the other hand, many blind children were neglected in school and, therefore, dropped out of school early. Verbal measurements of mental ability in these children were likely to be lowered and true ability underestimated. This very important area of verbal development in the blind child will be returned to in a later section.

In a very literal sense Bradway's study of 1937 (3) was one of the first attempts to assess the performance ability of the blind. She examined 73 residents of an institution for the blind using the Vineland Social Maturity Scale. Her results showed that the visually handicapped were deficient in the daily living skills measured by this scale. In 1942 Maxfield and Fjeld (3) studied preschool blind children also using the Vineland Social Maturity Scale and found results similar to those of Bradway's, i.e., a retardation of the Social Quotient when blind children were compared to visually unimpaired children of the same chronological age.

Shortly before World War II both Hayes in Massachusetts and Stephenson Smith in Washington did some experimental work toward developing a performance test of intelligence, but no finished tests were produced.

Nonverbal intelligence testing of visually impaired individuals actually began with Bauman's (4) Non-Language Learning Test in 1947. This test was specifically designed to measure the subject's improvement, through three successive trials, in his ability to follow rules, his ability to work with moderately complex form relationships and, therefore, his ability to develop concepts in concrete form. Bauman has always referred to this test as a clinical instrument and has stressed qualitative rather than quantitative observations. Bauman (5) found a low positive correlation between her Non-Language Learning Test and the Wechsler-Bellevue Verbal I.Q., and noted a clear differentiation between successfully employed and unemployed blind groups. In a personal communication (November 29, 1966), she warns against using this test with blind children any younger than ten.

MacFarland (6) reported on the possible use of mazes as a method of evaluating learning ability in blind individuals, but did not attempt to develop this into a test in the formal sense.

Newland (7), having become aware of the necessity for other than verbal tests, began active work toward the development of the Blind Learning Aptitude Test in 1952. This test has the virtue of being empirically developed in contrast to the usual practice of adapting tests for the sighted for use with visually handicapped individuals. The test and manual were published in 1969, by The American Printing House for the Blind.

Between 1954 and 1956, H. C. Shurrager, P. S. Shurrager, and S. B. Watson worked on the development of a five-test scale called Performance Scale for the Adult Blind (8). After some changes, a six-test scale evolved called the Haptic Intelligence Scale for the Adult Blind (9). Although they disclaim adaptation of the Wechsler Performance Scale, four of their tests in tactual form resemble the Digit Symbol, Block Design, Object Assembly, and Picture Completion tests of this scale. Additional tests added were the Pattern Board and Bead Arithmetic, the latter involving the use of an abacus. Their normative group was made up of 700 totally blind individuals ranging in age from 16 to 64 years, with 100 individuals in each of the age categories used by Wechsler for his WAIS norms.

The ease with which the color differences of the Kohs blocks can be translated into tactual differences has great appeal to test designers. Wattron (10) reported on the results of a study in which the Kohs material was adapted by roughening sections of wooden blocks. He found a correlation of .84 with the Hayes-Binet I.Q. and concluded that this type of performance task warranted further exploration. Ohwaki et al. (11) adapted the Kohs blocks by covering them with fabrics and developed extensive norms on the Japanese population. Suinn and Dauterman (12) utilized Ohwaki's apparatus to standardize a block design test on a significantly large population of American adult blind persons who might reasonably represent a cross section of applicants applying for rehabilitation services.

In 1957, Purdue researchers became engaged in a study of the nature of the potentialities and abilities which are related to the vocational success of the adult blind (13). It appeared logical to them to include measures of nonverbal ability in a test battery for the blind, since the greatest proportion of jobs available to the blind were industrial ones consisting of manual manipulation. The major performance tests which emerged from this project were the Vocational Intelligence Scale for the Adult Blind (14) and the Tactual Reproduction Pegboard (15).

In 1959, Anderson (16) made very ingenious copies of Raven Progressive Matrices in tactual form in order to provide a measure of performance intelligence for the adult blind. He later abandoned the project when he found so high a correlation with the WAIS Verbal Scale that almost no new information was gained by this very time-consuming adaptation. Rich (17) studied the validity of modified designs for tactual perception by blind children ages 6 to 15. Low but significant correlations were found with the WISC Verbal scores and a high concurrent correlation was obtained with academic achievement for children above chronological age 11. Further progress with this task has not been reported in the literature.

In 1962 Davis (18) reviewed the assessment of intelligence of visually handicapped children, and at that time described plans for the long-awaited adaptation and standardization of the 1960 Stanford-Binet on 2,500 blind children and young adults, ages 3 to 21. The new Perkins-Binet Test of Intelligence (now available from the Howe Press) will include verbal as well as nonverbal items.

Nolan and Morris (19) developed the Roughness Discrimination Test which had as its primary objective the prediction of braille aptitude in beginning grade school students.

In summary of the pertinent literature, the following facts appear to be relevant:

1. Performance tests have had a long successful history in testing the psychological capacities of the sighted but a relatively brief history in testing the visually impaired.

2. Performance tests have proven themselves capable of measuring functions left untapped by verbal instruments.

3. The attempts which have been made at bringing forth standardized performance measures of intelligence, learning ability, or general mental ability have resulted in commercially available tests for the blind adult 15 years old and older. The Vocational Intelligence Scale for the Adult Blind, the Tactual Reproduction Pegboard, the Haptic Intelligence Scale for the Adult Blind, and the Stanford-Kohs Block Design Test for the Blind are examples of these attempts.

4. Only one standardized performance test is presently available for blind individuals under 15 years of age--Nolan's Roughness Discrimination Test, which relates to braille aptitude. Standardized performance measures for psychological functions of blind youths other than braille aptitude, are unavailable.

CONSIDERATIONS IN THE VERBAL TESTING OF THE VISUALLY HANDICAPPED

Verbal and conceptual development in the blind individual from birth is an area worthy of extended study. This area is especially relevant since psychological testing, as carried on in most residential schools for the blind, is based almost exclusively on verbal measures derived from and normed and standardized for the sighted population.

Foulke (20), himself totally blind, has given an interesting theoretical framework within which to view the symbolic vocabulary building process of the visually handicapped. He states:

> "Because we can hear, we use language. The most basic class of words in a language is the class of words that name objects. Closely related to this class are the words that describe the sensory attributes of objects. When these descriptive words acquire common usage, and presumably common meaning, it is possible to impart to a person a knowledge of an object without the necessity for direct sensory experience with that object. Such secondhand knowledge is not a substitute for knowledge gained from direct experience. It is distorted by the irreducible subjectivity of both the sender and the receiver of such knowledge. However, the individual with a profound sensory impairment must of necessity rely upon this secondhand knowledge in many instances. Because it is frequently easier to impart knowledge about an object than to arrange for direct sensory experience with that object, people with sensory impairments usually have a much larger number of these secondhand concepts than the number made necessary by their impairment. There are, of course, certain experiences that are completely unavailable to people with profound sensory impairments. The blind person, for instance, can have no experience of color whatsoever. Nevertheless, color is a ubiquitous attribute of objects, and words that name colors are among the most common in our language. It is likely, therefore, that the blind individual will learn to use color-naming words, and, if he uses them in sufficiently conventional ways, his audience will probably not realize that he is using words which have no direct experiential meaning for him. In fact, because such words are so frequent, and because the blind child will learn to speak the language of those with whom he associates, he is likely to acquire and use a large number of these words. The consequence is that the thinking process comes to depend on concepts, a large number of which are secondhand or even completely meaningless. Thinking, so determined, is likely to achieve many conclusions that are less than valid."

Testing based on these verbal distortions may provide test results which are tenuous and unreliable. Decisions founded on such test results may, therefore, lead to less than the best outcome.

Claassen (21) has given added emphasis to that alluded to by Foulke. Claassen felt that verbal tests were inadequate for the blind child because of the following factors:

1. Blind children, out of necessity, often have a highly developed aural memory and rely many times on this ability as a substitute for thinking. There is evidence that blind children, when compared to sighted children, make disproportionately high scores on the Digit Span and Sentence Memory subtests of the Wechsler and Binet Intelligence scales, while their performance is inferior on tests of reasoning and concept formation as measured by the Comprehension and Similarities subtests of the WISC (22).

2. There are differences in the home environment of the blind child which might effect him more than his sighted peer is effected by his home environment. Furthermore, adjustment to blindness is apt to make purely verbal tests unreliable.

   a. In many homes, the blind child's primary contacts are with adults from whom he is apt to develop an adult vocabulary consisting of many polysyllabic words. But unless his parents are patient and understanding in training him and in describing and explaining things to him, he is likely to become a specialist in verbalization, much of which is meaningless to him or not fully understood. In general, social intelligence and reasoning may be woefully lacking. Many examples have also shown that I.Q.'s change significantly after first testing at an early age because of broader environmental stimulation which may be in contrast to the early more limited home environment (23).

   b. I.Q. testing of the blind is made more variable than that of the sighted not only because of variations in the environment, but also because of emotional factors and variations in the adjustment to the condition of being blind.

Claassen, in summary fashion, noted, "I am assuming that there is a high enough correlation between keenness of intelligence and keenness of tactile perception to warrant the use of performance tests for the blind either as occasional substitutes for, or in conjunction with, verbal tests."

It seems to this investigator that a serious omission has been perpetuated in testing the mental capacity of the blind child, i.e., a standardized performance test or tests for measurement of mental capacity. The need for standardized performance tests seems all the more relevant when the importance of tactual perception for the blind individual from birth is emphasized.

PREDICTION OF ACADEMIC ACHIEVEMENT

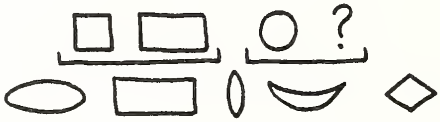
In most instances when a child enters a school for the blind, little relevant information is at hand regarding his academic potential. Some measure of this potential is urgently needed for planning an individualized program, especially during the first year. The tests which have been used in this evaluative process are exclusively verbal in nature, i.e., the Interim Hayes-Binet or the verbalized section of the WISC.

Newland, in two articles written in 1964, scrutinized the assumptions on which these intellectual evaluations are based. He states:

> "On the basis of *e* (experience) along with *c* (capacity or potential) we want to predict *a* (academic performances). In a sense, the "intelligence" tests have been developed and used as the basis of the type of thinking just described. However, in making ease-of-learning predictions, the testing has been done predominantly (in some cases solely) on the basis of our *e*. The experiences of individuals (what they had already learned up to the time of being given an "intelligence" test) were measured. The varying amounts of these experiences have been used to predict corresponding differences in future ease of learning. In probably at least 85 percent of all children this inferring-capacity-from-achievement was sufficiently accurate to make such "intelligence" testing worth the trouble. A further assumption was tucked away in this procedure: It was assumed that the cultural backgrounds of such children were essentially comparable. . . . As the results of such testing came to be analyzed more and more critically, the assumption of the comparability of experiential backgrounds has come increasingly to be challenged. . . to the extent that children's experiential backgrounds have been different from those of the group in general, the nature of the implications of such direct (or near-direct) evidence of capacity becomes particularly important. This is especially true of the blind, since their sensory impairment prevents them from encountering many of the experiences of the sighted. For blind children, most of whom fall among the other 15 percent, special efforts need to be exerted in two respects. In the first place, steps must be taken to avoid, or at least to temper, the assumption of comparability of acculturation of the blind with the non-blind.

> In the second place, there is the possibility of tapping directly, or nearly directly, the basic learning capacities of blind children. Many current "intelligence" tests have been constructed with this idea in the minds of their makers. Increasingly, such tests have contained two major categories of items: verbal and nonverbal, or language and nonlanguage. . . . (24)"

Since verbal tests may provide ambiguous results in the case of blind children due to the great amount of variability in their experiential backgrounds, what type of operation might measure basic capacity to learn independent of past learning? It is possible that those psychological processes which made achievement possible in the first place may be tapped. Newland outlined three types of tasks which might be appropriate for measuring these basic capacities, and which became the basis of the BLAT (7). A blind child tactually explores one figure and then finds its duplicate in a group of figures. Another type of task is to find the one figure that does not belong in a group. Still another type of task, somewhat more difficult, requires the blind individual to relate a figure to one in a group of five figures in the same relationship as the sample:



The blind child does not depend heavily on words to do these tasks, and when he is doing them he is employing psychological processes which contribute to his acquisition of symbols. An analysis of the first task indicates whether the blind child is able to recognize identities, just as he does when he compares the braille letter or word he has written with the correct model. The second and third items are really two aspects of the same psychological process. As one learns any concept, one not only has to be able to discern when something is different from another, but also to discover how things can (or should) go together in specified relationships. Children differ in the effectiveness with which these processes operate in them just as they do in how much life information they possess, which is usually tapped in most intelligence tests.

STUDIES RELATING INTELLECTUAL EVALUATION TO ACADEMIC ACHIEVEMENT

In the past 25 years there have been thousands of studies made on the correlation (and therefore the predictive validity) between tests of intellectual evaluation and academic achievement. Since the publication of the original 1916 Stanford-Binet Scale, many concurrent and predictive correlations have been made between Stanford-Binet I.Q.'s and school grades, teachers' ratings and achievement test scores. Most of these correlations fall between .40 and .75 (25). The number of studies of this kind with the blind, where the data have been carefully collected and analyzed, is quite small. The reasons for the dearth of such reported studies are varied. Perhaps foremost among them is that only recently have brailled standardized achievement tests been readily available. Perhaps equally contributive has been the fact that those working with blind children, particularly where there have been reasonable concentrations of blind children, have had to be oriented to service rather than to research. In isolated instances where such studies have been carried out, verbal indices of intellectual capacity have failed to indicate successfully later learning capacity. The fact is that such tests as the Interim Hayes-Binet sampled heavily the extent to which the child benefited from his early environment and relatively little of his inherent capacity to learn.

One of the few studies which has sampled the relationship of the Interim Hayes-Binet and the WISC to academic achievement was done by Lewis (26). She found a correlation of .94 between the I.Q.'s obtained by these two different scales and concluded that they were essentially measuring the same thing. In testing the relationship between I.Q. and academic achievement she arrived at the following:

1. A comparison between elementary school grade averages and the Interim Hayes-Binet I.Q.'s resulted in a concurrent correlation of .45.

2. A comparison between junior high school grade averages and Interim Hayes-Binet I.Q.'s resulted in a concurrent correlation of .46.

3. A comparison between senior high school grade averages and Interim Hayes-Binet I.Q.'s resulted in a concurrent correlation of .53.

Lewis concluded that statistical treatment (correlations) indicated the validity of her assumption that there was a positive relationship between mental ability and academic achievement. Although a positive relationship did exist, the crucial question centers around the meaning and relevance of these contingencies.

The crucial question seems to revolve around the importance of *predictive* validity as contrasted to *concurrent* validity, i.e., how well does the Interim Hayes-Binet I.Q. predict future academic achievement? Lewis did not deal with prediction.

Rich and Anderson (17), also concerned with concurrent validation, compared the relationship of the WISC and a tactual form of Raven's Progressive Matrices to various criteria of academic achievement. They found the correlations of the WISC Verbal with academic criteria to be higher than those between the CTPM (Children's Tactual Progressive Matrices) and the same criteria. The potential utility of the CTPM and the WISC Verbal as a test battery was evaluated by calculation of coefficients of multiple correlation using the CTPM and WISC as predictors and grade average as criterion. In the 12-to-15-year old group, a multiple correlation of .73 was found which appreciably exceeded the correlation of the CTPM with grade average (.61) or the WISC with grade average (.58). Two elements seem important when considering the relevance of Rich's study to the present investigation:

1. Rich, as well as Lewis, concerned himself with concurrent validation to the exclusion of predictive validation.

2. A performance task was able to increase substantially the correlation existing between a verbal task and a criterion of academic achievement.

Hecht and Newland (27) compared the Blind Learning Aptitude Test (BLAT), an experimental performance battery, to the WISC and Interim Hayes-Binet and concluded that:

> ". . . a high positive relationship does exist between the scores obtained on measures of learning aptitude (the BLAT, WISC and Interim Hayes-Binet) and those on educational achievement tests. The magnitude of the correlations suggests that such measures can be useful in educational planning. . . . These data yielded a (concurrent) coefficient of .793 between WISC MA and median achievement and of .839 between IHB MA and median achievement. . . . No single measure of learning aptitude appeared to be more predictive of school learning. The data suggest that a combination of the two kinds of behavior samples gives a more complete assessment of learning potential. The BLAT which taps nonverbal tactual perception is a useful supplement to established verbal materials, particularly during the years prior to the age of thirteen."

Hecht's finding substantiated that of Rich's by showing that performance tasks bear a positive relationship to criteria of academic achievement. Hecht's study suffered, however, from the same weakness as did those of Lewis and Rich, by dealing with concurrent validities to the exclusion of predictive considerations.

A thorough search of the literature turned up only one study explicitly concerned with predictive validity. This dealt with Nolan's Roughness Discrimination Test which has already been mentioned (28). Predictive validity for the first grade (N = 175) was determined by correlating RDT scores obtained during the initial two months of the first year of school with reading criteria obtained during the final two months of the same school year. The reading criteria were error and reading time scores derived from a braille adaptation of the Gilmore Oral Reading Test. The Pearson product-moment correlation between RDT scores and reading errors was found to be -0.53 ($p < 0.01$) and the correlation between RDT scores and reading times -0.57 ($p < 0.01$). In addition, Nolan found that prediction (N = 58) using both RDT scores and I.Q.'s yielded higher multiple correlations with reading criteria (R = 0.51 for errors and 0.48 for time) than when either RDT scores (r = -0.42 and -0.42) or I.Q.'s (r = -0.41 and -0.36) alone were used as predictors. Nolan's findings suggested the possibility of using performance tasks as predictors of academic achievement.

In summary of the discussion thus far, some observations are relevant. There is a dearth of studies explicitly concerned with prediction of academic achievement in blind children. The one study cited dealing with prediction showed that performance tasks can be correlated to later academic achievement. Concurrent validation studies show that performance measures bear a relationship to criteria of present academic achievement. Both types of studies indicate that performance predictors combined with verbal predictors can increase multiple correlations with academic criteria over and above the separate correlations which existed between each predictor and the criteria of academic achievement.

REFERENCES

1. S. P. Hayes. "Stanford Achievement Tests for the Blind: New and Old." *Teachers Forum*, 1941, Vol. 14, pp. 2-15.
"Alternative Scales for the Mental Measurement of the Blind." *Outlook for the Blind*, 1942, Vol. 36, pp. 225-230.
"Vocational Aptitude Tests for the Blind." *Perkins Publications No. 14*. Watertown: Perkins Institute and Massachusetts School for the Blind, 1946.
"Measuring the Intelligence of the Blind." In P. Zahl (Ed.), *Blindness*. New Jersey: Princeton Univ. Press, 1950, pp. 141-173.
Contributions to a Psychology of Blindness. New York: American Foundation for the Blind, 1952.

2. T. D. Cutsforth. *The Blind in School and Society.* New York: D. Appleton, 1933.

3. W. L. Dauterman, B. Shapiro, & R. M. Suinn. "Performance Tests for the Blind Reviewed." *International Journal for the Education of the Blind,* 1967, Vol. 17, pp. 8-16.

4. M. K. Bauman. "Report on a Nonlanguage Learning Test." *American Association of Workers for the Blind Proceedings,* 1947.

5. M. K. Bauman. *Adjustment to Blindness.* Harrisburg: State Council for the Blind, Commonwealth of Pennsylvania, 1954.

6. D. C. MacFarland. "An Exploratory Study Comparing the Maze Learning Ability of Blind and Sighted Subjects." *New Outlook for the Blind,* 1952, Vol. 46, pp. 259-263.

7. T. E. Newland. "The Blind Learning Aptitude Test." In *Report Proceedings of Conference on Research Needs in Braille.* New York: American Foundation for the Blind, 1961, pp. 40-51.

8. S. B. Watson. "Development and Standardization of a Performance Scale for Adult Blind." Unpublished doctoral dissertation, Illinois Institute of Technology, 1956.

9. H. C. Shurrager, & P. S. Shurrager. *HISAB Manual: Haptic Intelligence Scale for the Adult Blind.* Chicago: Psychology Research, 1964.

10. J. B. Wattron. "A Suggested Performance Test of Intelligence." *New Outlook for the Blind,* 1956, Vol. 50, pp. 115-121.

11. Y. Ohwaki, Y. Tanno, M. Ohwaki, T. Hariu, K. Hayasake, & K. Miyake. "Construction of an Intelligence Test for the Blind" (Ohwaki-Kohs Tactile-Block Intelligence Test). *Tohoku Psychological Folia,* 1960, Vol. 18, pp. 45-65.

12. R. M. Suinn, & W. L. Dauterman. *Manual for the Stanford-Kohs Block Design Test for the Blind; Final Report. Part Three.* VRA Project No. RD-1625S. Palo Alto, Calif.: Stanford University School of Medicine, 1966.

13. J. Tiffin, M. MacDaniel, & R. J. Teare. "An Investigation of Vocational Success with the Blind." Final Report: SP-188. Washington, D.C.: Vocational Rehabilitation Administration, Department of Health, Education and Welfare, 1960.

14. W. R. Jones. "Development of a Nonverbal Intelligence Scale for the Adult Blind." *Correlates of Adjustment to Vision Loss: A Symposium.* (Read at the American Psychological Association, Philadelphia, August 1963.) Wichita, Kansas: University of Wichita, December 1963.

15. A. Gruber. "Testing the Psycho-motor Skills of the Blind: The Development of a Measure of Tactual Perceptiveness and Gross Manipulative Dexterity." *Correlates of Adjustment to Vision Loss: A Symposium.* (Read at the American Psychological Association, Philadelphia, August, 1963.) Wichita, Kansas: University of Whichita, December 1963.

16. R. P. Anderson. *Modification of the Raven Progressive Matrices for the Blind.* Unpublished progress report and request for continuation. Project 670-61-1, U.S. Office of Vocational Rehabilitation, 1961.

17. C. C. Rich, & R. P. Anderson. "A Tactual Form of the Progressive Matrices for Use with the Blind." *Personnel and Guidance Journal*, 1965, Vol. 43, pp. 912-919.

18. C. J. Davis. "The Assessment of Intelligence of Visually Handicapped Children." *International Journal for the Education of the Blind*, 1962, Vol. 12, pp. 48-51.

19. C. Y. Nolan, & J. E. Morris. "Development and Validation of the Roughness Discrimination Test." *International Journal for the Education of the Blind*, 1965, Vol. 15, pp. 1-6. (a)

20. E. Foulke. "The Role of Experience in the Formation of Concepts." *International Journal for the Education of the Blind*, 1962, Vol. 12, pp. 48-51.
"A Multi-sensory Test of Conceptual Ability." *New Outlook for the Blind*, 1964, Vol. 58, pp. 75-77.

21. R. Claassen. "Tests for the Blind." *International Journal for the Education of the Blind*, 1954, Vol. 4, pp. 12-15.

22. J. G. Gilbert, & E. J. Rubin. "Evaluating the Intellect of Blind Children." *New Outlook for the Blind*, 1965, Vol. 59, pp. 238-240.

23. D. Kosimar, & M. MacDonnell. "Gains in I.Q. for Students Attending a School for the Blind." *Journal of Exceptional Children*, 1955, Vol. 54, pp. 127-129.

24. T. E. Newland. "Prediction and Evaluation of Academic Learning by Blind Children: I - Problems and Procedures in Prediction." *International Journal for the Education of the Blind*, 1964, Vol. 14, pp. 1-7. (a)
"Prediction and Evaluation of Academic Learning by Blind Children: II - Problems and Procedures in Evaluation." *International Journal for the Education of the Blind*, 1964, Vol. 14, pp. 42-51. (b)

25. A. Anastasi. *Psychological Testing.* New York: Macmillan, 1954.

26. L. L. Lewis. "Relation of Measured Mental Ability to School Marks and Academic Survival in the Texas School for the Blind." *International Journal for the Education of the Blind,* 1957, Vol. 6, pp. 56-60.

27. P. J. Hecht, & T. E. Newland. "Learning Potential and Learning Achievement of Educationally Blind Third-Eighth Graders in a Residential School." *International Journal for the Education of the Blind,* 1965, Vol. 15, pp. 33-38.

28. C. Y. Nolan, & J. E. Morris. *Roughness Discrimination Test Manual.* Kentucky: American Printing House for the Blind, 1965. (b)

A PRELIMINARY REPORT ON ULTRASONIC SPECTACLES FOR THE BLIND

L. Kay*

INTRODUCTION

The design of ultrasonic "spectacles" for the use of the blind has been completed recently, and an experimental prototype incorporating the final design has now been tested. The design is the culmination of ten years of research on the use of ultrasonic energy as a sensory aid for the blind, on the generation and reception of ultrasonics in air, on the study of auditory perception, on the presentation of auditory information to the ear, and on the problem of the mobility of blind travellers.

During the past three years, a group at Canterbury** has been working on the technical development of the spectacles, and studying to obtain the optimum form of display of auditory information to the blind person.

Investigation has been made to determine what information is essential for blind mobility. We think the simultaneous concern with the several aspects of the problem of mobility is unique, and a marked departure from previous practice in the development of sensory aids to mobility.

Blind subjects are now to be taught the use of the spectacles in conjunction with the long cane. The research program using 20 subjects, includes an assessment of the system by the end of 1970.

PRINCIPLE OF THE ULTRASONIC SPECTACLES

A number of studies have shown that the processing of environmental information used in the previously developed single-channel environmental sensor (the "Kay Sonic Aid"), provides an extremely rich output to the user. The spectacle version of the aid uses the same basic principle. (It is not our intention to give a detailed description of the entire system here as it is too complex, but only to convey a meaningful picture to the non-specialist.)

---

*Department of Electrical Engineering, University of Canterbury, Christchurch, New Zealand.

**The group consists of D. Rowell, Psycho-acoustic Engineer; G. Martin, Electronics Engineer; R. Pugh, Peripatologist; and G. Clark, Technical Officer.

Ultrasonic energy is radiated continuously through a cone of about 50 degrees solid angle (to the half-power points) from a radiator located at the center of the forehead. Energy flow in the center of the cone is greater than at the edges by a factor of two to one. Beyond the edges the energy fades slowly, and at angles greater than + or -50 degrees it is relatively weak.

Objects in space reflect some of the radiated energy to two receivers mounted adjacent to the radiator in the spectacle frame. The radiator and the two receivers are mounted in such a way that the frame may also carry optical lenses if desired (see Fig. 1). Thus, users who have some useful remaining vision may continue to use it. Colored lenses may be used also if desired.

Signals generated by reflection from objects in space are converted into audible sounds. Pitch of the sound is proportional to distance, and loudness gives an indication of the reflection properties of an object. Thus, a wall will produce a louder sound than a pole, but both objects would produce the same pitch if they were at the same distance and the wall were smooth. (The sound quality would differ if the wall were rough.)

Two receivers are used to provide binaural display of directional information. The left receiver feeds into the left ear, the right receiver into the right ear; the relative intensity of the signals in the two ears varies with direction. By correct shaping of the receiver polar response, it is possible to produce an auditory sensation which preserves the accuracy of direction from which the echo is obtained. The auditory response of individuals varies considerably, so that the shaping of the receiver response to suit one user may produce little or no indication of direction for another user. Clinical fitting, therefore, becomes essential. The design is such that it is not difficult to adjust the polar response to match an individual user's localizing function, but the measurement of that function under field conditions may pose some problems.

On first using the binaural device, the sound which it produces appears close to the forehead. A single pure pulsating note such as that elicited by the reflection from a pole, may appear to be somewhere inside the head, between the ears, depending on direction. After some experience with the aid, however, the sound begins to be projected outwards. The degree to which this phenomenon occurs varies among individuals. We have not measured the phenomenon since no one has used the device long enough to adapt fully to it; in fact only a few persons have had any experience with it. Opinion is unanimous that the sounds produced at the ears are not unpleasant to listen to.

The elevation of an object can be determined by an up and down motion of the head, the height being estimated from the angle of the head when the sound output is greatest. Although the description implies a nodding action, this is not so; a slight motion can indicate an upward or downward elevation relative to the height of the head, and that is all that is required. There are other factors involved while walking, to be discussed below.

GENERAL SPECIFICATION OF THE AID

The detection angle of the system is approximately 70 degrees. The angle can be varied in manufacture, and we shall decide upon a final value only after extensive user trials. An optimum detection depends in part on the individual localizing function (mentioned above) and on the ambient noise level.

The accuracy with which a user can determine direction is at least as good as it is for natural sounds. There is also some evidence that, with experience, this accuracy can improve.

If two objects are separated by a distance of 0.2 of their mean distance to the observer, they can be easily resolved. Subjects tested so far require differing minimal separations: as little as 0.04 to as much as 0.4, of the mean distance.

Whether more than two objects can be resolved is yet to be determined under laboratory conditions. It is well to keep in mind, however, that laboratory results may have very limited generality, since the effect of forward, sideways, and angular motion of the head while walking can have a significant influence on resolution of objects.

Detection range of the spectacles extends to about 30 feet. The maximum range is dependent on the pitch/distance relationship required by the user, and on his hearing ability. In the prototype design, and probably in future units, a wall at 30 feet will produce an output signal of 6 kHz. Beyond this distance the auditory display is poor. The sensitivity is such that a 1 1/2-inch diameter pole can be detected at 20 feet (the audible output is a tone of 4 kHz). Loudness increases as the distance is reduced. The output sound quality remains good down to a distance of about 6 inches (which gives a tone of about 100 Hz). The technology available to us does not permit any significant improvement on this performance except by tight coupling of earphones to the ear; a highly undesirable feature if the use of ambient sound is desired, as is usually the case.

The audible output is coupled to the ears through a small diameter plastic tube from the earphone, mounted in the temple area of the spectacle frame, down to the entrance of the ear canal. The tube does not touch any part of the ear, and there is no sensation of an obstruction near the ear. Persons with a highly developed auditory sense ("facial vision") note a barely perceptible change, to which they quickly accommodate.

FIG. 1.

Under quiet conditions the user hears no hiss or clicks, only reflections from objects. The sound level of the output can be varied by the user down to near-inaudibility. Under very noisy conditions, as in heavy traffic intersections where the noise level may peak to 85 phons, the sound level of the device may be increased until it is quite audible. When there is uncertainty between traffic noise and the output of the aid, this can be resolved by the user flicking a high-low gain-control switch, whereupon he can fix his attention on the desired signal; on the high-gain setting the sound of the device will predominate. Under high-noise conditions, as in traffic, the maximum range of the system will be reduced, but most street poles will still be detected at 15 feet on the high-gain setting.

PHYSICAL DESCRIPTION

The shape of the spectacle frames in Fig. 1 is not fixed; considerable variation to suit personal preference is possible, as with any other spectacle frame. It is not possible to hide the fact that the spectacles do not use the usual optical frame, but they need not be funny, ugly, or otherwise objectionable. The acceptance of the appearance of the aid by the sighted is an objective sought, but the effectiveness of the aid is our overriding consideration.

With the exception of small preamplifiers in the temple pieces, the electronics are mounted in a case along with a rechargeable battery. A cable connects the case to the frame. While considerable thought and effort has gone into the optimum design, in terms of performance, weight, cost, reliability, and the like, the transmitter is simply too large to be mounted in the spectacle frame. If user demand warrants, microlinear integrated circuits can be used in the aid, greatly reducing their present bulk. Since the cable is present whether the receiver electronics are in the frame or in a separate case with the transmitter, it is economical to use the latter arrangement.

Since the aid may be in use continuously for some hours, a battery service life of four hours has been chosen. A spare charged battery can be carried for longer use periods.

The case housing the electronics and battery measures approximately 3 x 2-1/2 x 1-1/8 inches. There are two controls, an on-off/volume, and a high-low gain switch.

PERFORMANCE OF THE UNIT

A few examples of the performance of the aid with inexperienced users may help in giving some idea of the potential of the system.

RING OF POLES

A ring of 10 half-inch diameter poles was set up outdoors. The ring was 16 feet in diameter. The starting point was indicated by an additional pole beside one of the poles forming the ring. A blindfolded sighted subject standing at the center of the ring was able to count the poles, even though there were always two poles in the field of view, and at very nearly the same distance. The difference between a single pole and double poles was easy to detect.

LINE OF POLES

A line of 12 poles, spaced five feet apart, was set up outdoors. The task for the subject was to walk in a line parallel with the poles, two to three feet from them, to the end of the row; then to walk around to the other side of the row and return to the starting point, again keeping parallel to the row. One subject, who had had some familiarity with the "language" of the single-channel torch aid (the "Kay Sonic Aid"), required only 30 minutes' orientation in the use of the spectacles before she accomplished the task. Her movement appeared naturally graceful, and she showed no excessive turning of the head. She had had no prior experience in following a shore line.

LONG STRAIGHT WALL

With a very short practice time, a subject can walk parallel to a straight wall four feet away without looking at it, and can tell before reaching the end point where the wall ends. Downpipes, buttresses, and the like are detected along the way, as are changes in texture or structure.

PASSING OBJECTS

When one passes an object, its relative angular position and its distance changes. These data allow a sighted person to pass an object at a predetermined distance without sudden changes of course. Similar behavior is permitted by the spectacles: the range, rate of change of range, angular position, and rate of change of angle, provide the necessary information. Course accuracy is not as high as with the sighted navigator, but it is sufficient to permit confident avoidance behavior.

The accuracy is also sufficient to allow the navigator to check on the straightness of his course on an open sidewalk past lamp posts. Users report that it is reassuring to "hear" a lamp post in its correct position in the distance while walking, and then to hear it pass by at the correct place. This is what one experiences.

DOORWAYS

When walking down a corridor, two to three feet from the wall on either side, the doorways can be counted without turning the head. One can also tell whether the door is open or closed. It is more difficult to pass through an open door at the end of a corridor, due to ambiguities in the system itself. That is, if two features of the environment (such as the sides of a doorway) are at the same distance and separated by an angle of 30 degrees, they are detected by a sound signal which resembles that of another object midway between them. The sound quality is not that of a closed door nor that of an open door. Perhaps it can best be described as "ghost-like," because as the doorway is approached the image vanishes, and the sides of the doorway become clearly discernible. The effect is somewhat disturbing at first, but one learns to recognize it quickly. We suspect large individual differences in accommodating to the effect.

OVERHEAD OBJECTS

Overhanging branches of trees, tops of doorways, shop signs, and the like which are clear of the head, can be detected as objects in the ultrasonic beam. The parameters of the device provide a clue to height, provided that the pattern of sound is correctly interpreted. When one is about to pass under an overhanging object, it is heard at, say, a distance of ten to twelve feet, depending on its reflectivity and its position in the beam. As it is approached, at a walking pace, the audible signal grows quickly weaker rather than stronger, the reason being that the object is moving out of the beam over the head. The rate at which the signal vanishes indicates the height, and a slight drop of the head confirms this, since the effect is accelerated. Recall that with the wide field of view, an object can be monitored continuously. Height is difficult to judge accurately at ten feet, but at a distance of six feet the pattern of sound has usually changed sufficiently to permit fairly good judgments to be made within the time scale involved. The vertical beam of the aid is normally tilted down slightly, due to the fitting angle and the altitude of the head position. This removes the up/down ambiguity almost completely, except at small angles.

MOBILITY AND ORIENTATION

The value of the long cane has by now been well established. Many users are able to travel in a relaxed and comfortable way in most situations. Obstructions such as those above the waist level, which do not broadcast their presence create enough stress to impede naturalness. Similarly, straight line travel or travel across intersections having well-marked curbs, are relatively easy for long cane users. Curbs not well defined are common dangers over the world. Most long cane users know that there are shortcomings in its use, but when no alternative is available one tends to ignore or suppress them. Where, then, would a new aid to mobility fit into the travel pattern of the long cane user?

The spectacles are clearly a useful adjunct to the cane. The spectacles do not protect the feet, the cane does not protect the head. The combination can, therefore, be of some value. Where the cane is of little value, as in orientation, the spectacle aid excels. With a range of 30 feet, orientation is much enhanced. Users say that it is comforting to reach the end of a sidewalk at a controlled intersection, find the traffic light pole, press the pedestrian pass button, wait for the traffic to stop, locate the position of the stopped traffic, cross in front of them at a clear distance, hear the signal from the traffic pole on the opposite side, and finally "home in" on it.

It is evident that the spectacles do add an increment of value to the information generating capability of the cane, without detracting from the value of the cane. Moreover, the sonic aid leaves the hands free, and requires only occasional adjustment of the volume control.

TRAINING

We are not yet able to say how much training in the use of the spectacles will be required to enhance mobility. Some subjects are now being trained to use the long cane and spectacles while blindfolded. When we have learned enough from the sighted blindfolded subjects, we shall try to teach blind persons to use the combination. The staff mobility and orientation instructor is teaching long-cane technique, and at the same time is developing a training method to use with the spectacles.

The test situations described above prove to be relatively easy, in the sense that little training is required. Only a knowledge of what one can expect from the device system is required to complete the tests satisfactorily. There appear to be two factors governing competent use in most situations:

1. Correct fitting of the aid to insure a match to the individual localizing function, thus permitting the most natural perception of direction for the wearer.

2. Appreciation of the pitch distance cue under travel conditions. We have found this appreciation to be different from static conditions.

There are certain complex situations requiring additional learning, but these are rarely encountered during travel outdoors. Movement of the head is so natural that we did not think it needed to be taught, but we suspect that some blind persons may have to learn or relearn this natural behavior.

The indications are that the use of the spectacles will not be hard to teach. No mechanical skills are required, and its essential features can be absorbed while learning the use of the long cane. Overlearning and nonconscious conduct of the required search patterns will take time to acquire, of course, but we feel that when a user has learned the long cane technique, he should also have had enough time to assimilate the use of the spectacles in his mobility behavior.

Initially, we intend to make the spectacles available only to persons who have learned the long cane technique, who are about to learn it, or who are learning to use the guide dog. When we have gained experience in teaching these persons, we hope the spectacles will be found to have a more general use as an environmental sensor.

INTRODUCTION OF THE SPECTACLES

By the end of 1970, we think enough experience will have been gained teaching blind people to use the spectacles that we shall be able to prepare a manual for use by mobility trainers. We propose to give a course for mobility and orientation instructors early in 1971, in which the aid can be evaluated effectively from their point of view. We think that the spectacles can be introduced into long cane and guide dog curriculae with but minor changes. An adequate field evaluation of the spectacles on a wide scale should be relatively simple and inexpensive. Since only major mobility training centers would be involved, each could prepare an evaluation report, including followup of trainees. With close liaison maintained by the research team in these efforts, we expect to gain considerable knowledge of the problems which arise in the field, to broaden the interchange of ideas, and to plan ahead for the time when the use of the device with young children can be planned.

RESEARCH

We have given no details of the psychoacoustic research undertaken by the research group during the last three years in this report. It is now being incorporated into a doctoral dissertation, and will be published separately. We are currently engaged in further psychoacoustic experiments oriented toward better understanding of the man-machine system. We are also developing an effective method of clinical testing.

No further technological development of the device itself is planned unless it is seen that a significant improvement in performance of the system could be gained. Some thought is being given, however, to controlling the receiver gain from the ambient-noise level. This refinement cannot be seriously considered until complete microminiaturization is undertaken.

ROLE OF THE "KAY SONIC AID" OR TORCH

Our enthusiasm for the spectacles may lead some to infer that the torch aid has a limited future. This is not the case. Indeed, the torch is capable of providing information in a variety of situations where the spectacles cannot, because of the high resolution combined with a narrow beam and the low height at which the torch is typically used. One must remember that there are also those people who, for one reason or another, cannot use either a long cane or a guide dog. We think that there is now sufficient knowledge of the training requirements for the torch to say what can be achieved with it, and at what cost in effort. The spectacles do seem to have greater potential, but one should avoid a hasty decision in a matter which would deprive some blind persons of aid in a limited environment. Indeed, we feel that we often encounter rather too much emphasis on mobility as a general concept, and rather too little emphasis on mobility in a specified area or along specified routes. It is the latter which seem to be the real need of the blind traveller. This is, however, the subject of another paper at a later date.

AN ELECTROMECHANICAL BRAILLING SYSTEM*

Richard W. Woodcock

American Guidance Service, Inc.**

This report reviews briefly the progress of several interrelated projects underway since 1961. The initial objective of these projects was to develop and evaluate a system of electromechanical devices for facilitating the transcription and small-scale reproduction of braille materials. Since January of 1964 the focus of the project has been broadened to include activities related to training potential users of the system.

HISTORY

Work with this system was begun by Richard Woodcock in 1961 at Colorado State College. At that time a pilot model of the system was designed and constructed to demonstrate the feasibility of the concept. The pilot model was comprised of an electrically-operated braille writer and several input devices for controlling the brailler. These input devices included an electric keyboard with the same configuration of keys as a manual brailler, a keyboard designed for one-hand operation similar in appearance to small adding machine keyboards, a typewriter keyboard which incorporated electric circuits for translating typing into equivalent braille-cell combinations, and a perforated paper-tape reader for automatic reproduction of braille materials. This pilot model was exhibited at the International Congress on Technology and Blindness held in New York City, June 1962.

Since January 1963 the project has been supported through research grants from the National Institute on Neurological Diseases and Blindness (U.S. Public Health Service). These funds have been used for redesigning and improving the system, evaluating its mechanical and electrical reliability, developing a self-instructional manual for braille transcribers using a specially modified Teletypewriter, and conducting a comparative study of three approaches for training braille transcribers.

---

*This project is supported by PHS research grant NB 05150 from the National Institute of Neurological Diseases and Blindness for the period 1/1/63 to 12/31/66.

**Publisher's Building, Circle Pines, Minnesota 55014. At the time this paper was written, the author was a faculty member of the J. F. Kennedy Center for Research, George Peabody College for Teachers, Nashville, Tennessee.

PRESENT STATUS

EQUIPMENT DEVELOPMENT

Equipment development since 1962 has been focused primarily upon three items: an electric brailler, a perforated paper tape reader, and a specially modified Teletypewriter for use by braille transcribers.

Until recently, developmental work on the electric brailler has been concentrated upon concept of an auxiliary power unit to be attached externally to a standard manual brailler such as a Perkins or a Lavender. This auxiliary unit operated the manual brailler through solenoids and a small motor. Recently Howe Press, manufacturer of the Perkins brailler, has built an electric brailler for the project. Figure 1 shows the appearance of this electric Perkins to be the same as the manual model except for a small motor mounted on the left side. Howe Press is continuing development of this device and may put an electric Perkins in production if the developmental models perform satisfactorily. Essentially, an electric brailler has the same advantages over a manual brailler as an electric typewriter has over a manual typewriter. Furthermore, the electric brailler has provision for electrical connections allowing operation by automatic paper-tape equipment, or special keyboards such as a typewriter keyboard. The estimated cost of an electric brailler in production, would be over $100, but probably less than $200.

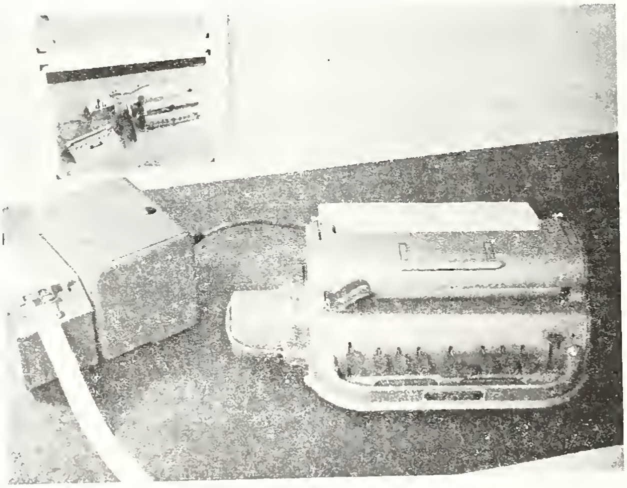


Figure 1. Electric Perkins Brailler with Tape Reader Attached for Automatic Operation.

The problem of providing a low-cost perforated paper-tape reader for the system has received considerable attention. Such a device will allow the use of any paper tape, punched according to the "Recommended Codes for Paper-Tape and Card-Controlled Braille Equipment" (Conference on Automatic Data Processing and the Various Braille Codes, Massachusetts Institute of Technology, March 17-18, 1961). Commercially available units, suitable for this purpose plus the necessary buffering circuits would cost approximately $500 to $600. A modified Teletype tape reader has been designed for use with this equipment which may cost $200 or less in production.

A significant outcome of this project has been the development of a specially modified Model 33 Teletypewriter for use as a braille transcribing device. Three major modifications were made by the Teletype Corporation in redesigning the Model 33 Teletypewriter as a braille transcribing device. First, the keyboard has been specially labeled, as shown in Fig. 2. Second, extensive redesigning of certain internal mechanisms was necessary in order to operate the machine in accordance with the braille code, rather than the machine code used by the Teletype Corporation in its equipment. Third, a special set of printed characters has been designed to represent the meanings associated with each of the 63 braille-cell combinations. This set of printed characters with associated braille-cell combinations and meanings in Grade 2 braille, are shown in Table 1. This set of print characters has been termed a *type-counterpart braille* by the project staff. This term has been reduced further to *tyco-braille*. The modified teletypewriter is referred to by the project staff as a *Tyco-brailler*. The basic output of these machines is a perforated paper tape, which in turn is used by a paper-tape reader to operate an electric brailler automatically. These tapes may be used also to operate stereotyping equipment in printing houses for the blind.

The development and use of this set of print characters is of special interest to sighted transcribers since it allows material transcribed into braille to be proofed visually by reading printed characters, rather than reading the embossed braille. Thus, it is not necessary for a braille transcriber using the Tyco-brailler to learn the braille cell combinations. This system of print characters provides an exact one-to-one relationship between braille cells and print characters. Figure 3 illustrates the tyco-braille printout obtained from the Tyco-brailler.

The Tyco-brailler is available from the Teletype Corporation as Model 33TC7571S (Fig. 4). Its present cost is approximately $1600, however, this price may be reduced somewhat if production lots become large enough so that the machines could be assembled on Teletype's production line rather than in their model shop. This project ordered three additional Tyco-braillers which were placed in the field for trial and evaluation.

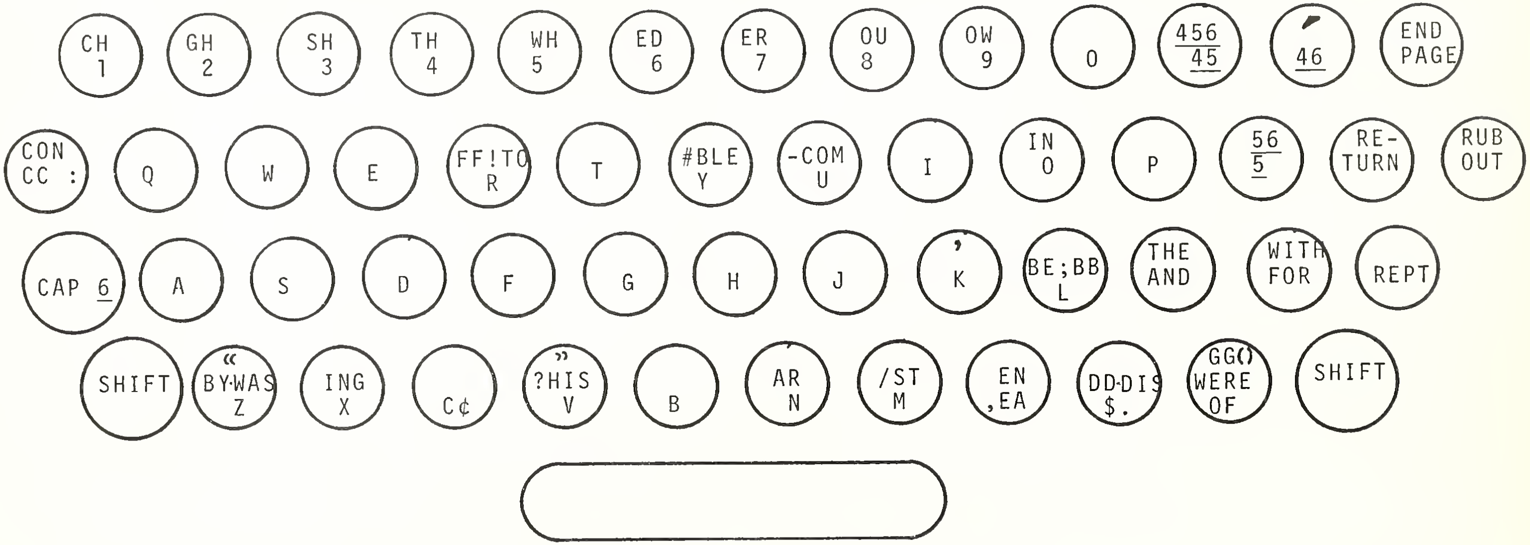
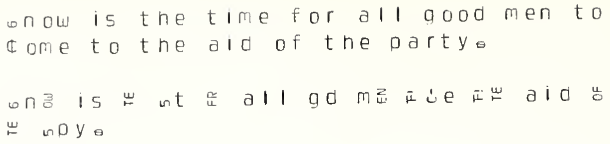


Figure 2. Tyco-brailler Keyboard

TABLE 1

Comparative Chart of Braille and Tyco-Braille Symbols

Braille Symbol	Tyco-Braille Symbol	Associated Meanings	Braille Symbol	Tyco-Braille Symbol	Associated Meanings	Braille Symbol	Tyco-Braille Symbol	Associated Meanings
⠁	a	a 1 (one)	⠧	V	v very	⠪	OW	ow
⠃	b	b but 2	⠺	W	w will	⠩	SH	sh shall
⠉	¢	c ¢ can 3	⠭	X	x it	⠌	S/	st still /
⠙	d	d do 4	⠽	y	y you	⠹	TH	th this
⠑	e	e every 5	⠵	Z	z as	⠱	WH	wh which
⠋	f	f from 6	⠜	AR	ar	⠯	&	and
⠛	g	g go 7	⠆	B;	bb be ;	⠴	B"	by was " (closing)
⠓	h	h have 8	⠼	#	ble number sign	⠿	FR	for
⠊	i	i 9	⠒	C:	cc con :	⠦	H?	his ? " (opening)
⠚	j	j just 0 (zero)	⠡	CH	ch child	⠔	IN	in
⠅	k	k knowledge	⠤	C-	com -(hyphen)	⠷	OF	of
⠇	l	l like	⠲	Đ.	dd dis $. (period)	⠮	TE	the
⠍	m	m more	⠂	E,	ea , (comma)	⠾	WT	with
⠝	n	n not	⠢	EN	en enough	⠘	45	45
⠕	o	o	⠫	ED	ed	⠨	46	46 italic sign . (decimal)
⠏	p	p purple	⠻	ER	er	⠸	.5.	456
⠟	q	q quite	⠖	F!	ff to !	⠐	5	5
⠗	r	r rather	⠶	G()	gg were ( )	⠰	56	56 letter sign
⠎	s	s so	⠣	GH	gh	⠠	6	6 capital sign
⠞	t	t that	⠬	NG	ing	⠄	'	' (apostrophe)
⠥	u	u us	⠳	OU	ou out	⠈	/	ʼ (accent sign)



```
6now is the time for all good men to
¢ome to the aid of the party.

6nOW is TE 5t FR all gd mEN F ce FTE aid OF
TE 5py.
```

Figure 3. Samples of Grade 1 and Grade 2 Tyco-braille Printout.

Figure 4. Tyco-brailler (Model 33TC7571S Teletype).

TYCO-BRAILLER TRANSCRIBER MANUAL

Since June 1964 extensive effort has been made toward developing a self-instruction manual for the training of braille transcribers using the Tyco-brailler. The braille manual by Ashcroft and Henderson, entitled *Programmed Instruction in Braille*, was used as a point of departure in developing the tyco-braille transcriber manual. The purpose of this manual is to provide instruction in the Grade 2.0 braille code and in the operation of the Tyco-brailler for future braille transcribers.

The present manual has been developed through several pilot runs with college students serving as subjects for the training of braille transcribers. As the subjects proceeded through the manual, their evaluation and criticism of each lesson was subsequently used in rewriting the manual.

COMPARATIVE STUDY OF BRAILLE TRANSCRIBER TRAINING APPROACHES

Since October of 1964 a comparative study of three approaches for training braille transcribers has been underway: the Library of Congress training program for braille transcribers, the Ashcroft-Henderson *Programmed Instruction in Braille*, and the Tyco-brailler approach. Approximately 20 subjects are being trained under each of the three approaches. Hours required to complete the training program, and transcribing accuracy are to be analyzed.

PROJECT STAFF

The following three persons were involved extensively in the project. Further information may be obtained from any one of them:

Dr. Samuel C. Ashcroft, co-investigator, was interested primarily in development of the tyco-braille manual.

Miss Carol Halliday, research assistant, had responsibilities primarily in developing the tyco-braille manual and in supervising the subjects participating in the comparative study of approaches for training braille transcribers.

Dr. Richard W. Woodcock, principal investigator, was primarily involved in the equipment development aspect of the project.

PUBLICATIONS OF NOTE

Benjamin, J. M., Jr. "A Review of the Veterans Administration Blind Guidance Device Project," *Bulletin of Prosthetics Research*, 10(9), pp. 63-90, Spring 1968.

Freiberger, H. "Progress on Veterans Administration Research Projects in Sensory Aids," *Bulletin of Prosthetics Research*, 10(9), pp. 193-201, Spring 1968.

Foulke, E. *The Comprehension of Rapid Speech by the Blind: Part III.* Final Progress Report, HEW Project No. 2430, Grant No. OE-4-10-127. Louisville, Kentucky: Non-Visual Perceptual Systems Laboratory, Graduate School, University of Louisville, September 1, 1969.

Hertzberg, R. "Twenty-Five-Year Follow-up of Ocular Defects in Congenital Rubella," *American Journal of Ophthalmology*, 66(2): 269-271, August 1968.

Lauer, H. L. "The Visotoner: A Personal Reading Machine for the Blind," *Bulletin of Prosthetics Research*, 10(9):99-103, Spring 1968.

Leonard, J. A., Armstrong, J. D., and Sharpe, R. "The Sonic Aid: Two Evaluations," *The New Beacon*, London, England: Royal National Institute for the Blind, 224 Great Portland St., LIII(632):317-319, December 1969.

Lotterman, S. H., Kasten, R. N., Revoile, S. G. "An Evaluation of the CROS-Type Hearing Aid," *Bulletin of Prosthetics Research*, 10(9): 104-109, Spring 1968.

Martin, W. P. *A Computer-Based Environment for Compression Experiments with Code Sounds from the Lexiphone*, Canada: The University of British Columbia, a thesis, Dept. of Electrical Engineering, Faculty of Applied Science, July 1969.

McClung, R. R. "Short Term Field Evaluation of Type 8A9 Ultrasonic Aid for the Blind," *Bulletin of Prosthetics Research*, 10(9):91-103, Spring 1968.

Nance, G., Causey, G. D. "Hearing-Aid Evaluation: An Examination of Two Procedures," *Bulletin of Prosthetics Research*, 10(9):119-124, Spring 1968.

Rusinov, V. S. (ed.). *Electrophysiology of the Central Nervous System.* New York: Plenum Publishing Corp. London: Donington House. 1969.

Scholl, G. T., Bauman, M. K., and Crissey, M. S. *A Study of the Vocational Success of Groups of the Visually Handicapped.* Research Grant #RD-2554-S, Division of Research and Demonstration Grants, Social and Rehabilitation Service, Department of HEW. Ann Arbor, Michigan: University of Michigan, School of Education, November 1969.

Scopelite, T. M. *Evaluation of an Upward Braille Writing Device.* Final Report, HEW Project J6032. Illinois: Engineering Mechanics Division, IIT Research Institute, January 1969.

"Sensory Aids for the Blind: Report of a Conference Held at the National Academy of Sciences, Washington, D.C., March 30-31, 1967," Committee on Prosthetic Research and Development, National Research Council, *National Academy of Sciences*, 1968.

Simon, G. R. "Physical Performance of Hearing Aids as Affected by Receiver Substitution," *Bulletin of Prosthetics Research*, 10(9):110-118, Spring 1968.

Witkin, H. A., et al. "Cognitive Patterning in Congenitally Totally Blind Children," *Child Development*, Illinois: The Society for Research in Child Development, Inc., 39(3):767-786, September 1968.

Zimmerman, D. R. "Shall We Have 'Seeing Aids' for the Blind?" *Today's Health*, published by the American Medican Association, 47(12):20-23, 79-81, December 1969.

Name: Braille Display Module

Source: N. B. Sutherland
The MITRE Corporation
P.O. Box 208
Bedford, Massachusetts 01730

Availability: Laboratory prototype

The device is intended to respond to machine-generated codes or electrical signals, converting them to braille. The module displays the equivalent of one braille cell by means of six sliding metal pins. It is operated by a combination of pneumatic and electromechanical action. The modules are plug-in units, 1/4-inch wide, which provide the standard spacing for braille when stacked in a row. The size of a display can be tailored to fit a particular application. While the pins are intended to be read directly, a permanent record can also be embossed from them when the display is locked into position.

Name: Punched Card Reader for the Blind

Source: James C. Swail
Radio and Electrical Engineering Division
National Research Council of Canada
Ottawa 2, Ontario, Canada

Availability: Production prototype

A manually operated mechanical device enabling a blind programmer to read single punched cards at his desk. A carriage with a row of 12 pins is moved across the card inserted in the Reader. Whenever a hole is encountered the appropriate pin rises, the carriage can be stopped, and the location of the hole identified from the raised scales on the device.

Name: Punched Card Reader (Electronic)

Source: James C. Swail
Radio and Electrical Engineering Division
National Research Council of Canada
Ottawa 2, Ontario, Canada

Availability: Production prototype

A new version of the Punched Card Reader in which the mechanical system of rollers and pins is replaced by photocells and vibrators.

Name: Reading Aid for the Visually Impaired

Source: N. M. Blachman
Sylvania Electric Products, Inc.
P.O. Box 205
Mountain View, California 94040

Availability: Experimental prototype

Stray light scattered by lenticular opacities often makes reading difficult for the visually impaired because it reduces the contrast between print and paper. To aid in restoring contrast by eliminating excess light, a piece of heavy-weight, dull, black cardboard 4" x 9" is used; a slot 1/4" x 7" cut slightly below its center. Eight no. 47 six-volt pilot lamps, wired in two parallel strings of four, are mounted in sockets that clip to the top of the cardboard, raising the cardboard slightly more than half an inch above the text surface and parallel to it. The bulbs are connected by a few feet of lamp cord to a 120/25-volt transformer, which is fitted with an on-off switch and a cord and plug.

In use the device is laid directly on the text and is slid down the page as it is read. One or two lines of text fill the slot.

Name: Blindreader

Source: National Physical Laboratory of Israel
Hebrew University Campus
Jerusalem, Israel

Availability: Laboratory prototype

Reading machine presents braille output one line at a time.

Name: Braille Verifier for the Blind Typist

Source: Dr. I. M. Neou
Department of Mechanical Engineering
West Virginia University
Morgantown, West Virginia 26506

Availability: Laboratory prototype

A printed-circuit braille encoder is attached to a typewriter keyboard. Depression of a key for typing simultaneously closes a particular logic circuit for embossing braille characters on a paper tape which can be finger-read later to locate and correct typing errors.

Name: Cassette Duplicating System

Source: The American Foundation for the Blind
15 West 16th Street
New York, N.Y. 10011

Availability: In operation

Name: Computer Printout of Braille

Source: English Electric Computers, Ltd.
Computer House
Euston Center
London NW1,England

Availability: Commercial prototype

Announcement has been made of a printout compatible with this firm's computer hardware to produce braille. The method uses a program block for conversion from inkprint analogue to braille analogue, and a modified line printer. Inkprint copy if read on to magnetic tape through a keyboard by a sighted operator. The program block then splits the information read into short lengths, and drives the high-speed line printer to emboss the braille characters in reverse on the specially adapted printer.

Name: Electronic Liquid Detector

Source: Mr. Jeffrey Burndrett
247 Elgin Avenue
Maida Vale
London W. 9, England

Availability: On special order

Price: £3 0s 0d

The device is hung over the lip of a liquid container. When the level of liquid reaches the level of the two electrode prongs, the battery-operated device emits a warning sound. Two sets of prongs are provided for two liquid levels.

Name: Finger Mounted Photodiode Probe

Source: E. K. Holden
Munmorah Power Station
New South Wales Electricity Commission
Australia

Availability: Experimental prototype

Price: Approximately $50 (U.S.)

A battery-operated photodiode secured to the finger by a flat spiral spring. It is used to guide blind operators to that portion of a control console indicating attention. A 400-Hz multivibrator is triggered by a photodiode with an emitter-follower audio stage. The output stage is biased-off until the oscillator starts; battery drain is 3 ma (battery voltage is 1.5 to 9.0 V.). The unit is equipped with a sensitivity control (from 10 inches down to actual contact with a light source); a test position (switching gating out of circuit, oscillator on); volume control for the loudspeaker; and a six-foot twin hearing-aid lead with polarized plug. The system, which has a fast response time and is highly directional, is comprised of the finger probe and a circuit box roughly 6-1/2 x 4-1/2 x 3-3/4 inches.

Name: French Braille Typewriter

Source: Roland Galarneau
Department of Public Works
Ottawa, Canada

Availability: Experimental prototype

This typewriter-like device uses a conventional typewriter keyboard and keys; the keys actuate a bank of telephone relays in a logic circuit. A word is not printed out until it is completed, and the logic circuits determine whether or not a contraction is appropriate. When the logical criteria are satisfied, the word is printed out in contracted braille. Thus, anyone capable of using a typewriter can produce fully contracted French braille. The relatively simple system configuration is possible because of the relatively simple rule structure for contractions in French. Simple systems of this type are useful when there is a scarcity of text in a language. Costs may be higher than for computer-transcribed braille in any language.

Name: Harmonic Compressor

Source: American Foundation for the Blind
15 West 16th Street
New York, N.Y. 10011

Availability: Laboratory prototype

Name: Improved Tactile Alarm

Source: American Foundation for the Blind
15 West 16th Street
New York, N.Y. 10011

Availability: In experimental stage

Name: Lexiphone

Source: Michael P. Beddoes
Department of Electrical Engineering
University of British Columbia
Vancouver 8, Canada

Availability: Production prototype

Personal reading machine. Inkprint scanned by means of 54 photocells is transformed into a melodic code on the basis of selected properties of the letters.

Name: Miniaturized Variable Frequency Power Supply

Source: American Foundation for the Blind
15 West 16th Street
New York, N.Y. 10011

Availability: In experimental stage

Name: Opticon

Source: James C. Bliss, Head
Bioinformation Systems Group
Engineering Techniques Laboratory
Building 30, K-1054
Stanford Research Institute
333 Ravenswood Avenue
Menlo Park, California 94025

Availability: Production prototype

Direct translation reading machine, with a tactile output in the form of a 6 x 24 array of vibrators. Scanning is done by a hand-held probe consisting of an array of photocells. The inkprint form, activating a group of photocells corresponding to its shape in the scanner, is reproduced by a corresponding group of vibrator rods within the tactile array.

Name: Olson TV-FM Portable Receiver

Source: Olson Electronics, Inc.
260 S. Forge Street
Akron, Ohio 44308

or

Eastern Sales Co.
P.O. Box 53
Woodlawn Station, Bronx, New York 10470

Availability: From suppliers above

Price: $40 plus taxes and shipping

This is a portable receiver, having dimensions of 8 x 5 x 2 inches, weighing under two pounds, which is able to tune both the 88 through 108 MHz FM band, and the audio portion of TV Channels 2 through 13. Although its performance in fringe area reception is not satisfactory in some tests, and the tuning arrangement may not be suitable for the visually impaired user, it is the only receiver of its kind available.

Name: Orientir

Source: Helmholtz Eye Research Institute
RSFSR
Sadovaja-Chernogriasskaja 14/19
Moscow, K-64, USSR

Availability: Experimental prototype

An ultrasonic transceiver incorporating translation circuitry to permit auditory discrimination of ultrasonic reflections from objects in the environment. No further details are available.

Name: Phylab Brailler

Source: Zvi Weinberger
National Physical Laboratory of Israel
Hebrew University Campus
Jerusalem, Israel

Availability: From supplier

Produces braille cells on half-inch machine paper tape. An adapted standard office typewriter provides the input in the form of electric signals from microswitches operated by the typewriter keys. By suitable interfacing the brailler can be adapted to accept input from computers, card readers, Telex tape and Monotype tape.

Name: Steubing Card Reader

Source: W. Steubing
Steubing Automatic Machine Co.
Cincinnati, Ohio

Availability: From supplier

Device for reading single punched cards. Cursor can be moved across card placed in the device and aligned with any one of the columns. Holes are located by running stylus down slot in cursor and their location in a column identified by relating them to holes in the cursor.

Name: TV Projection Reader

Source: American Foundation for the Blind
15 West 16th Street
New York, N.Y. 10011

Availability: Preproduction prototype

Optical reading device for the visually impaired. It consists of a closed circuit TV built into a desk; magnification ratio--4 to 24X.

Name: Electronic Playball

Source: Royal National Institute for the Blind
224 Great Portland Street
London W.1, England

Availability: From supplier, Catalogue No. 9201

Price: £6 9s. 0d.
£2 3s. 0d. - Concession price to blind in Great Britain and Northern Ireland (RNIB - Catalogue No. 9201)

A new production of the ball previously supplied by the Institute. Advances in electronic components have enabled the circuit to be redesigned, resulting in a ball smaller in size, lighter in weight, and more suitable for general use. It is not, however, intended or designed to be used for football, cricket, or any game employing a hard bat. The electronic unit is sealed inside the soft foam rubber ball, and is switched on and off by means of a jack plug which is provided. When the plug is removed a recurrent "bleep" is emitted to permit location of the ball when in play. When fully charged, the sound unit operates for approximately six hours, and can be recharged from a dry battery by means of the charging lead provided. Instructions are provided in braille and in inkprint. The ball is 5 inches in diameter and weighs 12 ounces.

Name: Rain Warning Device with Extension Lead

Source: Royal National Institute for the Blind
224 Great Portland Street
London W1N 6AA

Availability: From supplier, Catalogue No. 9345

Price: £6 10s. 0d.
£2 3s. 4d. - Concession price to blind in Great Britain and Northern Ireland (RNIB - Catalogue No. 9345)

A battery operated unit, similar to Catalogue No. 9291, but with the sensing head connected to the sound unit by means of a 30-foot flexible lead. It is intended that the sensing head should be made a permanent fixture outdoors, with the sound unit indoors. When switched on, the unit emits a loud sound at the first drop of rain. If the atmosphere is sufficiently moist to operate the device, it indicates that conditions are not suitable for drying clothes. The modified version is ideal for use in noisy environments, where it may prove difficult to hear the warning note from an instrument placed outdoors. Supplied with fixing screws and installation instructions in both braille and inkprint. The unit weighs one pound and nine ounces boxed; its dimensions are 3 x 3 x 2 inches.

Name: Sound Beacon

Source: Royal National Institute for the Blind
224 Great Portland Street
London W1N 6AA

Availability: From supplier, Catalogue No. 9425

Price: £3 0s. 0d.
£1 0s. 0d. - Concession price to blind in Great Britain and Northern Ireland (RNIB - Catalogue No. 9425)

This pocket-sized electronic device emits a sound which can be varied from a loud continuous whistle down to low intermittent "bleeps" at various pulse-repetition rates. It has a great number of potential uses, but in general is intended as a homing device. For example, when applied the blind user can find his way back to the lawn mower after emptying the grass catcher. Similar applications can be envisaged in the field of sport and in pastimes in which the beacon can be placed to help locate targets, the finishing line in straightforward races, and the position of the jack in a bowling game. The flat plastic case is fitted with a detachable leather carrying strap. The sound beacon is supplied complete with a battery, and with instructions in both braille and inkprint. The size of the unit is 4-1/2 x 3 x 1-1/8 inches, and weighs 7-1/2 ounces.