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ABSTRACT

The fourth in a series of Rand reports on information transfer problems of the partially sighted reviews earlier reports and describes an experimental secretarial closed circuit TV (CCTV) system which enables the partially sighted to type from a printed or handwritten manuscript. Discussed are experiments using a pseudocolor system to determine the most suitable color of print and background for use with the CCTV. Reading rates for normally sighted people using the CCTV are the focus of additional research reported. A final section compares the results and administration data for four methods of detecting visual color deficiencies, including the modified Farnsworth Dichotomous test for Color Blindness. Appended is information on the chromaticity of the Conrac color TV monitor. (CL)

INFORMATION TRANSFER PROBLEMS OF THE PARTIALLY SIGHTED: RECENT RESULTS AND PROJECT SUMMARY

PREPARED FOR THE DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE

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PREFACE

This is the fourth in a series of Rand reports under the project "Information Transfer Problems of the Partially Sighted," sponsored by the Social and Rehabilitation Service of the U.S. Department of Health, Education, and Welfare. The three earlier reports cover the major areas of research undertaken as part of this project. A brief summary of the content of those reports is given here. No attempt has been made, however, to synthesize the content of the earlier reports with this new, previously unreported material.

The present report contains the results of four research efforts not reported earlier. While these efforts did not reach the level of completeness of the other studies, they produced results that should be of interest to others doing research on problems of the partially sighted, as well as to those who provide that population with more direct services.

The first of the research efforts included here involves the design and construction of an experimental closed circuit TV system that allows the partially sighted to type from a printed or handwritten manuscript. It is aimed at assisting in the design and fabrication of new systems or devices that would help the partially sighted to cope with some of their more formidable visual information transfer problems. The other three research efforts discussed here were part of a supportive research program aimed not at producing results that would lead to the immediate improvements of aids for the partially sighted, but rather at shedding light on important problems that may take years to be satisfactorily resolved.

SUMMARY

This report begins with brief summaries of the three Rand reports that have already conveyed the major results of this project to its sponsor, the Social and Rehabilitation Service of the U.S. Department of Health, Education, and Welfare. Section II describes an experimental secretarial closed circuit TV (CCTV) system that was designed and fabricated as part of the project and that permits the partially sighted to type from a printed or handwritten manuscript. With it, users see a horizontally split image on a TV monitor of pertinent portions of the manuscript and of the typewriter platen as they are typing.

Section III describes the pseudocolor system we bought for use in this project, how that system has been used to make an in-depth study of the gray value and color sensitivity of two partially sighted subjects with profoundly different eye disorders, and what might be done if this research were to be continued.

Section IV discusses an important experiment carried out to determine how the reading speed of normally sighted people, using an individualized CCTV system for the partially sighted, varies as a function of the number of alphanumeric symbols that span the system's monitor screen.

Finally, in Sec. V, four methods for detecting or determining visual color deficiencies are described, including an interesting modification of the Standard Farnsworth D-15 Test and a screening technique of our design.

ACKNOWLEDGMENTS

We wish to thank Kathleen Hunt Julian for helping us collect data on the reading rates of people with normal eyesight when using a closed circuit TV system, Bonniesue Boyd for helping us to evaluate our experimental secretarial CCTV system, Roy H. Stratton for deriving the chromaticity equations used in the analysis of our pseudocolor experiments, and Dr. James Bailey of the Southern California College of Optometry for examining and commenting on the results of the pseudocolor experiments and for suggesting a very promising avenue for future research.

The authors also wish to thank Drs. Gene H. Fisher and R. Robert Rapp for the care with which they read the manuscript of this report. The incorporation of their comments and suggestions has greatly enhanced the quality of the final product.

In addition, we are grateful to Eleanor T. Gernert for guiding the manuscript through the publication process, James A. Beavers for taking and processing the photographs, and Margaret Wray for handling all the secretarial chores that are needed to make a project function efficiently, including typing the drafts of the project reports.

We also wish to thank again Dr. Frank D. Taylor, Assistant Superintendent/Special Services, and Dr. Robert J. Stillwell, Supervisor of Special Education Programs, both of whom are with the Santa Monica Unified School District, for making it possible for us to proof-test our interactive classroom TV system (ICTS) in one of that school system's resource rooms for visually handicapped students. Their enthusiastic support is greatly appreciated, and their deep concern for both physically and mentally handicapped children is respected by us and others serving handicapped youth.

Finally, we wish to thank Jadeane B. von der Lieth, teacher of the visually handicapped, for using our ICTS with imagination and enthusiasm to teach basic skills to partially sighted and other handicapped children in her Santa Monica resource room, and Dr. O. Arthur Rosenthal, Educational Psychologist, for selecting and administering several test instruments to the children in Ms. von der Lieth's classroom.

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I. INTRODUCTION

This is the fourth and final report on activities carried on with grant No. 14-P-55846/9 entitled "Information Transfer Problems of the Partially Sighted" from the Social and Rehabilitation Service of the U.S. Department of Health, Education, and Welfare. The first three reports, which cover the major areas of research in this project, are summarized below.

BINOCULARS REPORT

The first report[1] in this series examines the value of binoculars as a visual aid for the partially sighted. It points out that this aid has been long ignored by clinicians and others who serve the partially sighted. Binoculars are simple to operate, easily obtainable, and relatively inexpensive. Further, they can be used by the partially sighted in the home, at school, at work, and while relaxing.

The author of the report is himself partially sighted and has used binoculars in many ways, including the following:

- To determine the status of a traffic light.
- To take notes on or copy from a chalkboard.
- To determine the number and destination of a bus.
- To ascertain a street address.
- To locate an article that has become visually misplaced.
- To watch a ball game.
- To determine the nature and price of merchandise.
- To watch a movie or television.
- To determine what friends and family really look like.

The report points out that some partially sighted people, and particularly those who are myopic, will find that they can use binoculars that magnify as much as twenty times without much difficulty. While seated in an automobile, they can use binoculars that magnify eight or ten times, for example, to view objects passing by, without experiencing any physiological discomfort. Further, highly myopic people, who use binoculars whose prisms do not have a large index of refraction, will find that they can see one or more faces of these prisms, and, even more interesting, that they can see foreign matter, on the internal optical surfaces, that completely eludes the normal eye.

The report also explains how supplementary simple lenses placed over the objective lenses of a pair of binoculars can be used to bring objects into sharp focus outside the normal operating range of the binoculars, and, in particular, at short distances. Further, some partially sighted people, including the author, need to use a corrective lens over one or both binocular objectives to bring distant objects into sharp focus. (The need for this correction probably increases with age.)

[1] S. M. Genensky, *Binoculars: A Long Ignored Aid for the Partially Sighted*, The Rand Corporation, R-1402-HEW, November 1973, also published in *American Journal of Optometry and Physiological Optics*, Vol. 51, No. 9, November 1974, pp. 648-670.

The author has compared binoculars with monoculars and has found that the former are much easier to hold steady for long periods of time. The report also discusses the virtues and drawbacks of zooming binoculars, controllable internal irises, and telescopic spectacles.

Finally, the author points out that although his experience with binoculars may not be representative of all partially sighted people, he encourages clinicians to acquire a thorough knowledge of the aid and its potential for his partially sighted patients. If this knowledge is then applied to recommending and prescribing binoculars for the partially sighted, the visual horizons and capabilities of these people could be greatly expanded.

ICTS REPORT

The second report[2] describes a highly interactive teacher-student, closed-circuit TV system, also referred to as an interactive classroom television system (ICTS), that was designed and fabricated by the project staff in 1973. This multicamera-multimonitor instrument was proof-tested for its reliability and design rationality during the 1973-74 academic year in an elementary school resource room for partially sighted, mentally retarded, and hearing impaired school children. The system permits the teacher and her handicapped students to be in *continuous visual communication with one another*. It was originally built to satisfy the need for continuous visual links between partially sighted students and their teachers, and in that capacity, the system has already shown great promise. The system is currently being used primarily by partially sighted students, some of whom have additional handicaps.

The ICTS has four stations, each consisting of (1) a black and white TV monitor and stand; (2) a down-pointing black and white TV camera that generates images with normal or reversed contrast (i.e., black on white or white on black) selected by a switch on the front or underface of the camera, (3) a 5 to 1 zoom lens with a close-up adapter;[3] (4) a heat shielded light source; (5) an X-Y Platform with adjustable margin stops in the x-direction and frictional control in the y-direction, and (6) a stand that accommodates the TV camera, the light source, and the X-Y Platform. In addition, each station is provided with a switch that permits its light source to be turned on or off, another switch that allows power to flow or to be cut off from all of the station's electrical components, and an amber light that, when illuminated, indicates that the image displayed on the station's monitor is also being displayed on the room monitor.

The system includes a ceiling-mounted, room-viewing black and white TV camera equipped with a 10 to 1 zoom lens, a black and white room monitor, a cassette-

[2] S. M. Genensky, H. E. Petersen, R. I. Yoshimura, J. B. von der Lieth, R. W. Clewett, and H. L. Moshin, *Interactive Classroom TV System for the Handicapped*, The Rand Corporation, R-1537-HEW, June 1974.

[3] The zoom lens permits the user to vary the magnification of the image appearing on the TV monitor over some specific range by merely turning the appropriate ring on the lens. For example, a 5 to 1 zoom lens permits the user to vary the magnification of an image by as much as five times. The exact range over which magnification occurs is a function of many factors, including the lens construction, the monitor size, and whether supplementary lenses are used to change the limits of the magnification range or to permit the zoom lens to focus at shorter distances than it was originally constructed for.

type videotape recorder, a master control unit, a room camera control unit for the ceiling-mounted camera, and a teacher's channel selector.

Each of the camera-monitor stations is located on its own table. Three of these stations are specifically for use by students and the fourth is for use by the teacher, although it is sometimes used by a fourth student.

The master control unit is located on the same table as the teacher's camera-monitor station. With it, the teacher is able to present on any one of the four desk-supported TV monitors, independently of what she presents on any other monitor, the following pictures:

1. A full screen image of what any one of the five cameras is viewing or a videotaped picture.
2. A horizontally split image of what any two of the five cameras are viewing or a videotaped picture and what any one of the five cameras is viewing.
3. A full screen superposition of what any two of the five cameras are viewing or a taped image and what any one of the five cameras is viewing.

With this capability the teacher is able to work simultaneously with as many as three students, and if she chooses to work with fewer than three, she is still able to assign tasks, using the ICTS, to students with whom she is not working. These tasks may involve the students working alone or with occasional observation or guidance from the teacher.

Using the teacher's channel selector, the teacher can view individually but in any order on her own monitor what any of the students is seeing on his monitor. With this capability, she can, for example, point out mistakes to students individually, without going to their desks. Likewise, she can detect student successes and when appropriate display them on other student monitors while complimenting the good work.

The room camera control unit, like the master control unit and the teacher's channel selector, is located on the teacher's desk. With it, the teacher can cause the room-viewing camera to pan and tilt and present a positive or negative image (i.e., black on white or white on black) on one or more TV monitors. This unit also allows the teacher to control the opening of the zoom lens, bring objects into focus, and change the magnification provided by the lens.

The videotape recorder is used by the teacher to record visual interactions with her students, to prepare taped lessons, and to display these lessons as well as other taped material.

With the ICTS, handicapped children and in particular those who are partially sighted are able to see their teacher writing while she is at her desk or at a chalkboard. No longer is it necessary for her partially sighted students to ascertain what she has written *after* she has completed writing and *after* she has given an explanation of what she is writing. The ability to see what a teacher is writing *while she is actually writing and explaining what she is doing* is a vital factor in a student's ability to fully comprehend what is being taught.

In addition, the ICTS permits students, while seated in a comfortable and natural position, to work alone at camera-monitor stations. They can, for example, read *ordinary* printed and handwritten material, write with a pen or pencil, and carry on other activities that require precise eye-hand coordination.

Like the currently available individualized closed circuit TV systems for the partially sighted, the ICTS's cameras and monitors also permit the control, by teacher and students, of image brightness, contrast, polarity, and magnification to a far greater extent and with much greater ease than is possible with pure optical devices. Although pure optical systems can provide the same degree of magnification as CCTV systems, unlike the latter they must be kept at a rather precise distance from the viewed object to keep it in focus, especially at high magnifications. Further, unlike CCTV systems, pure optical systems are incapable of reversing image contrast, and hence are unable to provide partially sighted users with an image of print that scatters less light and that provides illumination from the information rather than from the background on which it is printed. The absence of these two constraints on CCTV systems makes them more attractive to the partially sighted than pure optical systems. Further, focus problems and lack of contrast control are the cause of much of the fatigue experienced by partially sighted people when trying to read with the aid of pure optical devices for long periods of time. One other advantage of CCTV systems over pure optical systems that has proved invaluable to the partially sighted is their ability to *enhance* both the brightness and contrast of a viewed object. With this capability and that of contrast reversal, the partially sighted are now able, for example, to view low contrast printed or handwritten material in an image that is bright, has high contrast, and that minimizes glare.

It should be noted that the ICTS has been in use in a classroom for over 12 academic months and that, during that time, it has been out of operation only one day due to equipment failure. Occasionally, the teacher has reported that some part or parts of the system are not functioning, but with the exception just noted, these malfunctions have been corrected by merely flipping a switch, plugging in a cable, opening a lens, or removing a lens cap.

The original grant application did not call for designing, building, and proof-testing an ICTS. The ICTS concept grew out of an accumulation of our research experience before and during the early months of this project. Permission to proceed with the design, construction, and proof-testing of such a system was granted by Mr. James F Garrett and Dr. L. Deno Reed after hearing about it and its potential for the partially sighted from the project leader. The foresight and flexibility of Mr. Garrett and Dr. Reed coupled with the enthusiastic and competent work of the project staff led to the design and construction of the system. Much is also owed to Drs Frank Taylor and Robert Stillwell of the Santa Monica Unified School District for permitting us to proof-test the ICTS in one of their classrooms for handicapped children, and to Ms. Jadeane von der Lieth for her enthusiastic acceptance and use of the system in her classroom.

DOUBLE X-Y PLATFORM REPORT

The third report[4] describes a mechanical platform called a double X-Y Platform When this platform replaces a single X-Y Platform as part of a closed circuit TV system for the partially sighted, it permits the user to read printed or handwritten material and to take notes on or copy from that material using a pen or pencil. The platform has two rectangular working surfaces whose motions in the left or

[4] S M Genensky, H E. Petersen, R. W Clewett, and H L. Moshin, *A Double X-Y Platform for RANDSIGHT-Type Instruments*, The Rand Corporation, R-1614-HEW, December 1974

right direction (x-direction) are completly coupled, but whose motions toward or away from the user (y-direction) are completely independent of one another. This design feature allows the user to change from reading (writing) to writing (reading) without having to search for the *line* that he was last writing (reading).

Other techniques for handling this important information transfer problem have been explored and are also described in this report. However, they do not appear to be as cost-effective as the double X-Y Platform.

A series of experiments was carried out with the cooperation of four partially sighted subjects who differed in age and ocular pathology. These experiments were an attempt to determine whether copying from unbound and bound materials using a CCTV system equipped with a double X-Y Platform can be expected to be more rapid than copying from similar materials using a CCTV system equipped with a single X-Y Platform, or using neither an X-Y Platform nor a CCTV system. The results of these experiments were not conclusive. However, three of the four subjects reported that they could copy more easily with a CCTV system equipped with a double X-Y Platform than they could using either of the other two techniques.

THE PRESENT REPORT

The present report, unlike the other reports, describes research efforts that on the whole can be regarded as incomplete, but that were carried out as part of this project. It is not surprising that some of the project activities were not completed by the termination date of the present grant, because time, staff, and money constraints rarely allow us to be as comprehensive in our work as we desire. Even so, this report does describe activities that have progressed far enough to have produced interesting results. For example, an experimental secretarial CCTV system has been designed and fabricated that permits a partially sighted person to type from a handwritten or printed manuscript. The system does not, however, permit the user to do as much as we would hope for.

In addition to the secretarial CCTV system, this report describes (1) the progress that has been made in examining the visual color sensitivity of two partially sighted subjects who have quite different ocular pathologies using a rather sophisticated pseudocolor generator; (2) an experiment carried out with the help of normally sighted subjects to determine how rapidly they could read with a CCTV system for the partially sighted; and (3) various tests of color sensitivity used on 19 partially sighted subjects, including a modification of the Farnsworth D-15 color sensitivity test that is as accurate as the standard test but that is easier for the partially sighted to cope with, because it is less taxing on their eyes.

II. AN EXPERIMENTAL SECRETARIAL CLOSED CIRCUIT TV SYSTEM

INTRODUCTION

One of the information transfer problems explored under the present grant (14-P-55846/9) was that of helping the partially sighted to type from a handwritten or printed manuscript. Although CCTV systems are currently commercially available that permit a partially sighted user, via a simple attachment, to view on a TV monitor a portion of the typewriter platen (including the characters that have just been typed), to our knowledge no one has ever before built a CCTV system that permits a partially sighted user to view pertinent portions of both the typewriter platen and printed or handwritten material that is to be typed. But even our experimental instrument is not as versatile as we would hope for. For example, like the currently available CCTV systems with typewriter attachments, it can be used only with typewriters with carriages that move to the left or right as typing proceeds. Further, the instrument permits the user to type only from printed or handwritten material that can be fed page by page into the system's copyholder. Despite these limitations, however, the system does work well.

We gave some thought to a system design that involved the use of two cameras —one for viewing the typewriter platen and the other for viewing the material to be typed. Such a system might, for example, present a horizontally split image on a TV monitor screen, one part of which might display a pertinent portion of the typewriter carriage and the other a pertinent portion of the material to be typed. Or, via a foot-operated control, it might present alternately full screen images of both of these areas of interest. Such a system might be able to cope with the problem of typing from both bound and unbound material. We decided not to pursue this approach, because we felt that the resulting experimental instrument would be considerably more costly and more difficult to operate than the one we did design and fabricate. This instrument made use of the experience we had gained in our examination of optical image splitting techniques during the early months of the project.

An evolution of the instrument we have designed and fabricated may someday permit adventitiously partially sighted people (1) to continue in jobs that they had before suffering a sight loss and that call for the ability to type from a printed or handwritten manuscript, or (2) to be trained to handle jobs that they had not held before their sight loss and that call for this typing skill. The same or a similar instrument would be of value to partially sighted students, authors, etc.

DESIGN OBJECTIVES

In our opinion an *ideal* secretarial CCTV system would include at least the following features:

1. A monitor display that permits the user to view pertinent portions of both the material to be copied and the typewriter platen.
2. A structure and optical design that does not interfere with the normal operation of the typewriter.
3. Controls that are simple and that are operated in ways that are natural, comfortable, and not confusing.
4. A mechanism that permits simple and rapid conversion of the system, back and forth, from a copying mode to a reading and writing mode. The latter mode and a simple typing mode are all that are now available in commercially produced CCTV systems.
5. A system design that permits use of the typewriter by anyone who is able to type, and that permits the typewriter to be removed and used independently of the rest of the system.
6. A system design that allows the use of any make or type of typewriter.
7. A system design that permits the user to type from all types of bound and unbound printed or handwritten material.
8. A system design that allows corrections to be made easily and pages to be aligned without difficulty.

Our current experimental system satisfies the first, second, third, fifth, and eighth criteria. We believe the fourth criterion is a very important one, and one that could be satisfied as part of a future research project. Although criteria 6 and 7 could be satisfied, the commercial evolution of a prototype system that met these criteria probably would be very expensive. As indicated earlier, what would be needed to satisfy criteria 6 and 7 is a system that, in addition to what the current system is capable of doing, would track and present an image of typing elements that move across a typing platen as typing proceeds and that would accommodate and present an image of bound as well as unbound material to be copied.

DESIGN APPROACH

After working out some design approaches, we carried out simple simulations to test the viability of these approaches and to uncover any unforeseen problems that a user might encounter in trying to work with a system whose design was based on these concepts. For example, the viability of using a motor to move a copyholder from left to right and from right to left was examined using RANDSIGHT® II, a system designed and built with funds provided by a previous SRS grant (14-P-55285/9).[1] This investigation revealed that the approach was indeed workable, but that some care would be needed in the placement and the selection of the controls that would drive the copyholder across a line and from line to line, in order not to confuse the typist and to simplify his handling of these controls.

[1] S. M. Genensky, H. E. Petersen, H. L. Moshin, R. W. Clewett, and R. I. Yoshimura, *Advances in Closed Circuit TV Systems for the Partially Sighted*, The Rand Corporation, R-1040-HEW/RC, April 1972.

THE IMAGE SPLITTING SYSTEM

Figure 1 shows the major parts of an image forming system in a schematic form. This figure will be of aid in explaining the principles of the operation of the image splitter and will help to point out major design considerations.

This simple diagram demonstrates how a real image is formed by a lens, on the front face of the vidicon tube (or photo surface) in a TV camera. Line AA_1 is a centerline passing through an object plane BC, a lens, and an image plane B_1C_1. The solid lines r indicate the cone of light rays radiating from point B of the object plane. These rays are gathered by the lens and refracted to converge at point B_1 on the image plane. The broken lines indicate similar rays radiating from point C and converging at C_1. The fact that from any point along the object plane radiating light rays are refracted by the lens to converge at an equivalent point of the image plane explains the formation of a real image by a simple lens. Incidentally, as indicated by the diagram, the image has been reversed, and its size is proportional to its distance d_1 from the lens. The size of the image B_1C_1 is related to the size of the object BC through the formula

$$B_1C_1 = (d_1/d)(BC).$$

As is well known, the camera lens is used to collect light and to focus an image on the camera's focal plane. For a fixed lens and fixed image plane, the images of objects that are in front of or behind the object plane are somewhat defocused. The degree to which they are defocused depends on how far they are from the object plane, the characteristics of the lens (e.g., its opening or aperture), and the distance from the lens to the object plane.

Lens defocusing is important when we consider possible image splitting geometries For example, suppose our object of interest consists of portions of material printed on two pieces of paper located in two different places, and we want to be able to view these portions simultaneously via the lens and TV camera system. Let us call one of the pages "the copy" and the other "the output." One method would be to cut out portions of the material we wished to see, paste them on a piece of cardboard, and place the cardboard in the object plane. In this way, a sharp image of the materials of interest could be obtained, but this solution to our problem is impractical for obvious reasons.

Let us change the arrangement slightly by introducing a thin mirror and by locating the copy and output as shown in Fig. 2. There are now two object planes, and if they and the mirror are arranged properly, the images formed from each will be in sharp focus. By "arranged properly" we mean that if the mirror is inclined at an angle ϕ with respect to the first object plane, the second object plane must make an angle 2ϕ with respect to the first object plane.

Further, the mirror collects rays from the second object plane and, via the lens, brings them to a focus in the image plane corresponding to the image of the first object plane. If the mirror were not present, none of the rays emanating from AC that would normally be refracted by the lens would be blocked, and none of the rays emanating from the second object plane would be brought to a focus by the lens.

Although this arrangement, in general, leads to sharply focused images of the copy and the output, it does not provide a sharply defined boundary between these images and in fact creates an overlap of the upper and lower images in the vicinity of the split (which in this case occurs near the optical centerline shown in Fig. 2).

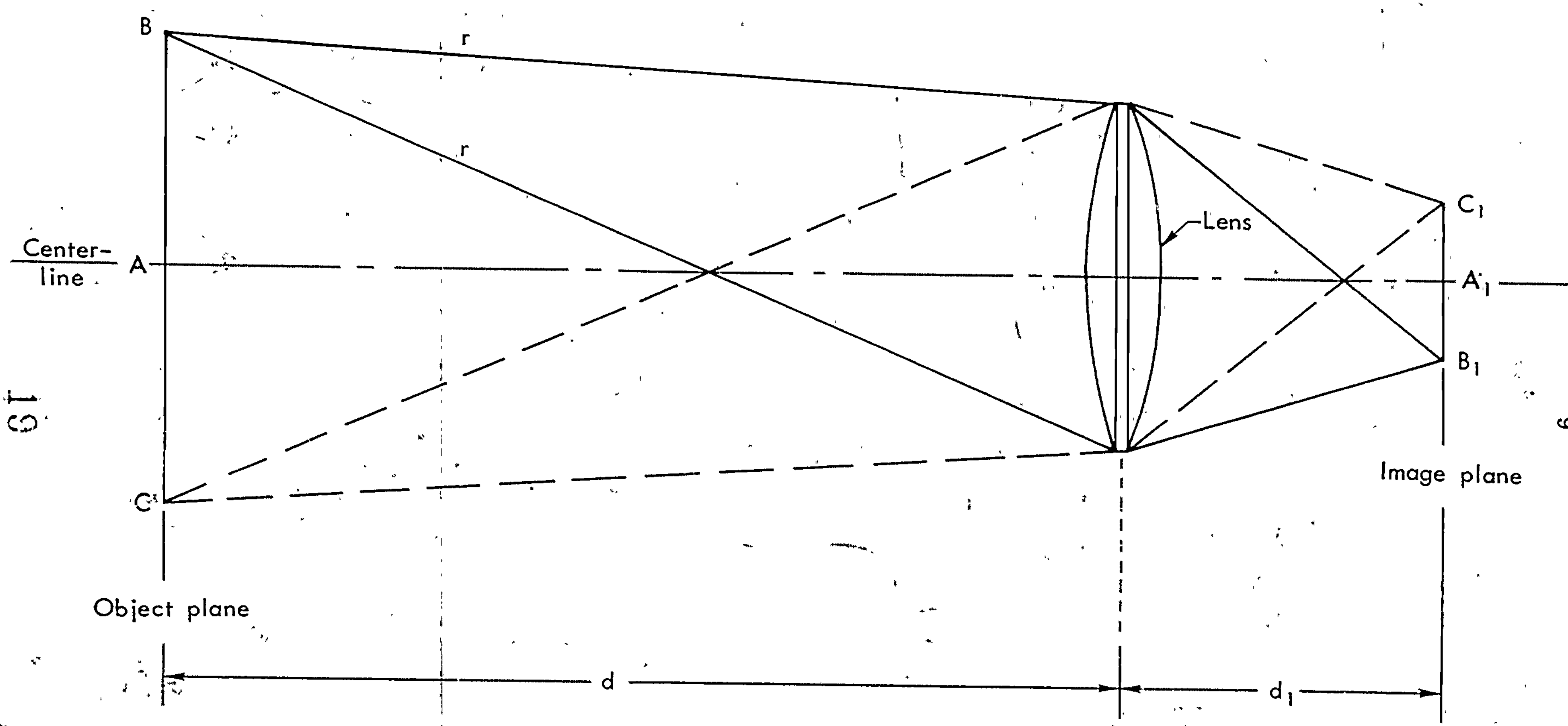

Fig. 1 — A simple image forming system

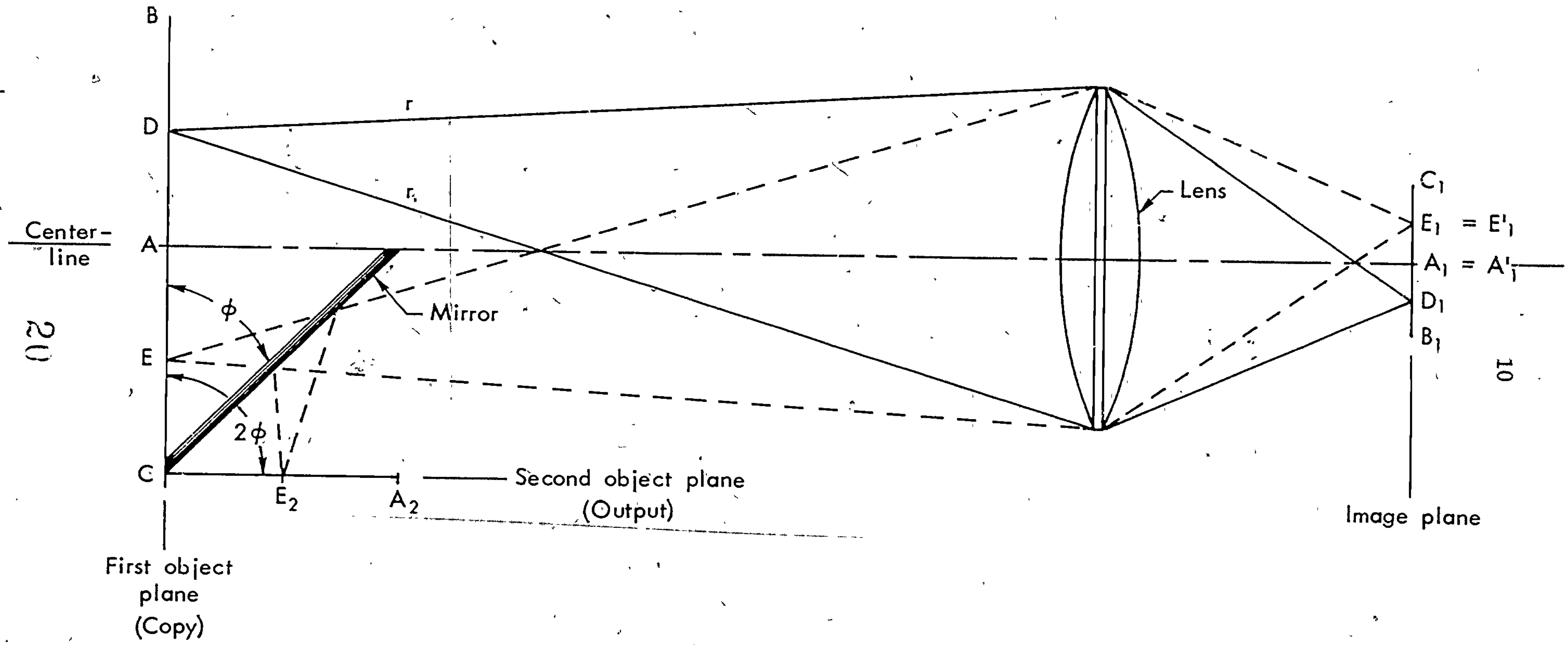

Fig. 2 — A simple image splitting system

Figure 3 diagrams the explanation of this gradation and overlap. The solid lines indicate the cone of light radiating from point F of the object plane that after passing through the lens converge to point F_1 of the image plane. The broken lines indicate light from point A, and the dashed lines light from point G, which is brought to a focus at points A_1 and G_1, respectively. If an opaque object M, such as the back of a mirror, is inserted into the system between the lens and the object plane BC, and the mirror's upper edge is at distance d_2 from the object plane, and if that edge touches the system centerline AA_1 at X, we find that all the light radiating from the area CG is blocked by the opaque object, while none of the light radiating from the area BF is obstructed. As for the cone of light radiating from the midpoint A, 50 percent is unobstructed and forms a reduced intensity image at A_1. Light from any point between A and G will be blocked by amounts greater than 50 percent, while light from any point between A and F will be blocked by less than 50 percent. Thus, there is a zero intensity image of G at G_1, a 50 percent intensity image of A at A_1, and a 100 percent intensity image of F at F_1.

The same degradation occurs with respect to the image reflected from the mirror. From Figs. 2 and 3 we see that there is a merging of the two images, and as one crosses this transition zone one image grows fainter as the other grows brighter.

The lens shown in Fig. 3 has a large diameter that permits it to gather more light than a lens of a smaller diameter. If we were to increase the light level on the copy and on the output or the sensitivity of the camera or both, we could then decrease the aperture of the lens and still achieve the same image quality. The lens in Fig 4 is much smaller in diameter than the one in Fig. 3, but has the same focal length. This indicates, pictorially, our ability to reduce the aperture of the larger lens Here, applying ray tracing to the region where the split occurs, we see that the edge of the mirror interferes with much less of the composite image than it did in Fig. 3. This results in a much sharper boundary between the image of the output and that of the copy. Holding the aperture fixed and moving the camera and lens farther away from the copy and the output leads to a similar result, because the entry angle of the rays that the lens can see and bring into focus on the camera's image plane is again reduced.

An examination of how this transition region depends on lens magnification reveals that the extent of the region of interference also increases with increases in magnification.

If the copy and the output are not at the same optical distance from the camera's focal plane and one of them is in the object plane, then the one that is not in the object plane will produce a defocused image. The amount of defocusing will depend on the lens aperture, the distance between the object plane and the image plane, and the distance between the object plane and the object that does not lie in this plane.

Figure 5 is a drawing showing a side view of the principal components of the image splitting system used in our experimental secretarial CCTV system. As indicated above, the single most critical design factor in this system is the requirement that the distance B be equal to the sum of the distances C and D so that both the upper and lower components of the image are in focus.

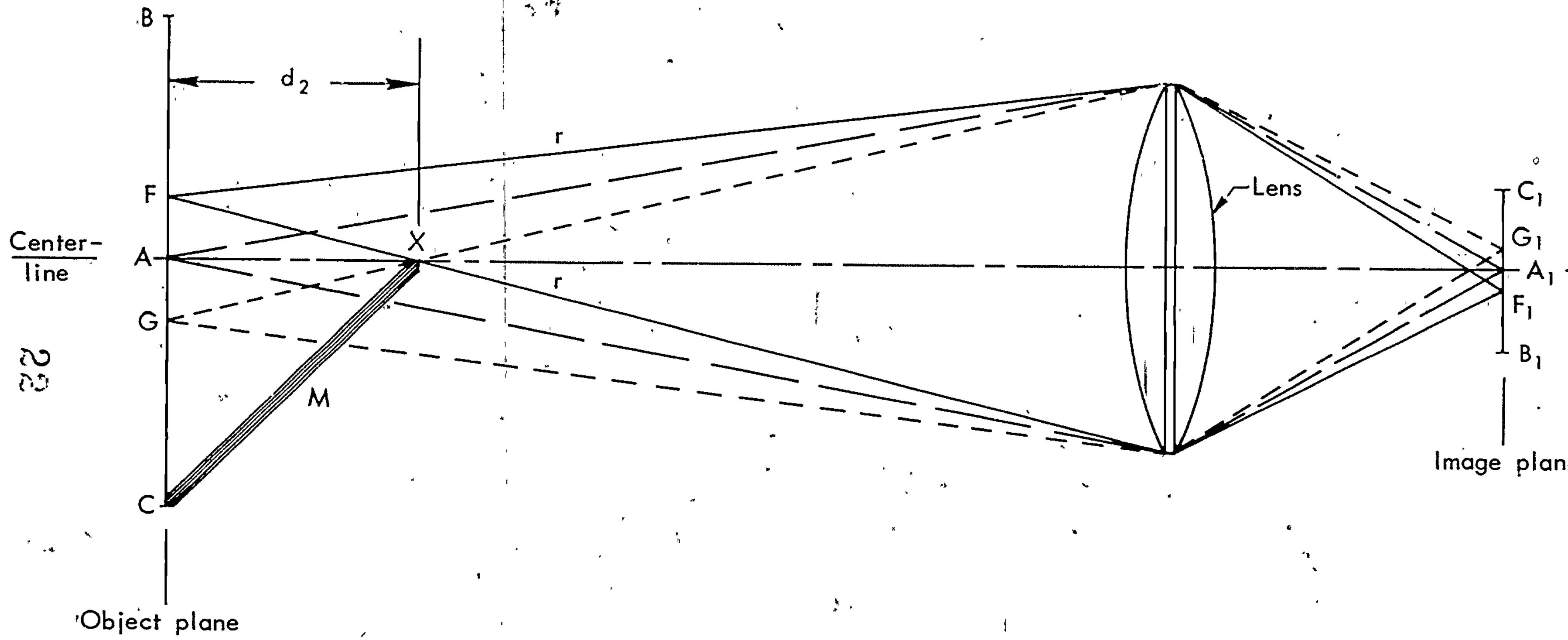

Fig. 3—Details of split gradation and overlap

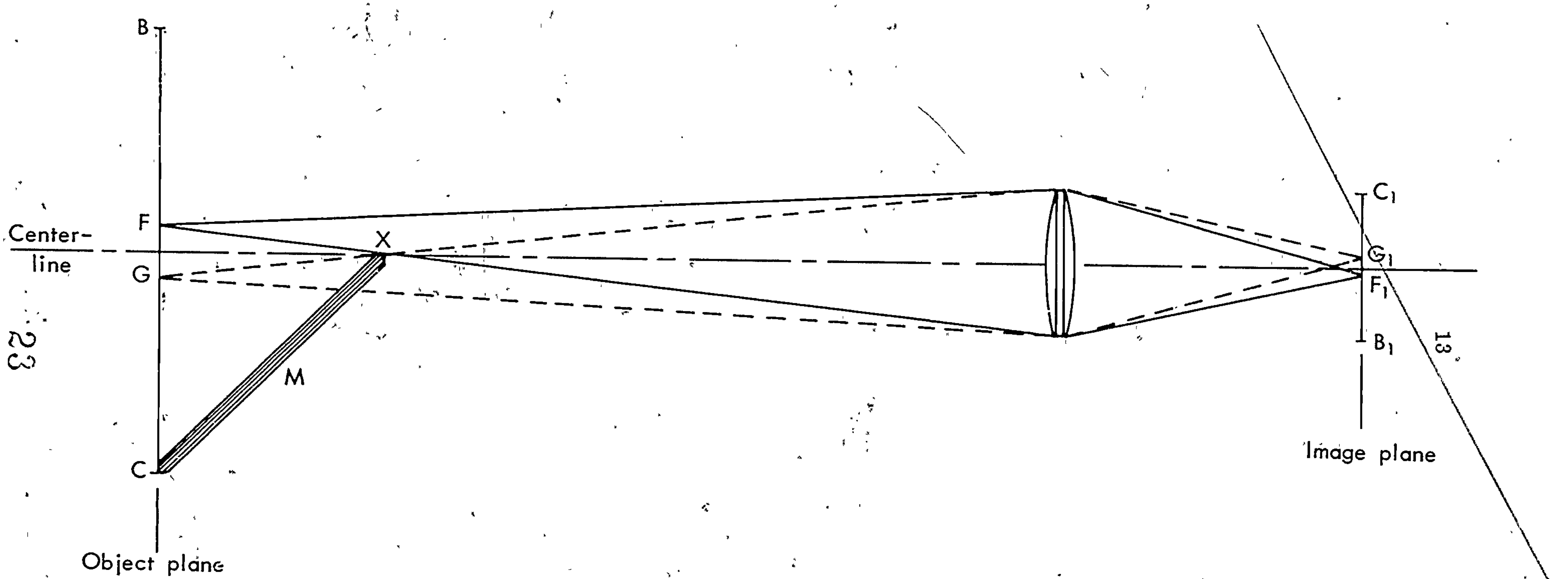

Fig. 4—Reduced aperture effect on split gradation

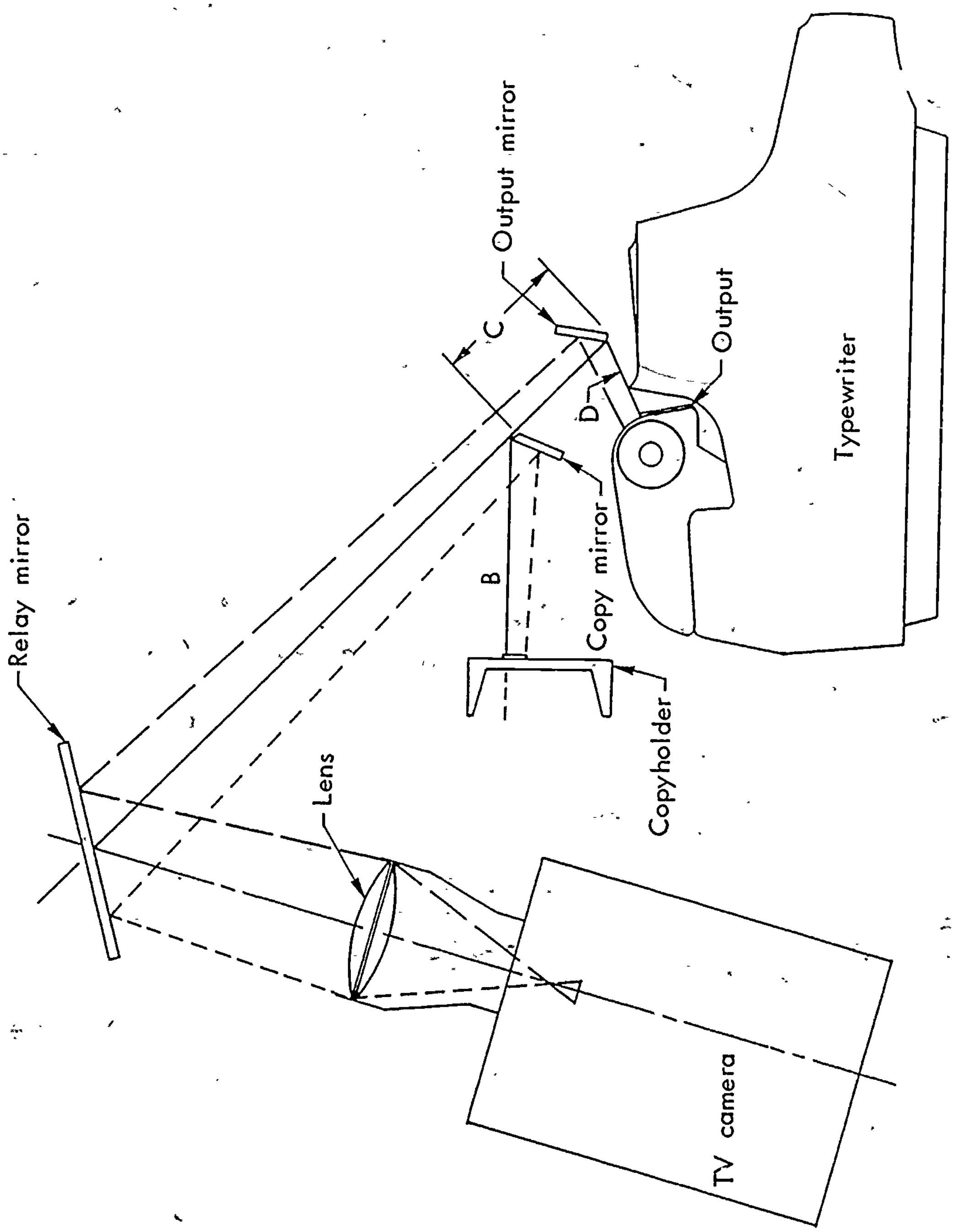

Fig. 5 — Principal components of the secretarial system

THE EXPERIMENTAL SYSTEM DESIGN

Figure 6 is a picture of the experimental secretarial system. The system evolved over time, and most of the changes that were made were carried out in an attempt to reduce vibrations that degraded image quality. For example, the entire plywood structure, including the base, is glued together, acting as a single unit, and is mounted on an ordinary typewriter stand which can be easily rolled from place to place. Observe that the base is reinforced by 3 inches of plywood along its back and sides.

The copyholder, that is, the device that holds the material to be copied, is mounted to the vertical portion of the plywood structure. It is located to the rear of the typewriter and above the typewriter carriage. The camera, illuminator, and relay mirror are also attached to the vertical portion of the plywood structure. The typewriter rests on a 0.5-inch felt typewriter pad, which in turn rests on the base of the plywood structure. The two image splitting mirrors (see Fig. 7) are mounted to the upper surface of the typewriter in front of the typewriter carriage. A discussion of some of the design features of the experimental system are taken up in what follows.

Image Splitting Mirrors

Figure 7 is a photograph of the image splitter and a portion of the typewriter to which it is attached. The upper or "nearest" mirror of the image splitter reflects a portion of the material to be copied to the relay mirror, and the lower or "farther" mirror reflects a portion of the typewriter platen to the same mirror. The resulting composite image is then reflected to the zoom lens, which in turn brings it to a focus on the image plane of the camera. The images reflected from the mirrors of the image splitter have undergone a reversal in the vertical direction, but this is rectified in the reflection from the relay mirror. The inclination of each of the image splitter's mirrors, relative to the horizontals that bisect these mirrors, can be varied. This permits making fine adjustments of the area seen by each mirror.

Illumination

We located a projection illuminator (an Art Beam Lite 75) to one side of the relay mirror, as close as possible to the optical centerline so that it reflected light from the upper mirror of the image splitter onto the typewriter platen. Although this arrangement provides illumination over a slightly larger area of the copy and platen than is seen on the monitor screen when the zoom lens is set to minimum magnification, this causes no difficulty. The arrangement used here may not be the best way to provide illumination of pertinent parts of the copy and platen, even so, it has proved adequate, and it has permitted us to devote our remaining limited resources to working on more critical problems uncovered in the course of instrument design and fabrication. A split image with a sharper boundary between the upper and lower components could be obtained if greater illumination of the pertinent portions of the copy and platen were provided. This would permit the zoom lens to be stopped down and in turn would allow a sharpening of the boundary between the components of the composite image seen on the monitor screen.

Fig. 6—The experimental secretarial system

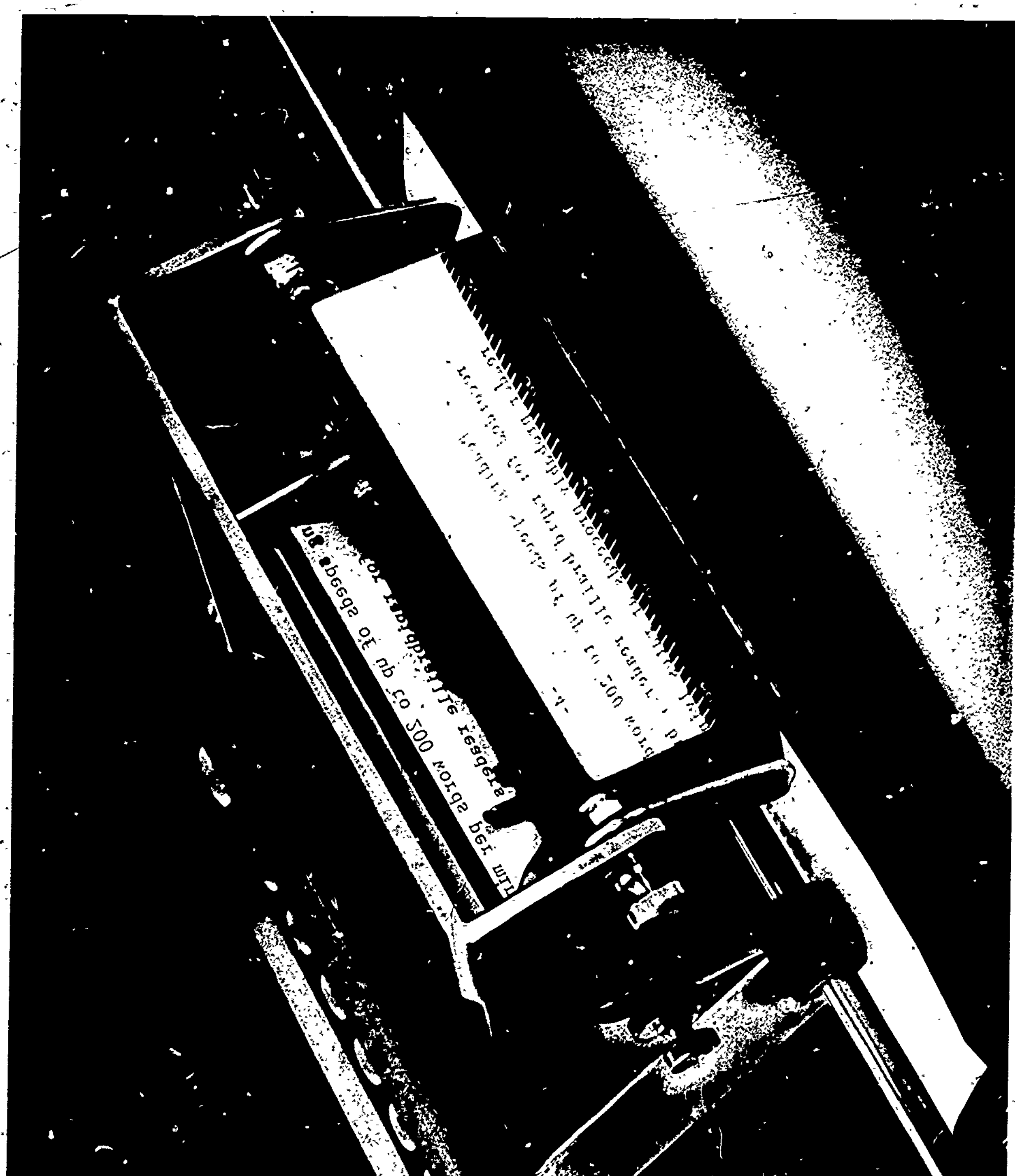

Fig. 7—The image splitting mirrors

Copyholder

A Pres-To-Line copyholder model 55M was disassembled from its stand and the copy platen mounted on a ball-bearing slide structure which permits motion to the left and to the right. Inside this structure an electric motor and appropriate gearing were arranged to allow the motor to drive the copyholder to the right and to the left via external control. The Pres-To-Line copyholder was selected because it is not very expensive.

Copy Motion

As pointed out above, we decided to provide copy motion to the left and to the right via a variable speed motor using a simple gear reduction system. Our simulation indicated that control of this motion, as well as that governing the line to line advance of the copy platen, was best carried out via foot pedals, which are shown in Fig. 8.

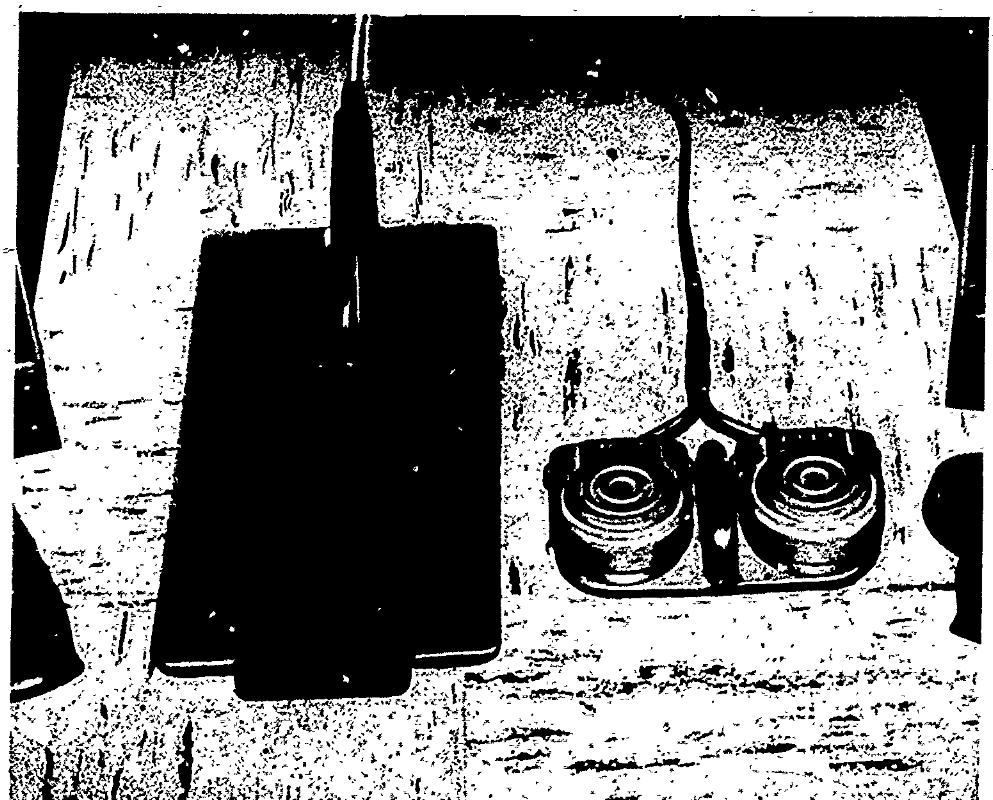

Fig. 8 — Foot pedal controls for the experimental secretarial system

The dual pedal on the right of the photograph governs the left and right motions of the copy platen. When the right-hand pedal of this pair is depressed, the copy platen moves to the left at a rate that depends on the power supply voltage, which can be adjusted by the user (but not via the foot pedal). Thus, the user can control the speed with which the platen moves to the left, and hence can make it move in that direction at a speed that is compatible with his ability to read the copy and to type from it. The platen will continue to move to the left as long as the pedal is depressed or until the platen reaches the left end of its path of travel. When the left-hand pedal of the pair is depressed, the platen moves to the right at maximum speed and continues to move in this direction until the pedal is released or until the platen reaches the right end of its path of travel. Note that in this case the platen moves at only one speed, namely, maximum speed, whereas in the previous case it can be made to move at any speed up to and including the maximum speed. The left-hand pedal of the pair is used to carry out a carriage return of the copy platen or to retrace only a part of a line. The operation of this pair of pedals is carried out using the right foot. This pedal pair was taken from a tape transcriber and as part of that device, it performed roughly the same tasks it is performing now.

The mechanical foot pedal on the left in the photograph controls the line to line motion of the copy platen. This pedal is operated with the left foot and when depressed, it actuates a cable, similar to a bicycle brake cable, that is connected between the pedal and the copy advance mechanism of the copyholder. Thus, the size of the advance of the copy, that is, the number of lines it advances, is governed by how far the pedal is depressed. The user can easily determine how far to depress this pedal by observing the line to line motion of the image of the copy on the TV monitor as the pedal is depressed. Similarly, the user can decide how far and for how long he should depress the other two foot pedals by observing on the monitor the motion of the material to be copied as he activates these pedals.

Vibration

From the beginning of our research on a secretarial CCTV system, we had anticipated that vibrations caused by the operation of the typewriter, the motion of the copyholder, or jarring of the typewriter stand would be very troublesome, since the apparent motion of any such vibration is magnified along with the image. Such vibrations did manifest themselves and their elimination or drastic attenuation made great demands on our skill and imagination.

System components, such as the relay mirror, the copyholder, and the TV camera, were securely mounted to a sturdy and relatively rigid wooden frame, and the typewriter was set on a half-inch pad that rests on the plywood base of that frame. The frame is made of 0.50-inch plywood and all its joints are glued together. The illuminator is also mounted to the frame, next to and to the right of the relay mirror. The long optical paths between the mirrors of the image splitter and the relay mirror, as well as the one between the relay mirror and the camera lens, coupled with the motion of the relay mirror resulting from the operation of the typewriter, led to noticeable and disagreeable motions in the image of the typewriter platen on the TV monitor screen. This image vibration was eliminated, or at least reduced to a tolerable level, by placing a large mass on the uppermost face of the wooden frame. Clearly, in designing an acceptable secretarial CCTV system careful attention will have to be paid to mechanical design in order to eliminate such vibration problems.

Such a design might call for placing illuminators closer to the mirrors of the image splitter, using a separate illuminator for each area to be viewed.

The Camera Mounting

The TV camera was mounted at roughly an angle of 75 degrees to the horizontal with its lens pointing upward. This permitted not only the extension of the length of the optical path from the image splitting mirrors to the camera's focal plane, but also a lowering of the center of gravity of the supporting frame and the components mounted to that frame—and perhaps also a lengthening of the life of the camera's vidicon tube. Various manufacturers have informed us that vibration of a TV camera may loosen material from the cathode of its vidicon tube. If the camera were pointing downward when this occurred, the loosened material might fall on the photosensitive surface, and hence degrade the image produced by the camera.

EXPERIENCE OF PARTIALLY SIGHTED SUBJECTS

During and after the construction of the secretarial system, four partially sighted people used the system and gave us their thoughts and comments on the device. These people included a high school student, a college student, and the two adult men for whom visual data are given in the next section of this report. Although none of these people are expert typists, they all had had some typing experience before using the secretarial system. None of them was able to type from handwritten or printed material without the aid of a secretarial system,[2] but all of them were able to type from such material using our system. By this we mean that they were able to view an image of printed or handwritten material on the TV monitor while they typed from it, and were also able to view an image of the typewriter platen on the same monitor when they chose to look at it. All of these people recognized the great value of the secretarial system to the partially sighted, and all spoke enthusiastically about it.

EXPERIENCE OF A SIGHTED TYPIST

We asked a normally sighted female typist who does not wear corrective lenses and does not need eyeglasses to take part in an experiment of typing from a printed or handwritten manuscript. In the first part of the experiment she used her own typewriter at her desk, and after about a minute of pre-test typing, she typed at a rate of 86 words per minute (wpm) and made 4 mistakes.

In the second part of the experiment, she spent an hour learning about and practicing with the experimental secretarial CCTV system. At the time of this experiment, the line to line motion of the platen of the copyholder was controlled by a horizontal lever arm that projected toward the user to the right of the typewrit-

[2] This is not strictly true because they could type from such material if, for example, they picked it up to read a few words, put it down, typed these few words, and repeated the process until they had completed the task However, this method of typing from printed or handwritten material is so inefficient that it soon would discourage even the most tenacious of the partially sighted.

er Thus, to bring about that motion of the copyholder platen, the user was obliged to use her right hand. This meant that she had to take her right hand off the typewriter keys, move the lever arm, and then put her hand back on the keys. This maneuver, not being part of the normal typing routine, tends to upset the user's typing rhythm. With this version of the secretarial system, the secretary was able to type at a rate of 67 wpm and she made 5 errors. Since the secretarial system permits easy interchange of typewriters, the test was carried out using the secretary's own typewriter.

In response to her comments on the hand control of the line to line advance of the copyholder platen, that control was replaced by the foot-operated control described earlier in this section. After working about ten minutes with the altered secretarial system, the secretary typed at a rate of 75 wpm and made 4 errors.

In the three parts of the experiment described above, the subject observed the composite image on a 17-inch monitor at a distance of 40 inches and requested an image with a normal gray scale.

THOUGHTS ON A TEST PROGRAM

We did not have the time nor the funding to carry out a well-designed test of the experimental secretarial CCTV system. Even if we had had the time and funds to do the job, we would have been reluctant to do so using the present instrument. We believe that it would be wiser to design and build a second system that incorporates features and changes that became apparent to us during the construction and proof-testing of the present instrument. This would include a more rational design of the supporting structure, a redesign of the method of illumination, and the inclusion of a simple and rapid method of switching the instrument from operating as a secretarial system to operating as an individualized CCTV system for reading and writing and vice versa. The inclusion of the last feature would permit a user to use the system to type from a manuscript, to read ordinary printed and handwritten material, to write with a pen or pencil, and to carry on other operations that involve precise eye-hand coordination. Such a device would be valuable in the office, in the home, or at school.

Whatever secretarial CCTV system is selected in any future effort to determine whether such a system would help partially sighted people to qualify for jobs that call for typing from printed or handwritten material, these people would have to meet certain standards before they could be considered qualified to compete with sighted typists. They should have the ability

1. To type at a speed of at least 50 wpm without making more than 6 errors.
2. To type from handwritten and printed material as well as from recorded material.
3. To proofread what has been typed and make the necessary corrections.
4. To align and center the material in the typewriter and in the copyholder.[3]

[3] These standards are taken with a slight modification from "typist clerk," "technical typist," and "secretarial" job descriptions used by Rand and from "Definitions of Titles," *Dictionary of Occupational Titles*, Vol. I, 3rd ed., U.S. Department of Labor, Washington, D.C., 1965, pp. 136, 635, 767.

We urge the Rehabilitation Services Administration to fund a project aimed at determining whether partially sighted people could learn to use a secretarial system to qualify for jobs at performance rates that are comparable with those expected of sighted people. The project should probably also investigate how such a system could be used to help partially sighted students, particularly those in high school, college, or graduate school. Although this research could be carried on using the current secretarial system, we would prefer that it be undertaken with a more precisely designed system. Therefore, we encourage RSA to include in the recommended project allowance for the design and construction of such a system.

III. PSEUDOCOLOR EXPERIMENTS

The research described in this section was carried out to ascertain whether the following hypothesis is correct: *Using our pseudocolor system, partially sighted people will be able to read the whitest white letters on the blackest black background or the blackest black letters on the whitest white background that the system can generate, as well, if not better, than he or she can read these letters when they and the background are assigned, by the pseudocolor system, any other combination of grays and/or hues.* Although the validity of this hypothesis was not resolved by the experiments described below, useful data were gathered, which when analyzed stimulated the formulation of a very significant further experiment.

If future research were to support our hypothesis, we could safely conclude that a CCTV system, to be used by the partially sighted for reading printed or handwritten material and for writing with a pen or pencil, need not include a color camera or a color monitor. However, if it is found that some or all of the partially sighted can read or write better when viewing letters of particular hues or gray values on backgrounds of other particular hues or gray values than they can when viewing white (black) letters on a black (white) background, for these people, it would be wise to consider constructing and supplying them with CCTV systems that could produce one or more of these hue or gray combinations. If some of the preferred combinations involved white or black as one component and a hue as the other component, these combinations could probably be produced with a black and white CCTV system with appropriate color filters placed over the face of its monitor.

INTRODUCTION

The pseudocolor equipment used in these experiments was purchased from Spatial Data Systems of Santa Barbara, California. It consists of a vertically mounted and down-pointing black and white TV camera equipped with a plumbicon tube, a 6 to 1 zoom lens, an X-Y Platform, a 19-inch color monitor, an illuminator, a control panel built to our specifications, and an electronics cabinet that contains the appropriate logic (see Fig. 9[1]). With this equipment we are able to divide the gray scale into as many as 10 contiguous and nonoverlapping segments of arbitrary length and to assign to each of these segments one of 4080 hues plus 16 gray values. The hue or gray value assigned to any one segment is not dependent on the hue or gray value assigned to any other segment. Thus, for example, we can focus the TV camera on a black and white photograph having a continuous gray scale and create, on the TV monitor screen, a pseudocolor image of that photograph having as many as 10 hues or gray values. Further, each of these hues or gray values will replace the grays in the photograph that lie in the segment of the gray scale to which that hue or gray value was assigned. Thus, one might visualize the pseudocolor equipment as replacing the photograph's continuous gray scale by a finite gray scale,

[1] The illumination system shown in Fig. 9 is not the one used in the experiments described in this section. In our experiments, we used an Art Beam Lite 75 illuminator.

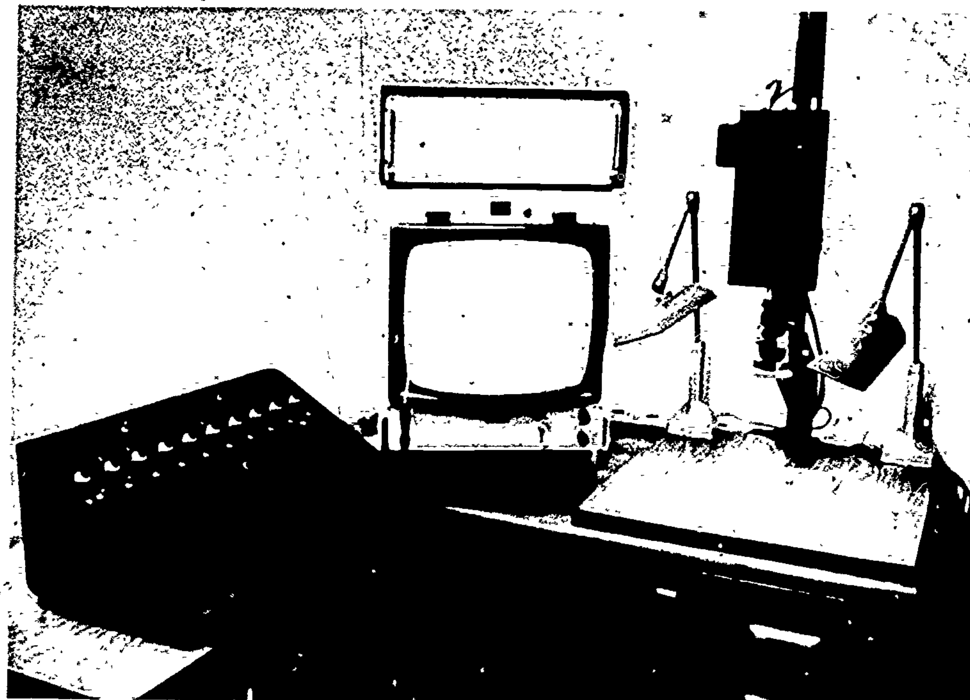

Fig. 9—The pseudocolor system

having up to 10 segments or components, and as assigning a particular hue or gray value to each of these components. The equipment also allows the operator, at any time, to change the hue or gray value assigned to any one or more of the segments and to change the length of these segments, provided they always remain contiguous and nonoverlapping.

This pseudocolor system has enormous potential for exploring the color sensitivity of the partially sighted. For example, when working with text printed in one color on paper of another color,[2] the gray scale can be split into two segments, and since any one of 4096 hues or gray values can be assigned to each of these segments independently of the hue or gray value assigned to the other segment, it follows that over 16.7 million color combinations can be displayed on the TV monitor.

THE PARTICIPANTS

Two partially sighted people participated in the experiments described below. One of them, Bill, is a 43-year-old historian. He has macular scars in both eyes resulting from histoplasmosis in 1968 and 1972. His distant visual acuity with correction is 20/200 in the left eye and 20/160 in the right eye. He is able to read the 20/100 line on a reading card at about 4 inches with his right eye and the 20/25

[2] Here the term "color" is used rather loosely because we mean it to include gray values as well as hues.

line at about 3 inches with the same eye. He uses corrective lenses for distance viewing, but removes them when trying to read at distances of 4 inches or less. Although he has central scotomas, his peripheral vision is good enough to permit him to maneuver safely in an unfamiliar environment without the help of a sighted person, a guide dog, or a cane. He is right-handed and right-eye dominant.

The other subject, Sam, is a 47-year-old applied mathematician. He has had corneal scars since shortly after birth. As a result of glaucoma, partial iridectomies were performed on both eyes when he was four months old. His distant visual acuity is nil in his left eye and 20/750 in his right eye. He is able to read the 20/20 line on a reading card at about 1 inch from his right eye. He does not use conventional eyeglasses, but he does use binoculars for a variety of purposes and closed circuit television systems, at home and at work, to carry out nearly all of his reading and writing. He is very myopic, and to the best of our knowledge, his right visual field is of normal extent. He is able to maneuver safely in an unfamiliar environment without the aid of a sighted person, a guide dog, or a cane. He is right-handed and right-eye dominant.

THE BLACK AND WHITE EXPERIMENT

In this experiment, and in the one that follows, sheets of paper were placed below the down-pointing camera on an X-Y Platform. This paper contained capitalized letters typed double-space in three columns. Each column was nine spaces wide, but only five letters appeared in each typed row of a column since a blank space was left between each of the letters. The sheets were typed with an IBM Selectric typewriter, which produced 10 symbols to the inch and which was equipped with a Gothic 12 element. The typed letters were copied from a computer printout containing the results of a computer program that generated random strings of letters of the alphabet. A decision was made to eliminate "Q" from the alphabetic symbols to be randomized, because we felt that the participants might have difficulty distinguishing an "O" from a "Q."

Because good quality typewritten material has only two gray values, namely, that of the type and that of the background, it was only necessary to require that the pseudocolor system divide the gray scale into two segments. The point of division chosen was one that resulted in the letter thickness remaining the same whatever combination of grays or hues were assigned to the images of the letters and to the background in which these letters were embedded.

Throughout the experiment, the letters shown to subject Bill were magnified 5 times on the 19-inch monitor and those shown to subject Sam were magnified 10 times. During the experiment, the participants sat on chairs that rolled easily from place to place.

The participants were first shown, on the monitor screen, images of five-letter sequences in which the whitest white producible by the pseudocolor system was assigned to the portion of the segmented gray scale that is associated with the image of the letters and the blackest black was assigned to the portion associated with the image of the background.[3] The participants were then asked to move their chairs

[3] Although it is less precise, for brevity let us say that the pseudocolor system assigned the whitest white that it could produce to the letters and the blackest black to the background, elsewhere in this

to a position that they found most comfortable for reading the displayed letters clearly. The experimenter asked them to read three five-letter strings of the randomly chosen letters. If they read them rapidly and without making a mistake, the experimenter recorded the distance between the participant's eyes and the face of the monitor, and this subject-to-monitor distance was used for the participant in subsequent experiments. If the subject-to-monitor distance proved unsatisfactory, it was changed, and the rest of the procedure was repeated until the participant felt that he was comfortable and was able to read the letters rapidly and with complete accuracy.

A lower magnification was used for subject Bill than for subject Sam, because we wanted both participants to sit at reasonable distances from the monitor; and since Bill's visual acuity is considerably better than Sam's, using the same magnification for both participants would have placed Sam too close to the monitor or Bill too far from it. As it turned out, Sam viewed letters magnified 10 times at a distance of 10 inches and Bill viewed letters magnified 5 times at a distance of 80 inches. We had considered presenting Bill with letters magnified less than 5 times, but we found that the image quality of the letters fell off sharply at magnifications that were significantly smaller than 5.

The settings of the contrast and brightness knobs on the TV monitor were the same throughout the experiments. Further, all measurements made with the pseudocolor equipment were taken in a darkened room. At the beginning of each data-gathering session, the participants were permitted to become adapted to the dark *before* they were asked to respond to data displayed on the TV monitor.

The black and white experiment consisted of having each participant (1) sit at the determined distance from the TV monitor with his chin on a chin rest, (2) view the letters displayed on the screen, and (3) read aloud the letters in a particular row and column.

Initially, the knobs on the control panel, which govern the intensity of the signal delivered by the monitor's red, green, and blue guns and which govern the gray value or hue taken on by those portions of the image corresponding to the background in which the letters are embedded, were all set in their zero position (0,0,0). Let us call these knobs the background color control knobs (BCCKs). Likewise, the knobs on the control panel, which govern the intensity of the signal delivered by the monitor's red, green, and blue guns and which govern the gray value or hue taken on by those portions of the image corresponding to the letters, were all set in their zero position (0,0,0). Let us call these knobs the letter color control knobs (LCCKs). This setting of the BCCKs and the LCCKs produces black letters on a black background, and since these blacks are indistinguishable from one another, no letters were visible on the monitor screen. Even so, the participants were asked what they saw on the screen and their responses were recorded. In this and subsequent cases where the gray values of the background and the letters were the same, neither participant reported seeing any symbols on the screen.

The LCCKs were then each set in their one position (1,1,1), and the BCCKs were kept in their zero position (0,0,0). Here, as in all subsequent settings of the color

section, we will refer to the pseudocolor system as assigning a gray value or hue to the letters and another gray value or hue to the background when we really mean that the system assigns a gray value or hue to the portion of the segmented gray scale that is associated with the image of the letters and assigns another gray value or hue to the portion of this gray scale that is associated with the image of the background.

control knobs, the experimenter displayed a sequence of 15 randomly selected letters, asked the participants to identify these letters, and recorded the participants' responses. The letters were displayed five at a time, and different strings of letters were shown every time a change in the knob settings was made.

The LCCKs were then each set in their two position (2,2,2), and measurements were made as described above. The procedure was repeated for LCCK settings of (3,3,3), (4,4,4), (5,5,5), up to and including (15,15,15). After that, the BCCKs were each set to 1 (1,1,1) and the process was repeated for LCCK settings of (0,0,0), (1,1,1), up to and including (15,15,15). Similar measurements were made while BCCKs were held in turn at (2,2,2), (3,3,3), up to and including (15,15,15). Thus, measurements were made at the 256 settings of the BCCKs and the LCCKs that produce the combinations of gray values that can be generated with two channels of the pseudocolor system.[4]

Table 1 contains the experimental results obtained with subject Bill, and Table 2 contains the results obtained with subject Sam. The column data in these tables arose from trials in which the settings of the BCCKs were varied and the LCCKs were held fixed. The row data in the tables arose from trials in which the settings of the LCCKs were varied and the BCCKs were held fixed. The entry in the ith column and (2j)th row ($i = 0, 1, \ldots, 15$; $j = 0, 1, \ldots, 15$) is the percentage score achieved by the participant when viewing letters with the gray value corresponding to the LCCK settings of (i,i,i) on a background whose gray value is determined by the BCCK settings of (j,j,j). The entry in the ith column and the $(2j+1)$th row is the average time in seconds that elapsed between the time the participant first saw each string of five letters and the time he reported what he saw. Here the gray value of the letters was determined by the LCCK settings of (i,i,i), and the gray value of the background was determined by the BCCK settings of (j,j,j).

Zero entries in the tables indicate that the participant definitely said that he saw nothing on the monitor screen. Dashes indicate that no response time was recorded, because the participant definitely said that he could not see any symbols on the monitor screen. The letter "T" indicates that the participant saw the trace of something resembling symbols on the screen, but could not identify any of the symbols. The letter "L" indicates that the participant took somewhat more than 10 seconds to report what he saw, and the letter "S" indicates that the participant took somewhat less than 10 seconds. Where Ls and Ss appear in the tables, the experimenter *did not* record a definite average response time.

In Table 2, above the principal diagonal, observe that once subject Sam achieved a perfect score he tended to maintain that score for increases in letter brightness and decreases in background brightness. However, below the principal diagonal he was not as successful when letter brightness was decreased or background brightness was increased. In Table 1, note that both above and below the principal diagonal subject Bill had trouble maintaining a perfect score once he achieved it. These results may have arisen, at least in part, from the fact that Sam's visual pathology has led to serious corneal opacities as well as to some degradation in media transparency, whereas Bill's has led to serious retinal scarring as well as possible post-retinal defects. Sam definitely prefers to view bright letters on a dark background rather

[4] Other gray values could have been obtained if we had changed the settings of the TV monitor's brightness and contrast control knobs.

Table 1

Results of the Black and White Experiment Using the Pseudocolor System for Subject Bill

BCCK	LCCK 0[a]	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0[b]	0 —	0 —	T L	T L	T L	T L	T L	33 S	93 9	93 8	67 5	87 8	73 5	100 4	100 5	100 5
1	0 —	0 —	T L	T L	T L	T L	T L	60 6	100 3	87 10	93 11	93 S	87 8	87 7	100 9	93 9
2	T —	T L	0 —	T L	T L	T L	T L	33 20	80 S	100 9	93 5	93 5	80 6	100 7	100 6	100 7
3	T L	T L	T L	0 —	T L	13 L	T L	60 10	93 7	93 5	100 6	93 5	87 4	93 8	100 7	100 6
4	T L	T L	T L	T L	0 —	T L	T L	80 12	100 S	93 10	100 6	87 7	93 5	73 15	100 7	87 12
5	T L	T L	T L	T L	T L	0 —	T L	87 S	93 10	93 12	93 6	100 8	100 8	100 5	100 6	100 10
6	T L	T L	T L	60 L	T L	T L	0 —	T L	100 5	93 L	100 6	93 6	93 17	80 8	100 8	100 10
7	T L	T L	T L	T L	T L	T L	T L	0 —	T L	73 12	93 5	93 6	93 7	100 5	93 5	93 7
8	T L	87 22	T L	100 10	T L	60 5	T L	T L	0 —	T L	100 4	93 8	100 8	100 5	100 6	100 6
9	T L	87 L	T L	100 13	100 8	87 3	87 20	T L	T L	0 —	T L	87 8	87 9	93 6	100 3	100 6
10	13 L	100 9	87 30	100 4	93 15	27 L	100 11	47 20	T L	T L	0 —	T —	87 16	100 9	100 9	93 6
11	53 15	87 L	93 7	100 5	100 14	80 11	93 6	87 17	80 6	T L	0 —	0 —	T L	100 25	93 11	100 6
12	93 L	100 L	93 16	100 4	80 6	93 12	100 7	87 12	100 10	67 S	T L	T L	0 —	T L	50 19	93 10
13	93 L	100 L	93 9	87 S	93 5	87 12	93 5	93 5	93 9	93 7	87 13	T L	0 —	0 —	T L	27 12
14	93 L	87 L	100 7	100 3	100 8	93 8	100 5	93 6	100 5	100 6	93 11	93 10	T L	0 —	0 —	0 —
15	87 12	100 4	93 10	100 5	93 9	100 7	100 7	100 6	100 7	100 9	93 7	100 6	100 11	T L	0 —	0 —

[a] Each of the numbers in this row is an abbreviation for a triplet having that number for each of its three elements. Each such triplet represents the LCCK settings that were used when making the measurements reported in the column below the abbreviation for the triplet.

[b] Each of the numbers in this column is an abbreviation for a triplet having that number for each of its elements. Each such triplet represents the BCCK settings that were used when making the measurements reported in the row next to the abbreviation for the triplet and in the row that follows.

Table 2

Results of the Black and White Experiment Using the Pseudocolor System for Subject Sam

BCCK	LCCK 0[a]	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0[b]	0 —	T L	87 L	T L	93 4	100 3	100 3	100 3	100 S	100 2	100 2	100 2	100 S	100 S	100 2	100 2
1	0 —	0 —	T L	T L	93 S	100 S	100 3	100 2	100 S	100 S	100 2	100 2	100 2	100 2	100 2	100 2
2	T L	T L	0 —	T L	100 S	100 S	100 3	100 2	100 S	100 S	100 S	100 3	100 S	100 2	97 2	100 2
3	T L	T L	T L	0 —	87 L	100 S	100 3	100 S	100 S	100 S	100 2	100 S	100 S	100 S	100 3	100 2
4	27 L	T L	T L	T L	0 —	60 5	93 8	87 4	100 2	100 S	100 2	100 3	100 2	100 2	100 2	100 2
5	T L	27 L	T L	T L	T L	0 —	T L	93 4	100 S	100 S	100 2	100 3	100 2	100 3	100 2	100 2
6	87 S	27 L	33 L	20 L	20 L	T L	0 —	87 17	93 4	100 2	100 S	100 3	100 S	100 S	100 2	100 2
7	73 S	53 8	67 L	93 S	87 S	T L	T L	0 —	0 —	80 11	87 2	100 S	100 2	100 3	100 3	100 S
8	87 S	93 S	93 S	93 S	93 S	87 S	87 7	T L	0 —	T —	57 9	93 5	100 4	100 3	100 4	100 2
9	93 S	93 S	93 S	87 S	87 S	100 S	93 7	T L	0 —	0 —	T L	93 13	93 6	100 4	100 4	100 3
10	100 5	100 S	93 S	100 5	93 3	100 11	93 7	T L	T L	T L	0 —	T L	93 7	100 5	100 4	100 2
11	100 5	100 S	100 3	87 5	100 S	93 12	100 5	87 13	T L	27 10	T L	0 —	T L	T L	100 5	100 3
12	100 S	100 S	100 3	100 S	80 S	100 S	100 S	100 9	20 L	87 6	T L	T L	0 —	0 —	27 11	87 5
13	100 S	100 10	100 S	100 6	87 5	100 4	100 2	100 8	87 15	93 6	60 18	T L	T L	0 —	0 —	53 15
14	93 5	100 3	100 S	100 3	100 S	93 S	100 S	93 5	100 20	100 5	87 8	T 20	T L	0 —	0 —	0 —
15	100 3	93 4	100 S	100 5	100 4	93 4	100 4	100 5	87 12	87 5	93 7	53 20	T L	T L	0 —	0 —

[a] Each of the numbers in this row is an abbreviation for a triplet having that number for each of its three elements. Each such triplet represents the LCCK settings that were used when making the measurements reported in the column below the abbreviation for the triplet.

[b] Each of the numbers in this column is an abbreviation for a triplet having that number for each of its elements. Each such triplet represents the BCCK settings that were used when making the measurements reported in the row next to the abbreviation for the triplet and in the row that follows.

than dark letters on a bright background, and during the experiments he frequently complained about the glare from a bright background, whether or not that background had a hue or a gray value. His discomfort when confronted with a bright background probably arises from the fact that the scar tissue in the cornea of his right eye and the defects in the vitreous humor of that eye tend to scatter the light from such a background. Bill was not bothered as much as Sam by such backgrounds, because his corneas, lenses, and optical media are not impaired. However, the damage to his retinas and possibly to his optic nerves may be, in part, responsible for the lack of consistency in the scores he achieved in trials that lay both above and below the principal diagonal.

The experimenter noted that high scores were not always correlated with short response times. For example, Bill achieved a score of one hundred, the maximum, 64 times, but in these cases his average response time for reading five letters was more than 10 seconds 5 times and more than 5 seconds at least 42 times. Similarly, Sam achieved a score of one hundred 121 times, and in these cases his average response time was greater than 10 seconds at least 6 times. Thus, it is important to note both the score and the time it takes to achieve that score if we really wish to ascertain how well a participant is able to read symbols under various contrast conditions The same statement is applicable when we are trying to determine how well a participant is able to read symbols under various contrast conditions, or how well he can read symbols of one hue or gray value that are embedded in a background of another hue or gray value.

In relation to the letters used in these experiments, and those described in the next section, the experimenter observed that there may be a difference in how easily the participants were able to perceive these letters, which is a function of what letters are being observed. The "relative visual acuities" (for observers with *normal vision*) required to identify the various letters of the alphabet have been determined by various investigators. The "visual acuities" required to identify the letters of the alphabet were measured, and then were normalized with respect to the "relative visual acuity" of the letter that proved most difficult to identify, namely, "B." Table 3 gives the "relative visual acuities" for selected letters of the alphabet.

Table 4 contains the relative luminosity values of the 16 grays that are producible by the pseudocolor system using the 19-inch Conrac monitor with its brightness knob set at 70 and its contrast knob set to produce maximum luminosity.

THE COLOR EXPERIMENT

In the color experiment, the same conditions prevailed as in the black and white experiment relative to

1. The settings of the brightness and contrast knobs on the TV monitor.
2. The monitor-to-participant distances.
3. The magnification of the image on the monitor screen.
4. The darkening of the test facility.
5. The participants' adaptation to darkness before each trial period.
6. The type of material displayed on the TV monitor.
7. The subdivision of the pseudocolor system's gray scale into two segments.
8. The point of division of that gray scale.

Table 3
Relative Visual Acuities of Selected Letters of the Alphabet

Letter	Visual Acuity	Letter	Visual Acuity	Letter	Visual Acuity
L	.70	Y	.80	E	.85
T	.74	F	.81	R	.85
V	.78	P	.81	S	.88
U	.79	D	.81	G	.89
C	.79	Z	.84	H	.92
O	.80	N	.84	B	1.00

SOURCE: I. M. Borish, *Clinical Refraction*, The Professional Press, Inc., Chicago, Ill., 1970, pp. 384-387.

Table 4
Relative Luminosity of Grays Produced by the Pseudo-color System

r,g,b Setting	Measured Brightness
0,0,0	.030
1,1,1	.035
2,2,2	.065
3,3,3	.180
4,4,4	.450
5,5,5	.850
6,6,6	1.440
7,7,7	2.150
8,8,8	3.070
9,9,9	4.160
10,10,10	5.360
11,11,11	6.780
12,12,12	8.350
13,13,13	9.930
14,14,14	11.570
15,15,15	13.400

In this experiment, however, the participants were shown letters of one hue or gray value displayed on a background of another hue or gray value. The hues and gray values used in this experiment were determined by triads of randomly selected integers in the range 0 through 15. Six such randomly selected integers were used for each trial; the first three were used to determine the hue or gray value of the background and the second three to determine the hue or gray value of the letters. A different sextuple of integers was used for each trial that a participant took part in, *but* each participant was shown the same hues and gray values in the same combinations.

The first integer in a triad determined the intensity of the signal generated by the TV monitor's red gun, the second integer determined the intensity of the signal generated by its green gun, and the third integer determined the intensity of the signal generated by its blue gun.

We made measurements of the intensity of the signals produced *individually* by the TV monitor's red, green, and blue guns, as reported in Table 5. These measurements were made with the system set to respond to a viewed object's entire gray scale, and that gray scale was not subdivided by the pseudocolor system, that is, only the first of the system's ten channels was used. For the red gun, measurements were made for control knob settings of (r,0,0) where r = 0, 1, . . ., 15; for the green gun, they were made for settings of (0,g,0) where g = 0, 1, . . . 15; and for the blue gun, they were made for settings of (0,0,b) where b = 0, 1, . . ., 15. These measurements were stored in a digital computer, and a computer program was written and used to convert any knob setting triplet (r,g,b), where r, g, b = 0, 1, . . . 15, into CIE[5] coordinates.

Table 5

Measured Intensity Values for a Brightness Setting of 70

Knob Setting	Red Value	Green Value	Blue Value
0	.010	.010	.010
1	.010	.015	.010
2	.015	.040	.010
3	.040	.120	.020
4	.090	.310	.050
5	.170	.610	.070
6	.280	1.060	.100
7	.420	1.580	.150
8	.630	2.240	.200
9	.880	3.000	.280
10	1.160	3.840	.360
11	1.450	4.870	.460
12	1.800	5.970	.580
13	2.180	7.050	.700
14	2.610	8.130	.830
15	3.060	9.350	.990

Each participant was asked to read 15 randomly selected letters and was asked to do this for 200 hue or gray value combinations.

Results of these 400 trials were analyzed primarily by determining the CIE coordinates for the hue or gray value of the background and the hue or gray value of the letters, plotting these values on the CIE diagram and drawing the vectors connecting these values. The CIE diagram represents an attempt to describe in two dimensions the three-dimensional color space arising from various degrees of in-

[5] Commission Internationale d'Éclairage, denoting a standard system for specifying color.

teraction between three primary colors. Figure 10 is a CIE diagram; it shows the location of various saturated colors, the white corresponding to various color temperatures, and the location of the three primary colors generated by the pseudocolor system. Given the energy or luminosity of these primary colors (see Table 5), the X and Y coordinates in the CIE diagram of the color resulting from the mixing of primaries having these energies are given by the formulas

$$X = \frac{0.1339R + 0.1161G + 0.0640B}{0.2125R + 0.3745G + 0.4130B}, \quad (1)$$

$$Y = \frac{0.0723R + 0.2228G + 0.0289B}{0.2125R + 0.3745G + 0.4130B}, \quad (2)$$

where R = the relative amount of energy rising from the action of the red gun,
G = the relative amount of energy arising from the action of the green gun,
B = the relative amount of energy arising from the action of the blue gun.

Equations (1) and (2) only apply when the source of color is a cathode ray tube (CRT) that is coated with the same phosphor as those that were used in making the CRT used in this experiment. The equations were derived by Mr. Roy H. Stratton using information supplied by the Conrac Corporation. The derivation of Eqs. (1) and (2) is given in the appendix.

We used the computer program to analyze data arising from trials in which the participants achieved a perfect score in identifying 15 letters and in reading these letters at an average rate of no less than five letters per 15 seconds. Subject Sam succeeded in doing this in 45 of the 200 trials and subject Bill in 65 of these trials.

Table 6 contains the collected and calculated results of the trials in which subject Sam was a participant and Table 7 those of subject Bill. Column 1 in these tables, ID No., contains the trial identification number; col. 2, Letter Energy, is the measured relative energy or luminosity of the letters; col. 3, Back Energy, is the relative energy or luminosity of the background in which the letters were embedded, col. 4, Contrast Ratio, is the contrast ratio computed by the formula

$$\text{Contrast ratio} = \frac{(\text{Letter energy}) - (\text{Background energy})}{\text{Background energy}};$$

cols. 5 and 6, Letter, give, respectively, the X and Y CIE coordinates of the hue of the letters; cols. 7 and 8, Background, give, respectively, the X and Y CIE coordinates of the hue of the background in which the letters are embedded; col. 9, Vector Magnitude, is the magnitude of the vectors connecting the X and Y CIE coordinates of the hue of the letters with the X and Y CIE coordinates of the hue of the background in which the letters are embedded, col. 10, Vector Angle, gives the angle that the vectors, referred to in the description of col. 9, make with the CIE diagram's x-axis; and col. 11, Read Time, is the average time in which the participants read a string of five letters.

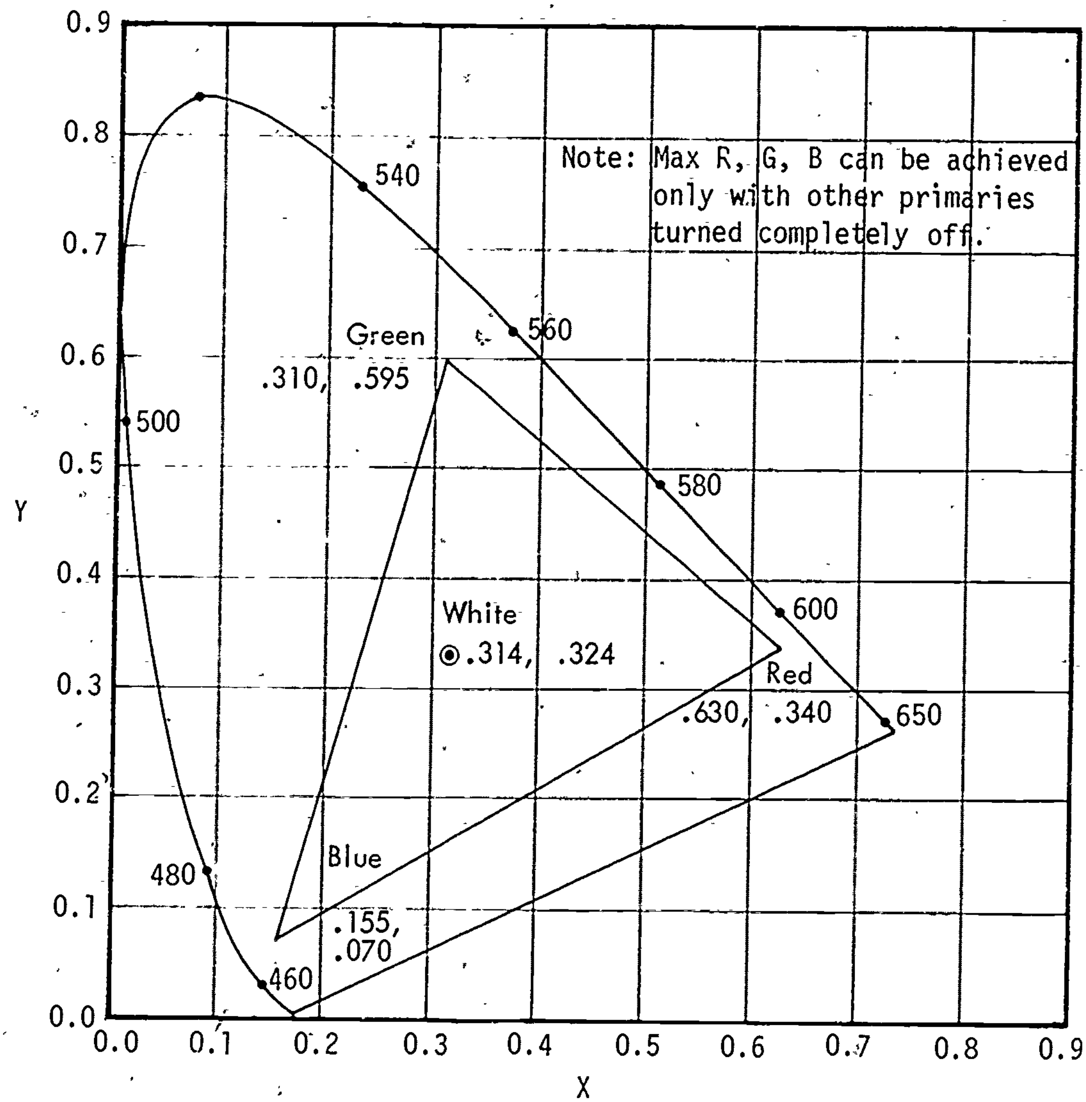

Fig. 10—Conrac color monitor: CIE 1931 (X, Y) chromaticity diagram

The data in Tables 6 and 7 did not provide us with many insights into the meaning of the experimental results. However, an examination of the data in Table 6 does reveal one interesting fact, namely, that many of the vector angles lie roughly in the ranges 90 to 110 and -90 to -110. Table 7 also reveals an angular preference. Further, both tables indicate that a wide range of energies (or luminosities) as well as hues are to be found in the data. What was needed was a technique that would separate the effects of these two parameters.

In an attempt to roughly accomplish this end, we determined, for each trial reported in Tables 6 and 7, the absolute value of the difference between the luminosity of the background and the luminosity of the letters, ascertained the largest and smallest of these absolute differences; divided the span between these two values

Table 6

Experimental and Calculated Results for Subject Sam

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
ID No.	Letter Energy	Back Energy	Contrast Ratio	Letter X	Letter Y	Background X	Background Y	Vector Magnitude	Vector Angle	Read Time
1	9.55	4.66	1.05	.3266	.4264	.2171	.2359	.220	60	3.0
2	1.54	4.84	− 68	.3321	.5768	.3944	.2384	.344	100	15.0
3	.94	2.85	−.67	.6104	.3484	.1773	.1248	.487	27	15.0
4	13.55	.54	24.09	.3741	.5167	.3934	.2056	.312	94	1.7
5	1.35	6.05	−.78	.2250	.2211	.3031	.1847	.086	155	3.0
6	4.40	3.70	.19	.2347	.2834	.5887	.3313	.357	−172	4.3
7	11.62	3.25	2.58	.3898	.4785	.1910	.1669	.370	57	5.0
8	14.30	3.94	2.63	.3453	.3775	.2765	.4264	.084	−35	2.0
9	6.78	1.27	4.34	.3100	.5949	.4465	.2358	.384	111	2.0
10	5.13	14.92	−.66	.3530	.2611	.4003	.4833	.227	−102	3.5
11	1.11	11.71	−.91	.2889	.2222	.3206	.5865	.366	−95	3.5
12	7.97	4.73	.68	.3905	.3048	.3981	.4788	.174	−93	3.0
13	13.26	4.43	1.99	.2434	.3203	.2548	.1920	.129	95	2.0
14	12.04	2.21	4.45	.3367	.3328	.4105	.2325	.125	126	2.7
15	7.06	10.79	−.35	.3880	.4990	.3156	.4184	.108	48	7.0
16	1.55	7.55	−.79	.3206	.5441	.3593	.5476	.039	−175	3.5
17	2.92	.59	3.95	.2647	.4415	.3235	.1658	.282	102	3.0
18	1.26	6.48	−.81	.2408	.1675	.3024	.4304	.270	−103	5.0
19	.72	7.14	−.90	.4384	.2313	.4543	.3830	.153	−96	3.5
20	7.85	1.58	3.97	.2244	.2871	.2667	.2334	.068	128	3.0
21	4.82	14.14	−.66	.4864	.4502	.4322	.4938	.070	−39	3.0
22	3.99	10.33	−.61	.2394	.2346	.3100	.5949	.367	−101	6.5
23	11.67	4.18	1.79	.3080	.5641	.3994	.2173	.359	105	2.0
24	1.66	9.08	−.82	.1972	.0965	.3467	.4983	.429	110	10.0
25	3.05	1.75	.74	.2846	.4357	.2319	.1826	.259	78	2.7
26	3.24	8.06	−.60	.2464	.2312	.3188	.5879	.364	−101	5.0
27	7.15	.41	16.44	.3041	.3688	.3410	.1758	.196	101	2.7
28	12.11	2.97	3.08	.3884	.4682	.3566	.4137	.063	60	3.0
29	.99	1.23	−.19	.1837	.0863	.5470	.2939	.418	−150	3.0
30	2.93	.42	5.98	.6048	.3530	.5057	.3397	.100	8	2.7
31	10.59	4.33	1.45	.3612	.4275	.3352	.4959	.073	−69	2.7
32	11.97	.68	16.60	.4131	.5103	.6214	.3471	.265	142	1.3
33	4.62	.20	22.69	.2682	.3377	.6245	.3447	.356	−179	1.7
34	5.28	.68	6.76	.3323	.3635	.1657	.0761	.332	60	4.0
35	3.22	8.75	−.63	.5230	.2794	.2456	.3719	.292	−18	9.0
36	9.45	3.87	1.44	.3147	.5911	.2116	.2263	.379	74	6.3
37	8.42	.82	9.27	.2841	.4892	.2521	.1384	.352	85	2.3
38	1.66	1.93	−.14	.2953	.1518	.6192	.3489	.379	−149	4.0
39	2.13	11.73	−.82	.5837	.3510	.3136	.3814	.272	−6	5.0
40	.94	10.89	−.91	.1626	.0746	.3256	.3653	.333	−119	4.7
41	11.77	3.11	2.78	.3487	.3624	.6283	.3417	.280	176	2.0
42	7.70	3.74	1.06	.3495	.5542	.5548	.3375	.298	133	2.0
43	8.95	9.71	−.08	.3855	.4775	.2721	.3466	.173	49	2.3
44	8.37	3.25	1.58	.2911	.5118	.1829	.1635	.365	73	4.0
45	7.05	1.18	4.97	.3279	.4429	.3100	.2523	.191	85	1.8

Table 7

Experimental and Calculated Results for Subject Bill

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
ID No.	Letter Energy	Back Energy	Contrast Ratio	Letter X	Letter Y	Background X	Background Y	Vector Magnitude	Vector Angle	Read Time
151	5.32	1.96	1.71	.3272	.4579	.1963	.1985	.291	63	4.0
152	8.77	.14	61.64	.3723	.5438	.4064	.2130	.333	96	4.0
153	2.30	5.89	−.61	.2348	.3402	.2757	.4575	.124	−109	9.0
154	.23	3.17	−.93	.1723	.1166	.2981	.1599	.133	−161	7.3
155	.09	1.56	−.94	.2421	.2252	.3835	.2258	.141	−180	10.0
156	7.05	1.13	5.26	.3967	.5025	.1688	.1148	.450	60	6.0
157	9.08	1.57	4.80	.3547	.3941	.2695	.4521	.103	−34	5.7
158	2.21	9.81	−.77	.3745	.2368	.4070	.5026	.268	−97	5.0
159	8.60	1.70	4.06	.2342	.3199	.2321	.1458	.174	89	8.5
160	7.13	.95	6.51	.3450	.3344	.4491	.2373	.142	137	7.5
161	.30	3.88	−.92	.3100	.5949	.3433	.5684	.043	141	5.0
162	5.82	1.96	1.97	.2700	.4594	.2197	.2303	.235	78	10.0
163	.20	3.63	−.94	.4732	.2511	.5192	.3958	.152	−108	5.7
164	4.10	2.47	.66	.3247	.4727	.3982	.2083	.274	106	7.0
165	2.69	7.77	−.65	.5503	.3977	.2943	.5416	.294	−29	7.5
166	2.06	9.17	−.78	.5213	.4216	.4367	.4941	.111	−41	8.0
167	7.71	2.39	2.22	.3082	.5873	.4320	.2275	.380	109	6.0
168	2.12	.36	4.97	.3100	.5949	.2652	.3193	.279	81	8.5
169	.96	4.63	−.79	.2114	.1713	.3106	.5944	.435	−103	6.3
170	3.42	.10	33.20	.2929	.3747	.3094	.1578	.217	94	8.3
171	.24	6.81	−.96	.1550	.0700	.3180	.5785	.534	−108	5.5
172	.20	2.19	−.91	.4732	.2511	.3278	.5808	.360	−66	9.0
173	8.56	3.13	1.74	.3653	.4398	.3362	.5239	.089	−71	8.0
174	9.78	.44	21.23	.4118	.5114	.6301	.3402	.277	142	10.3
175	3.34	.13	24.69	.2636	.3423	.6301	.3402	.367	180	6.0
176	2.68	4.62	−.42	.3429	.2361	.3100	.5949	.360	−85	7.5
177	2.64	7.10	−.63	.5469	.2930	.2473	.3814	.312	−16	14.5
178	7.72	2.72	1.84	.3122	.5932	.2027	.2110	.398	74	4.7
179	.43	3.43	−.87	.1550	.0700	.4719	.2626	.371	−149	14.7
180	9.08	2.88	2.15	.3462	.4975	.2453	.1865	.327	72	6.0
181	5.26	15.51	−.66	.3299	.1932	.3946	.4528	.268	−104	7.7
182	12.57	5.51	1.28	.4047	.4525	.4781	.3124	.158	118	9.3
183	12.45	3.49	2.57	.2606	.3248	.5388	.4129	.292	−162	6.0
184	6.28	12.29	−.49	.2403	.2462	.3147	.3475	.126	−126	6.0
185	2.52	5.76	−.56	.2964	.4028	.2856	.2196	.184	87	14.0
186	5.85	9.53	−.39	.3192	.5763	.2266	.2736	.317	73	14.0
187	2.82	7.91	−.64	.2969	.1962	.4889	.4526	.320	−127	11.7
188	.70	1.99	−.65	.1784	.1099	.2085	.1482	.049	−128	10.5
189	1.10	2.85	−.61	.3632	.1973	.3102	.5717	.378	−82	6.3
190	5.78	14.13	−.59	.3129	.5812	.4339	.4964	.148	145	5.0
191	3.00	2.21	.36	.3032	.4882	.3177	.5888	.102	−98	26.7
192	1.58	12.02	−.87	.2937	.4671	.2858	.4778	.013	−53	4.3
193	3.48	7.92	−.56	.1800	.1455	.2161	.2694	.129	−106	7.0
194	5.78	12.13	−.52	.3129	.5812	.3885	.3893	.206	112	4.7
195	2.41	9.37	−.74	.2977	.1512	.2796	.2943	.144	−83	7.0
196	10.58	2.52	3.20	.3145	.3533	.2205	.2789	.120	38	5.7
197	6.65	.90	6.39	.5164	.3981	.1550	.0700	.488	42	6.3
198	8.22	1.06	6.75	.2276	.2713	.3258	.5213	.269	−111	6.0
199	1.55	9.38	−.83	.1638	.0771	.2820	.2520	.211	−124	6.0
200	6.08	1.28	3.77	.3879	.4934	.2096	.2511	.301	54	6.3
201	5.85	1.44	3.06	.2325	.2827	.3196	.2349	.099	151	7.5
202	.91	7.43	−.88	.1583	.0734	.2467	.2884	.232	−122	5.0
203	1.37	7.38	−.81	.1925	.0964	.3207	.5520	.473	−106	6.5
204	1.48	3.11	−.52	.3886	.2146	.3868	.2033	.011	81	11.8
205	1.70	9.10	−.81	.2490	.1643	.4445	.4536	.349	−124	4.0
206	1.78	7.26	−.75	.5752	.3539	.2758	.4789	.325	−23	5.0
207	.06	9.84	−.99	.3100	.5949	.3222	.5470	.049	104	4.7
208	4.05	.20	21.50	.4327	.4480	.4998	.2661	.194	110	6.7
209	.90	4.47	−.80	.1899	.0919	.2371	.3060	.219	−102	12.7
210	7.55	1.54	3.92	.2494	.3838	.3222	.1655	.230	108	7.0
211	3.89	7.07	−.45	.3143	.5914	.3100	.5949	.006	−39	5.7
212	.17	4.33	−.96	.1550	.0700	.2411	.2344	.186	−118	6.0
213	.32	4.94	−.94	.5370	.2912	.2982	.5528	.354	−48	5.3
214	1.60	8.21	−.81	.3100	.5949	.2988	.5571	.039	74	3.7
215	7.31	.45	15.24	.2892	.3595	.3950	.2546	.149	135	5.0

into four equal intervals; plotted on the CIE diagram, for each participant and for each interval, the vectors (whose CIE coordinates are given in Tables 6 and 7) that determined the trials that gave rise to absolute luminosity differences that lie in these intervals, and then plotted the chromatic vectors corresponding to the trials on a CIE diagram. Thus, a separate diagram was made for each of the four luminosity intervals and separate diagrams were prepared from the data obtained with Bill as the participant and with Sam as the participant. Figures 11 through 14 contain the data obtained with subject Bill and Figs. 15 through 18 those with subject Sam. Energy level 1 is the interval in which absolute luminosity differences were the smallest, and energy level 4 is the interval in which they were the largest. The asterisk or head end of each vector is the CIE point that arises from the hue assigned to the letters.

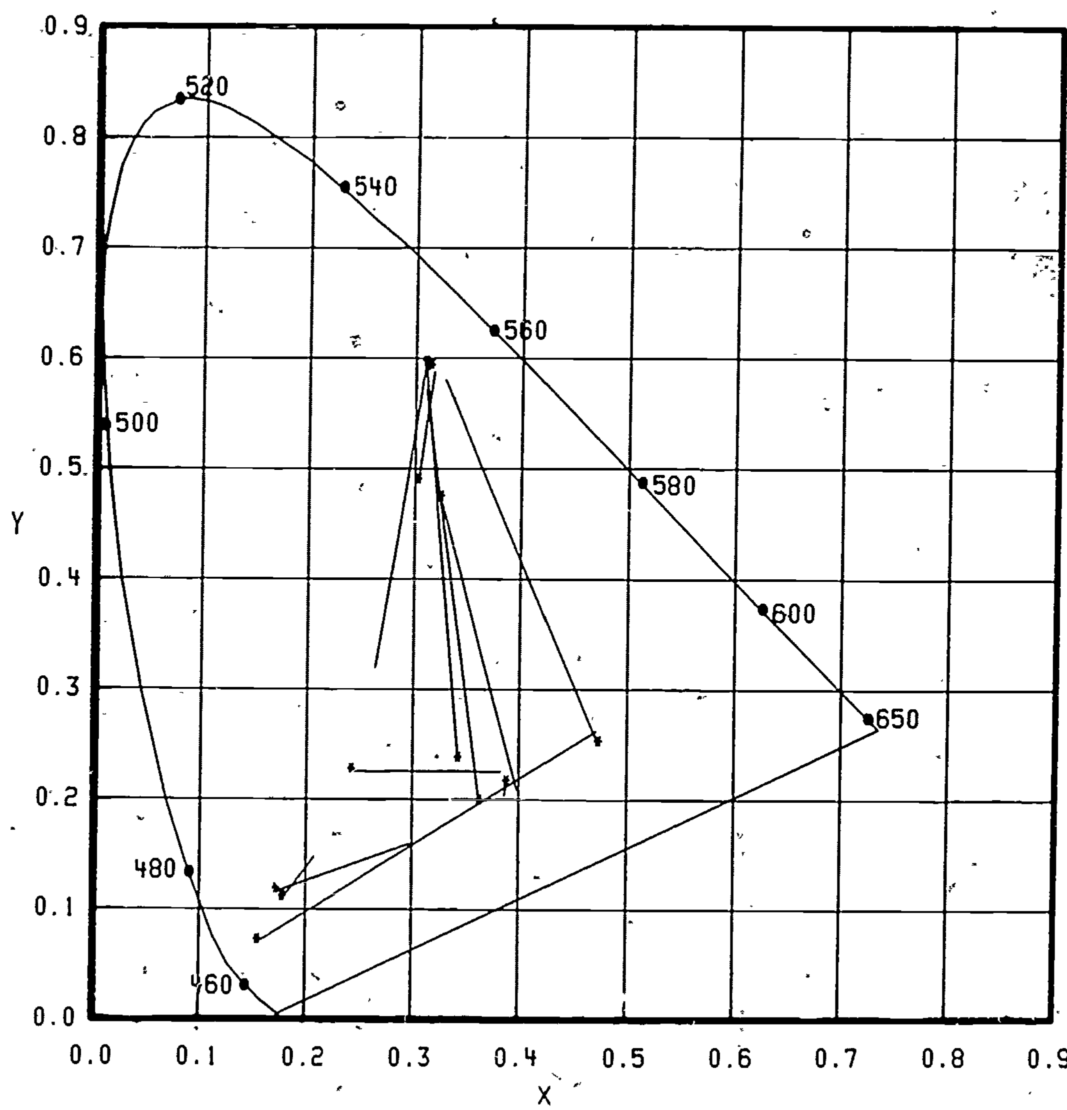

Fig. 11—Reading vectors plotted on 1931 CIE diagram, data set Bill: energy level one

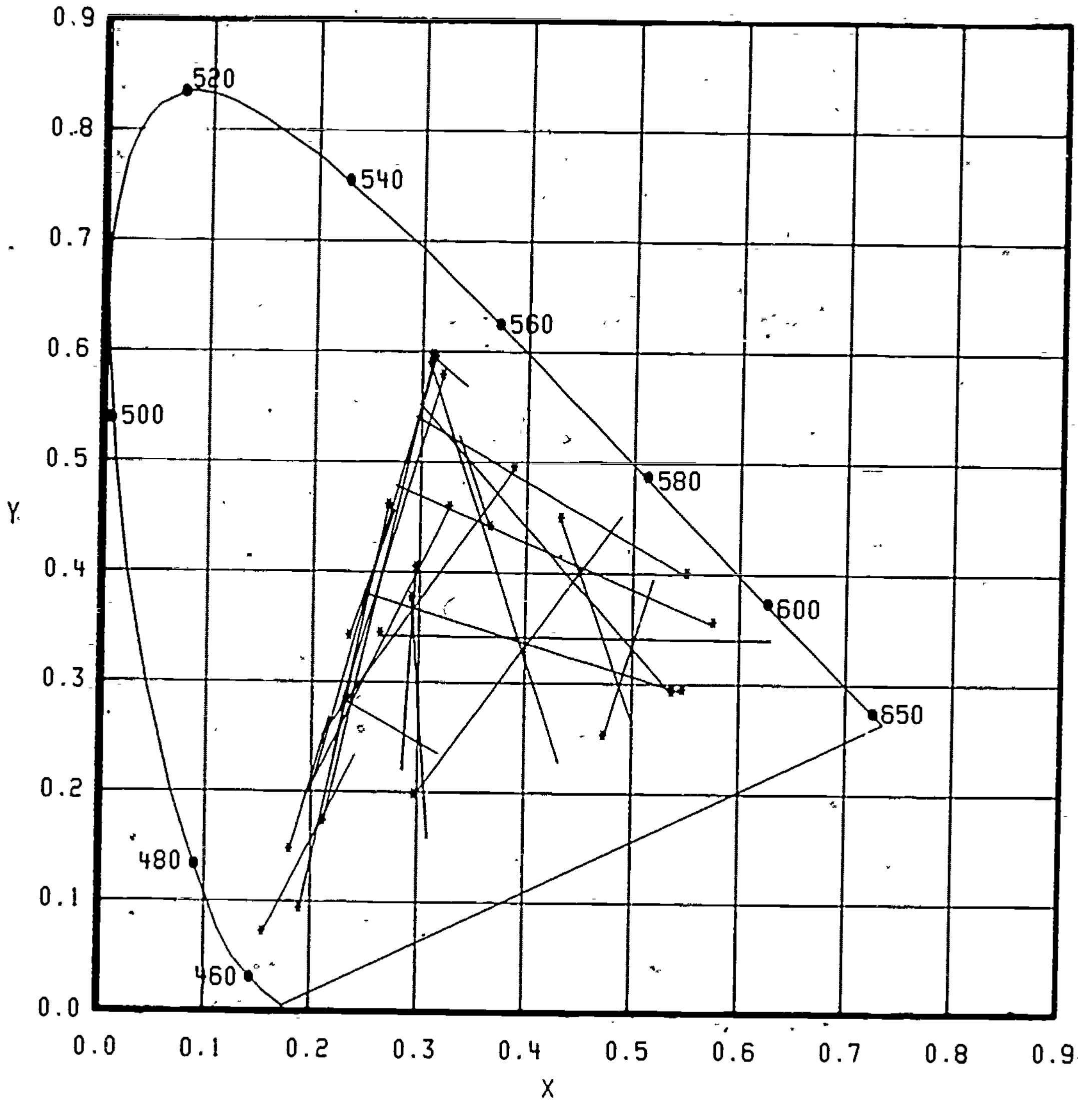

Fig. 12—Reading vectors plotted on 1931 CIE diagram, data set Bill: energy level two

An examination of Figs. 11 through 18 reveals that none of the vectors have one of their ends near the white region of the CIE diagram. This is not surprising when one considers how the experimental conditions were established. With white as one test pair hue, the chromaticity contrast that can be obtained is lower than that which might be obtained with pairs whose components are more saturated colors. Also, the luminance contrast is smaller with white and a hue than it is with black and white. However, it should be pointed out that the sample of 200 combinations of hues is very small compared with the more than 16.7 million that can be produced with two channels of the pseudocolor system, and hence, the sample, although chosen randomly, may not be large enough to reflect all the important features of

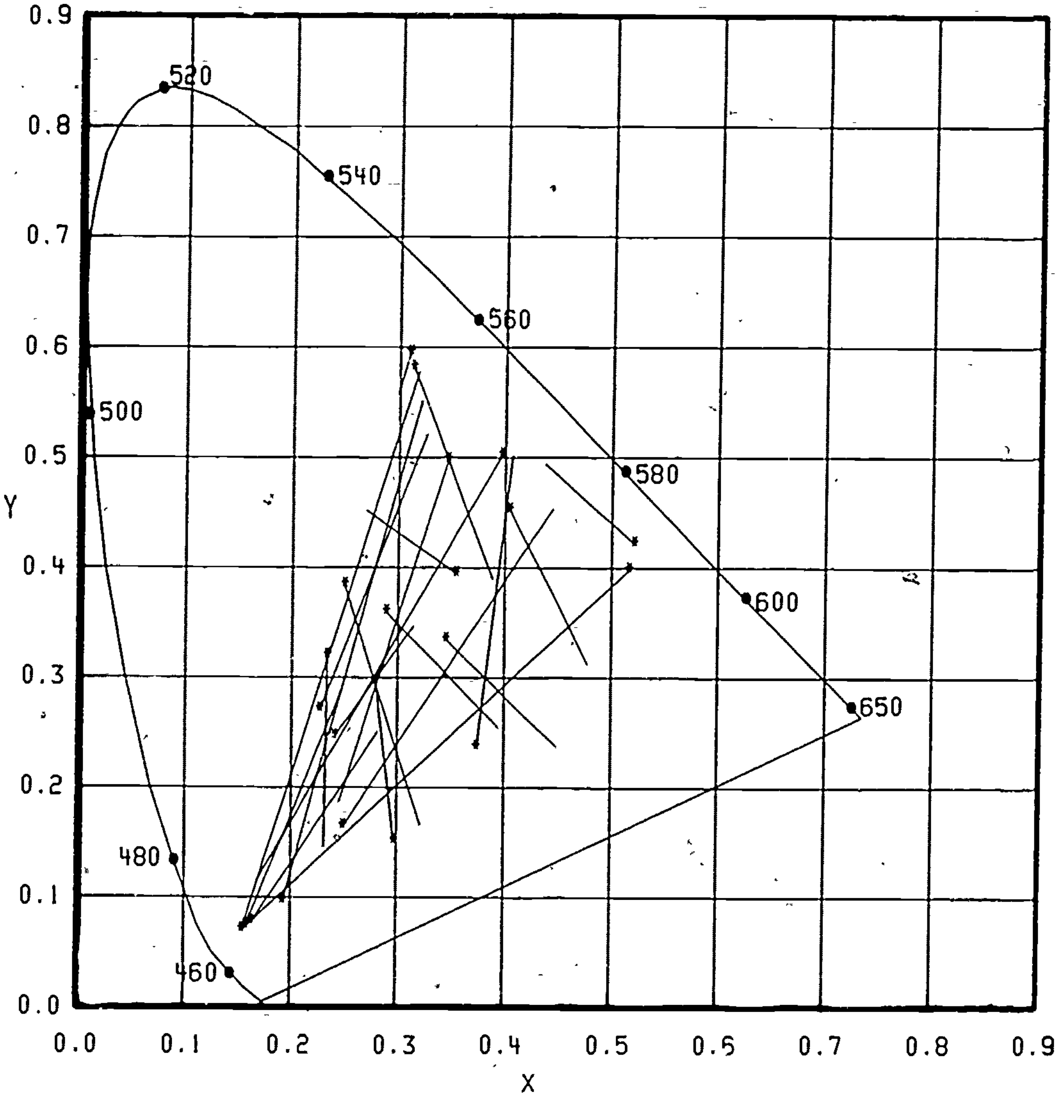

Fig. 13--Reading vectors plotted on 1931 CIE diagram, data set Bill. energy level three

the 16.7 million possibilities. For example, what would have happened if subjects Bill or Sam were confronted with (15,15,15) letters on a (2,0,1) background?

Nevertheless, even with our limited sample we can observe, for example, that for small absolute luminosity differences (level 1 differences) subject Sam tended to show a visual preference for red on blue and blue on red, while subject Bill showed a visual preference for blue on green and green on blue. For Sam the blue to red and red to blue vectors represent the lowest absolute luminosity differences at which he achieved a perfect score.

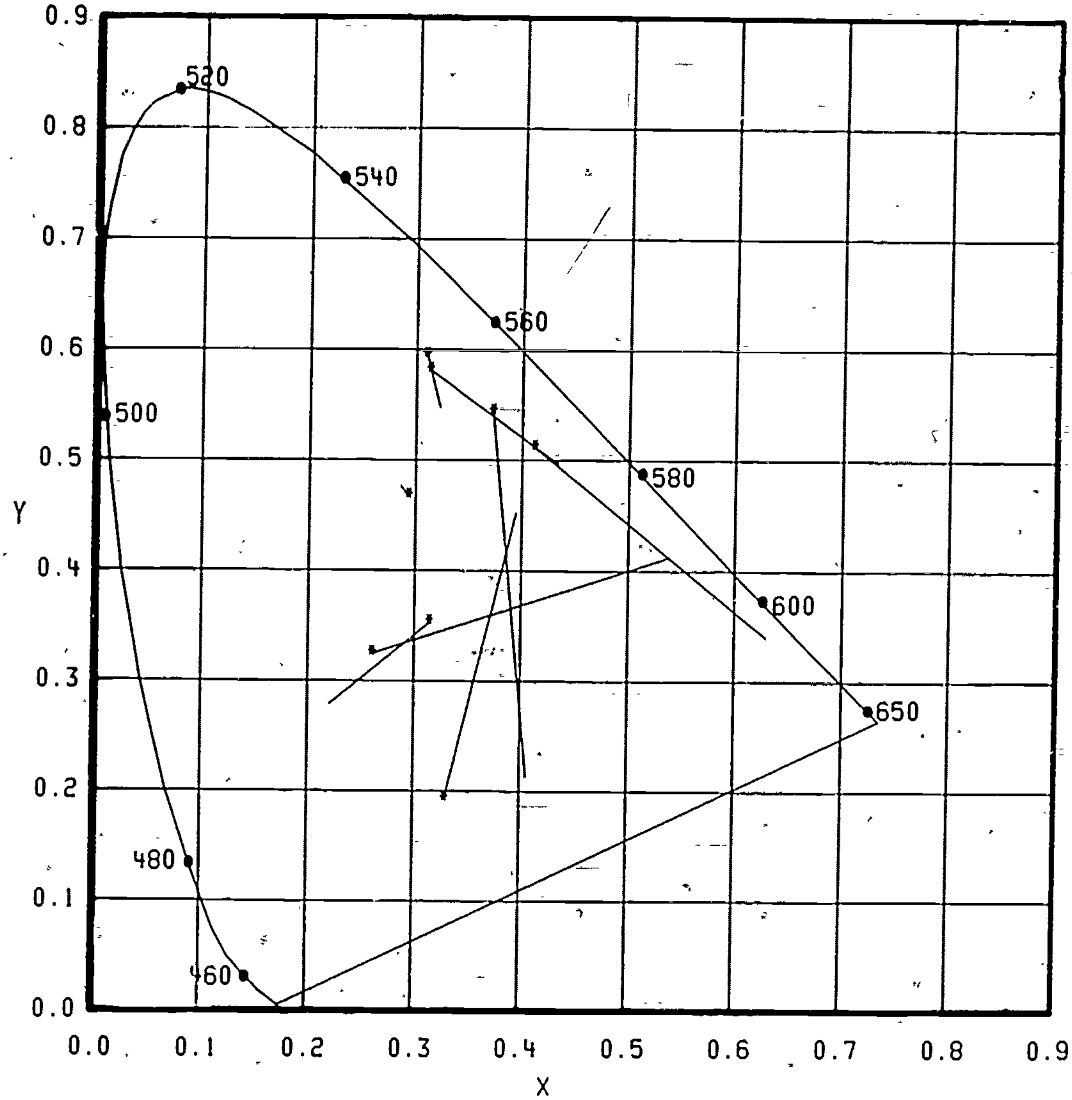

Fig. 11—Reading vectors plotted on 1931 CIE diagram, data set Bill. energy level four

AN AVENUE OF FUTURE RESEARCH

The computer program that we have prepared would permit us to compute the relative luminosity for each of the 4080 hues and 16 gray values that can be produced by the pseudocolor system. Further, the program, perhaps slightly modified, would permit us to list these hues and gray values in increasing or decreasing order with respect to their relative luminosities. From that list we could easily determine which combinations of hues and grays lie in various intervals of the range of available absolute or actual luminosity differences. Thus, for example, we could determine those combinations of hues and grays whose absolute luminosity difference is

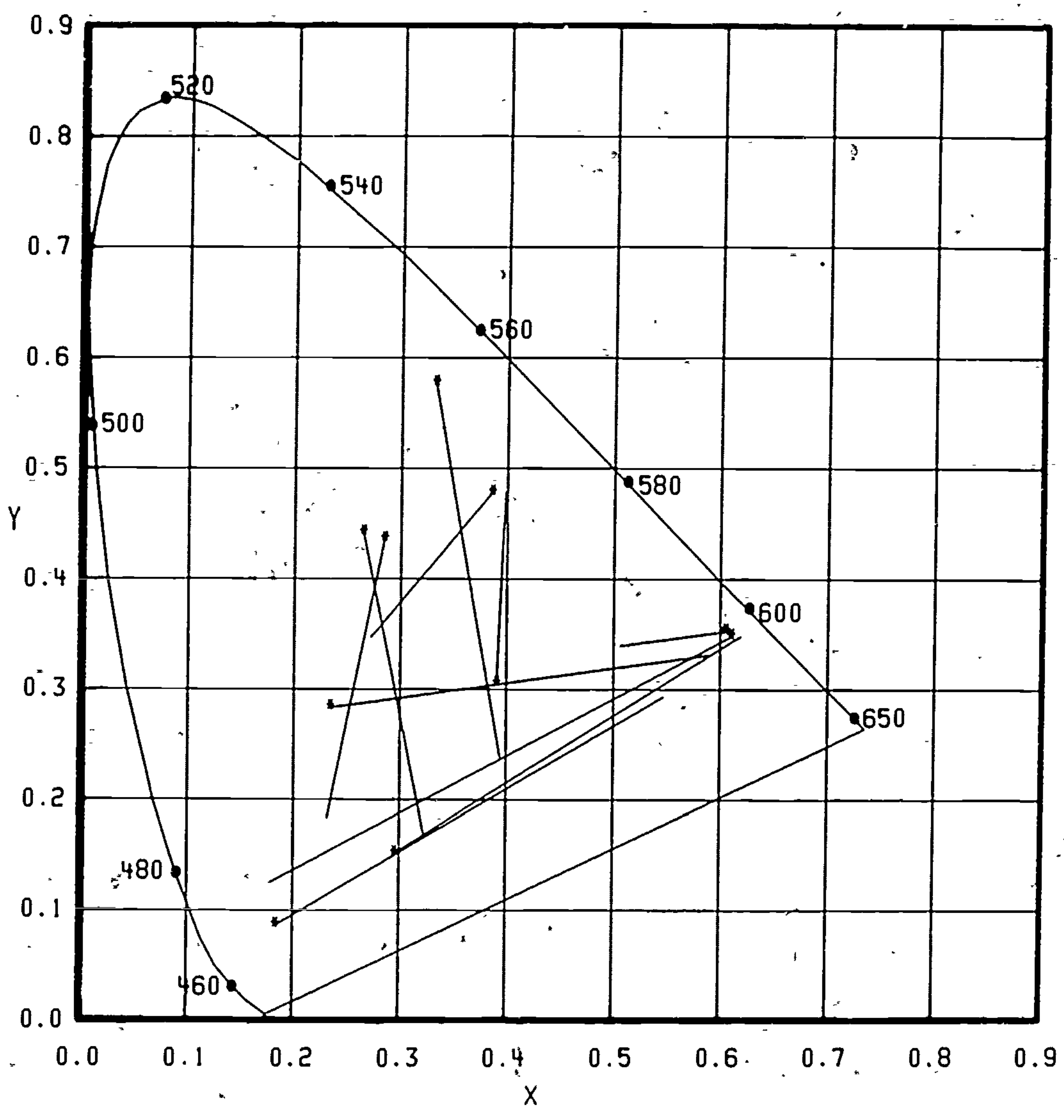

Fig. 15—Reading vectors plotted on 1931 CIE diagram, data set Sam. energy level one

less than some small number α and then carry out trials, similar to those described above, using these pairs of hues and grays as background and letter colors. Such an experiment would allow us to determine how well partially sighted participants can determine chromatic differences of hue and/or gray pairs whose components have nearly the same luminosities.[a] We would be interested in pursuing this and similar experiments aimed at learning more about color and the pathological but seeing eye.

[a] This experiment was suggested to us by Dr. James Bailey of the Southern California College of Optometry.

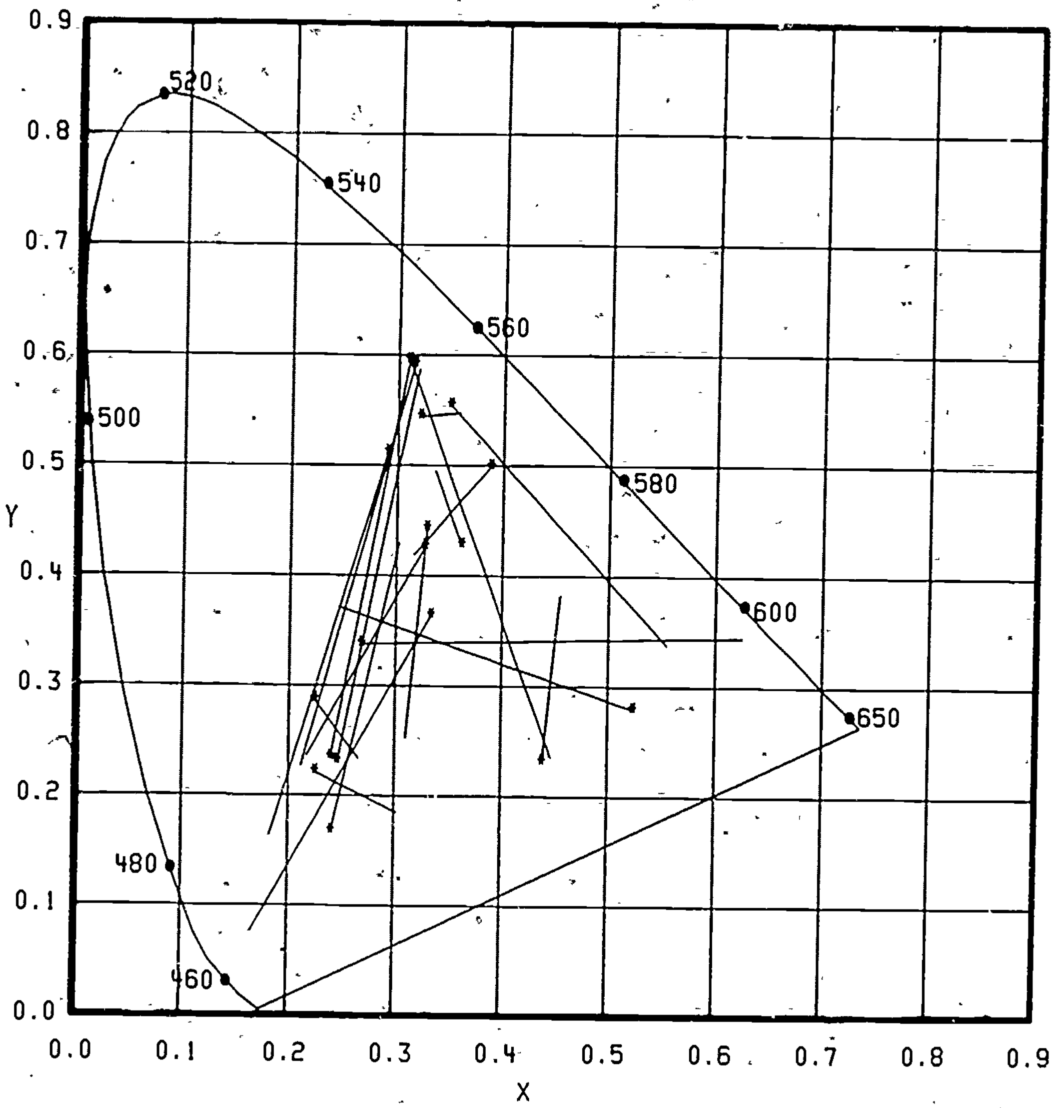

Fig. 16—Reading vectors plotted on 1931 CIE diagram, data set Sam: energy level two

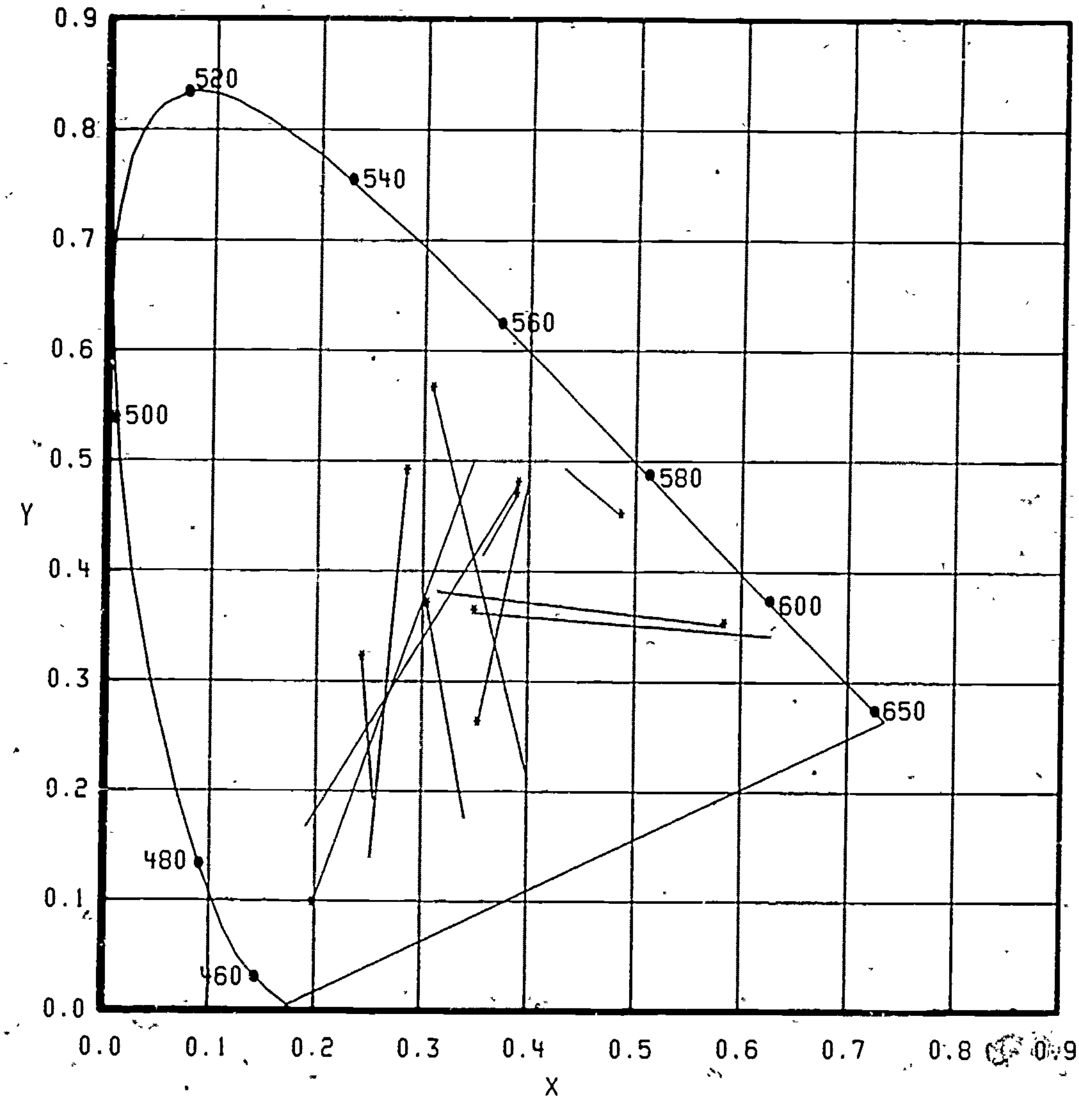

Fig. 17—Reading vectors plotted on 1931 CIE diagram, data set Sam. energy level three

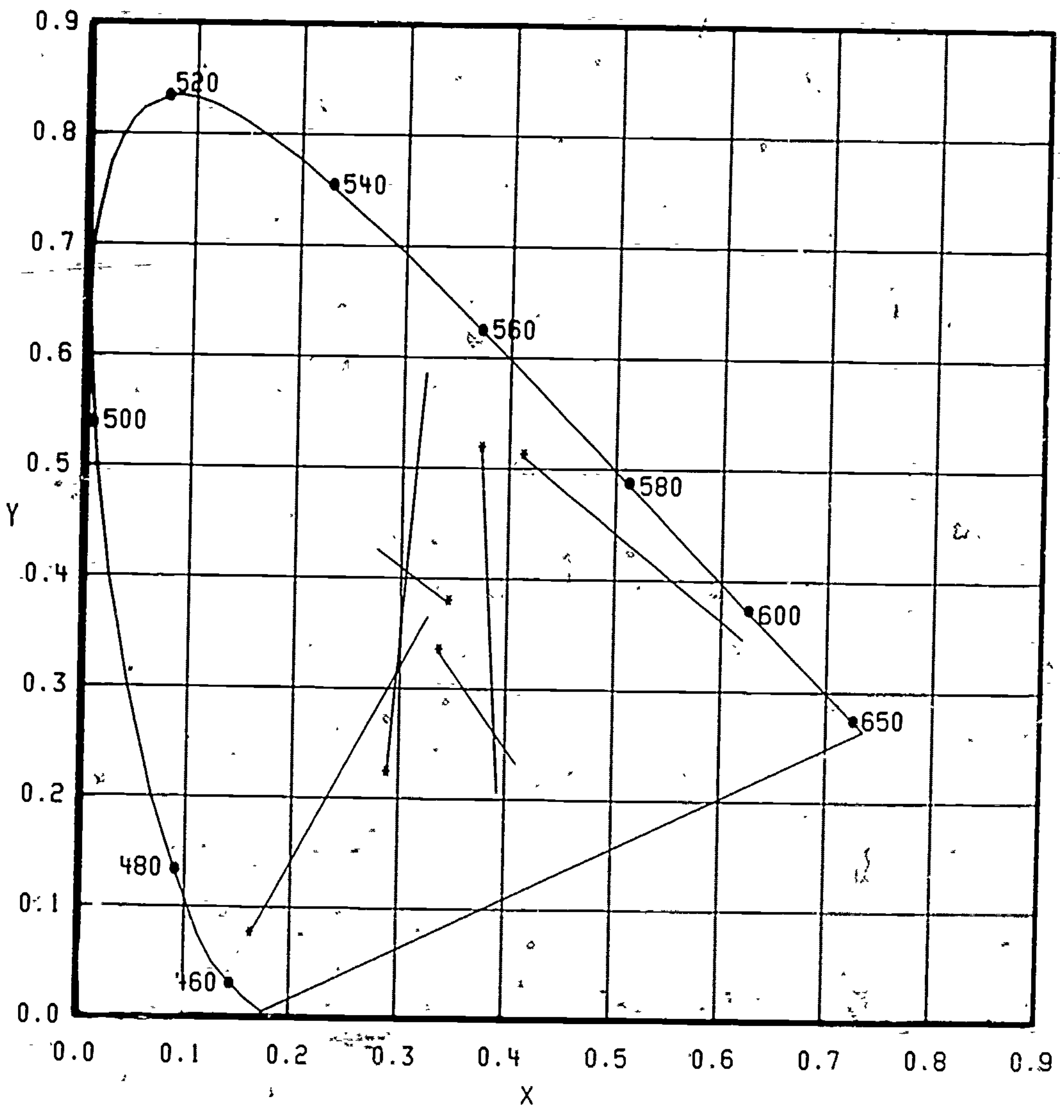

Fig. 18—Reading vectors plotted on 1931 CIE diagram, data set Sam: energy level four

IV. CCTV READING RATES OF PEOPLE WITH NORMAL SIGHT

At the suggestion of Dr. Edwin B. Mehr of Santa Clara, California, we decided to determine how well the normally sighted could read typewritten material when using a CCTV system, and when viewing at any instant on the TV monitor a string of alphanumeric symbols of a given length. We recognized that, unlike the case of the partially sighted, restrictions on the reading speeds of normally sighted people using a CCTV system would be due to factors other than those resulting from poor eyesight. In addition, we believed that the results of such an experiment would indicate how rapidly the normally sighted can read with a CCTV system as a function of the number of alphanumeric symbols that span a line on the system's monitor. We had thought that the speeds attainable by the normally sighted would represent a level of performance that the partially sighted could not be expected to exceed However, the experimental results indicate that this conjecture may not be valid.

SUBJECTS

Eight subjects were chosen who had a corrected visual acuity of 20/20 in each eye. They ranged in age from 20 to 35 years, and half were male and half female. None had a previous history of visual disorders, and seven had normal color vision; one subject had a mild red deficiency. They were also chosen so that none had any previous experience with the use of a closed circuit television visual aid nor with television-like computer terminals. They represented a wide range of employment—from secretary to scientist.

PROCEDURE

All subjects used the same closed circuit television system equipped with a 9-inch monitor and an X-Y Platform. Among the monitors we had available, the 9-inch monitor provided the best resolution when used at a magnification of one, where it displayed a full line of text from an 8½ by 11-inch page. The subjects were allowed to choose the most comfortable working distance, that is, the distance between their eyes and the monitor screen; to adjust the contrast and brightness; and to select whether positive or negative contrast would be used for each level of magnification. Further, practice was permitted before each trial, although not of course with the test material. The test material was selected from *Reader's Digest* graded readers. This provided a uniform level of reading difficulty. All test materials were typed double-space on separate pages in order to avoid focusing and other manipulative problems that arise from the use of bound materials with a CCTV system. Each of the subjects was asked to read an entire page of approximately 250 words during each test trial. A different page of material and a different magnification were used during each trial, and measurements were made with 3, 5, 7, 10, and

20 characters spanning the screen as well as with a full line of text occupying the width of the screen. Reading rates were recorded at one-minute intervals and at the end of each trial. In addition, we determined the normal reading rate without a CCTV system for each subject using similar reading materials.

RESULTS

The actual reading rates for each subject, when using the CCTV system, are plotted in Fig. 19 as a function of the number of characters visible on a single line in the center of the monitor screen. The corresponding linear magnifications as measured on the 9-inch monitor are also shown along the abscissa. Each line is identified by a subject number, and each subject's normal reading rate is plotted at the extreme right of the figure. As can be seen, there is a wide range of normal reading rates in the experimental population. It is interesting to note that all but one of the subjects read faster with television at magnification of one than he or she did without the instrument, and in one case as much as 20 percent faster. The average improvement was 5 percent.

All the subjects showed a similar decrease in reading rate with increasing magnification and fewer characters per line on the screen. For each subject and for each magnification, measurements were made that allowed the computation of the subject's reading rate at one minute intervals. These reading rates were roughly randomly distributed about the subject's average rate, and they did not vary from the average by more than 5 percent. This indicates that under these conditions the subjects did not appear to fatigue, nor did they show any short-term learning effects. In addition, it is interesting to note that a roughly two to one range of reading rates between subjects seems to apply at all magnifications. Subjects' reading rates ranged from 25 words per minute to slightly more than 50 words per minute, when three characters spanned the screen. This appears to indicate that, even with the correspondingly large magnification of about 20, one might expect a partially sighted user to be able to read at "useful" rates. One subject volunteered to read at a magnification that permitted just one character to appear on the screen at one time. She achieved a reading rate of about 25 words per minute though she did not read an entire page, because she experienced considerable visual distress.

Normalized reading rates were calculated as the percentage of each subject's normal reading rate, and are plotted in Fig. 20 as a function of the number of characters on the screen as in Fig. 19. From Fig. 20, the increase in reading rate over the normal rate using a CCTV at a magnification of one is very apparent. Although the variation in normalized rates seems very large for 20 characters per line, this is easily explained by the large range of the subjects' normal reading rates that were used for normalizing.

To compare the performance of the partially sighted with the normally sighted test group, the average reading rate for the eight subjects was plotted as a function of the number of characters across the screen. The reading rates for a number of partially sighted subjects who were reading with a CCTV system for the first time were plotted on the same graph.[1] In addition, reading rates for three relatively

[1] The reading rates for the partially sighted subjects were obtained from S. M. Genensky, H. L. Moshin, and H. E. Petersen, *Performance of Partially Sighted with RANDSIGHT I Equipped with an X-Y Platform*, The Rand Corporation, P-4943, January 1973, also published in *American Journal of Optometry and Archives of American Academy of Optometry*, Vol. 50, No. 10, October 1973, pp. 782-800.

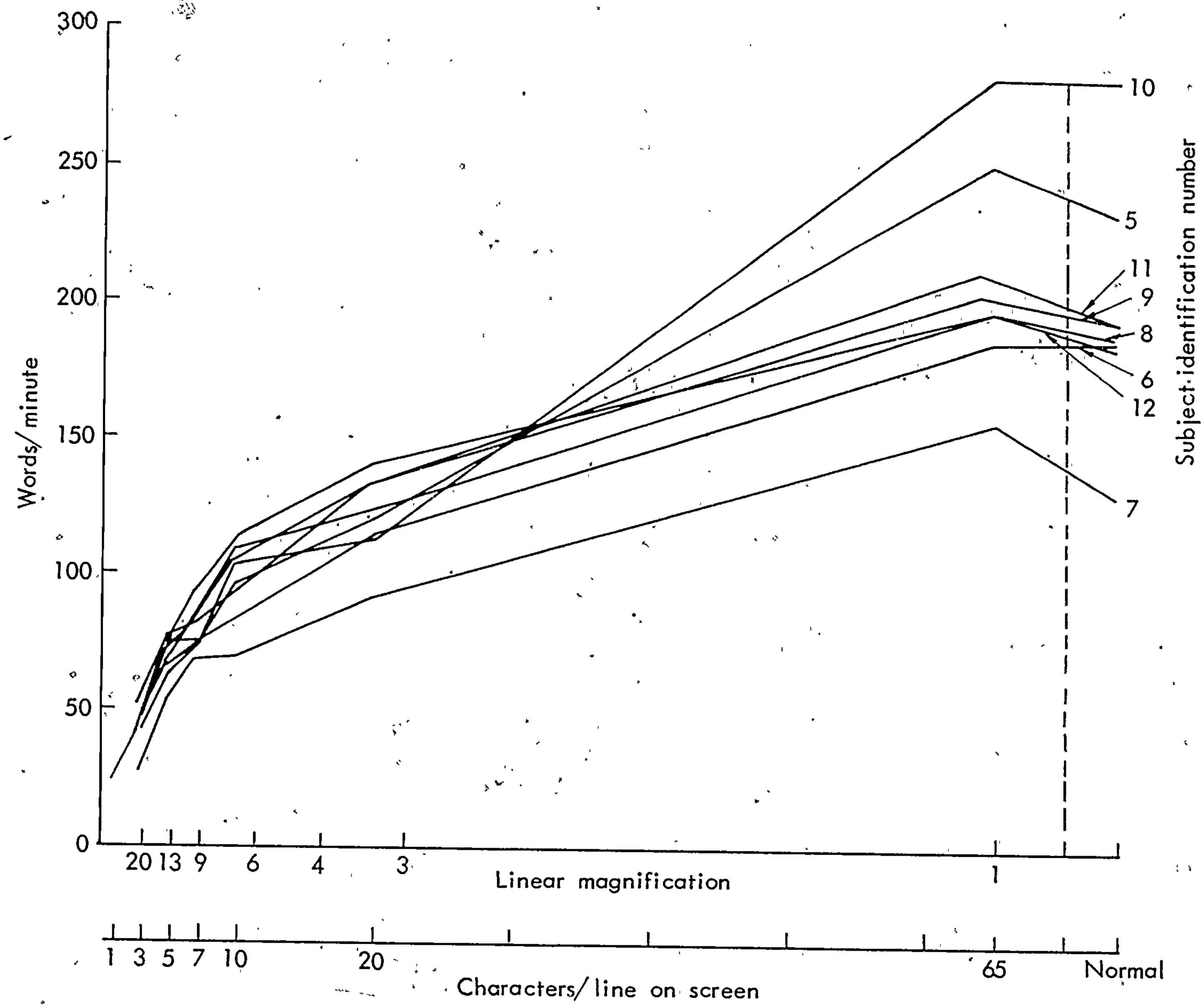

Fig. 19—Actual reading rates of normally sighted subjects using the CCTV

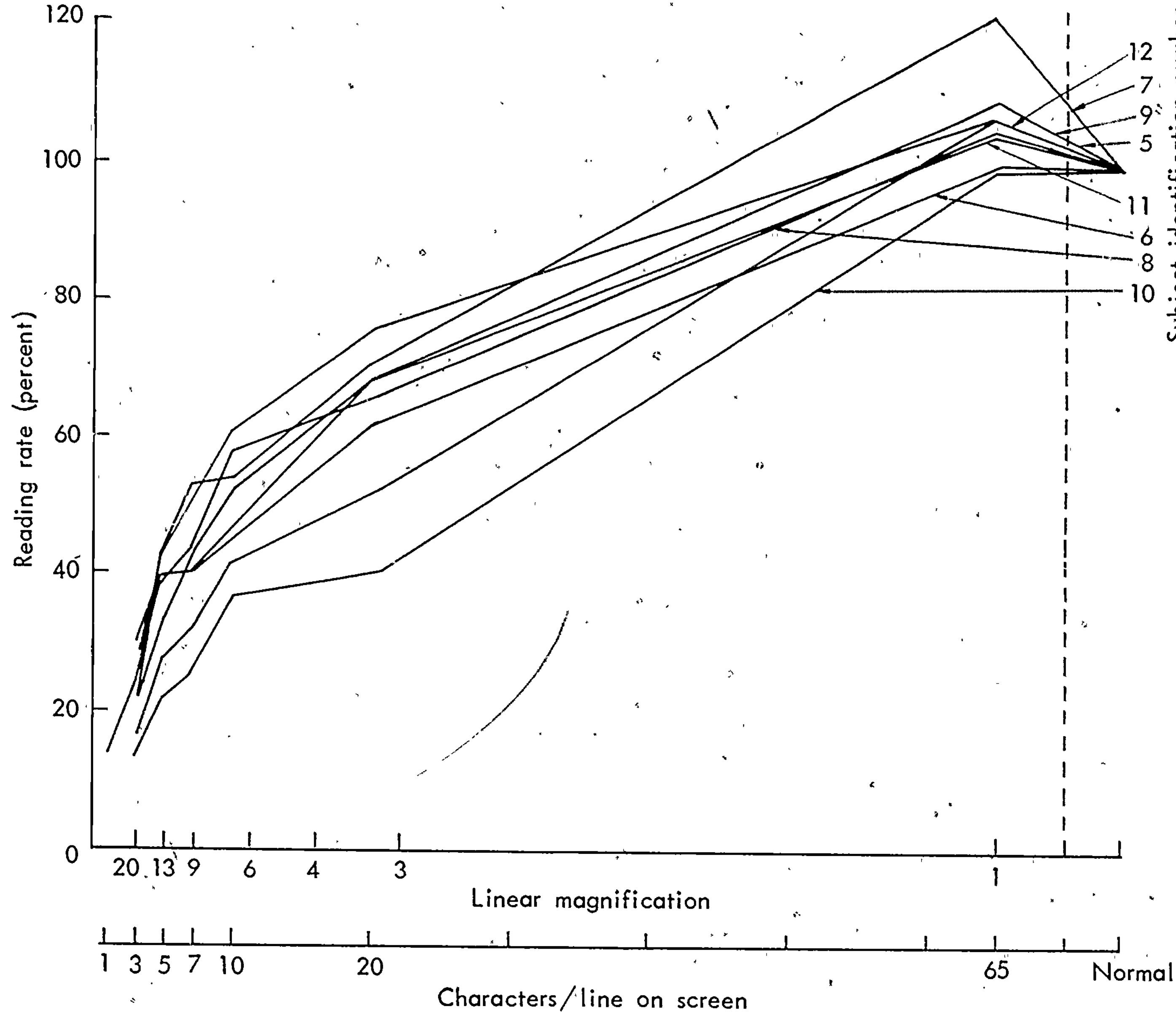

Fig. 20—Normalized reading rates of normally sighted subjects using the CCTV

experienced users were also plotted on the graph as indicated in Fig. 21. The results for the partially sighted population are about what would be expected except for the one very high rate of nearly 200 words per minute. Of the experienced partially sighted subjects, the highest rate shown is for the world's most experienced user, and as such probably indicates the limit of improvement that practice would permit for someone with his ocular pathology. This rate is also very near the maximum rate achieved by any of the normally sighted test group with the same number of characters on the screen. The other experienced users had about two or three months of intermittent use of their CCTV systems at the time their reading rates were measured.

IMPLICATIONS

The results of this experiment have some interesting implications. We have shown that reading rate decreases as the number of characters that can be seen on the monitor screen is reduced. Thus, the results clearly show that the number of characters displayed on a line across the monitor screen should match, as closely as possible, the number of characters that the user can see at one time without moving his head across the line. Since magnification is a function of the size of the monitor screen, for a given magnification, more characters of a given size can span the screen of a larger monitor than a smaller monitor. Although not all users may benefit from the use of larger monitors, due to focusing limitations or field restrictions arising from scotomas, many may benefit from any effort that makes the use of a larger monitor possible. As can be seen from the experimental data, this is especially important if the user's ocular pathology requires that he work with high magnifications.

Although no learning effects were observed during this experiment, it should not be inferred that no learning would have occurred among partially sighted users. Many of the partially sighted population whose reading rates are reported in Fig. 21 had not read anything in print for as long as several years before using the CCTV system, and hence if they had participated in this experiment, their reading ability would probably have shown considerable improvement over time.

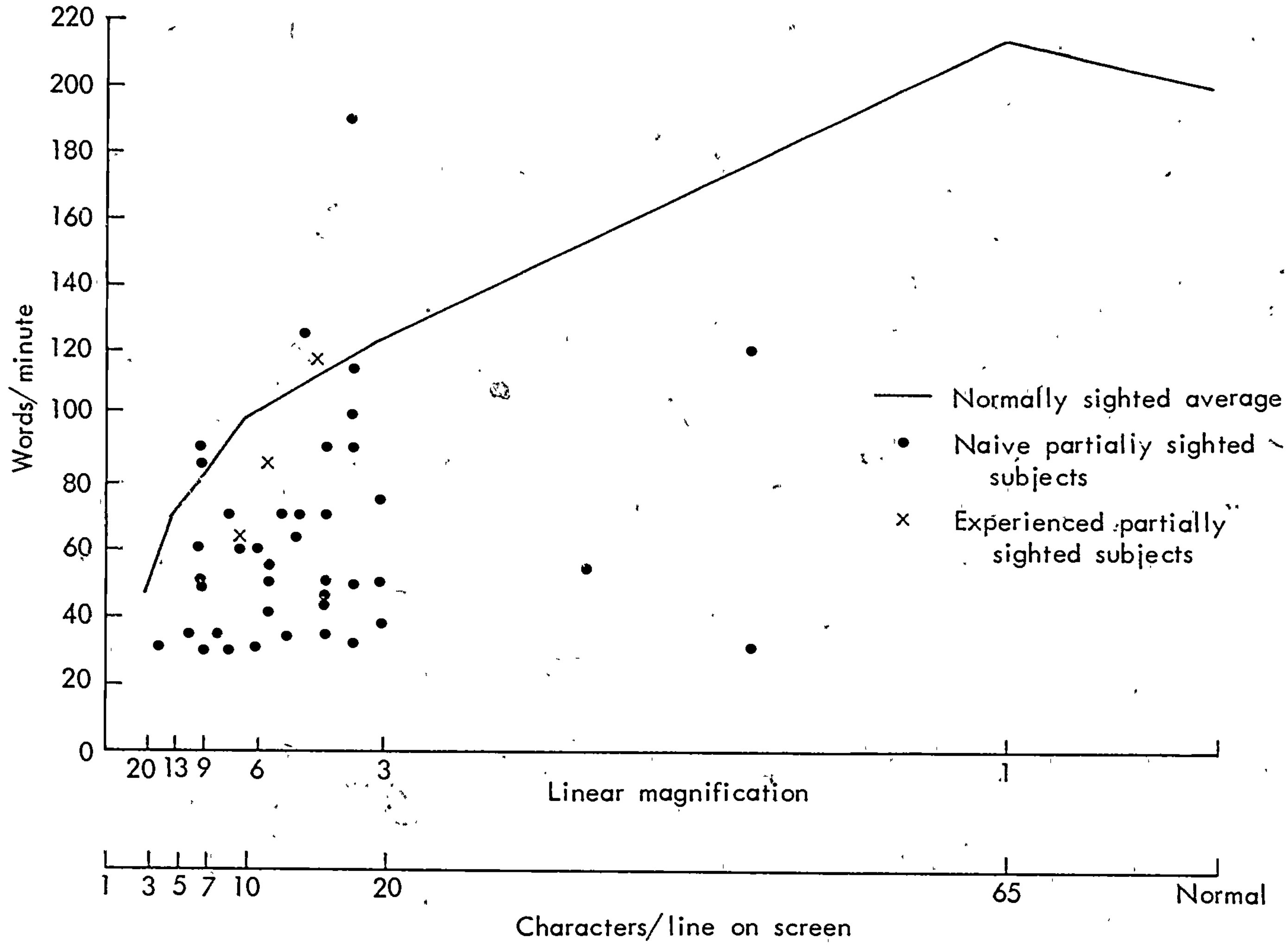

Fig. 21 — Actual reading rates of both normally sighted and partially sighted subjects using the CCTV

V. COLOR VISION TESTING

INTRODUCTION

All too often partially sighted subjects have come to our laboratory facilities and reported to us that they have been told by their ophthalmologist or optometrist that they have no color vision. These people tend to take such a pronouncement quite literally, even though the clinician who made the statement may not have meant that to be the case. In addition, in many of those cases where color vision testing has taken place, there is some reason to believe that the tests that were administered may not have been appropriate or that the conditions under which the tests were administered may not have been realistic. For example, the tests may have measured factors in addition to color such as the ability to discern a geometrical object embedded in a confused background, or the tests may have been given under lighting conditions that do not represent those that would normally prevail when the patient views objects with the same level of detail as that of the test materials.

In view of these facts, we decided to investigate the color vision of the partially sighted people who visited our laboratory. The color discrimination of these subjects was measured using four different color vision tests, two of which are regarded as standard methods for making such measurements and two represent departures from these standard techniques. The standard tests were the American Optical Handy-Rand-Rittler (AO H-R-R) Pseudoisochromatic Test and the Farnsworth Dichotomous Test for Color Blindness, Panel D-15. The tests that represent departures from the standard tests we call the Color Chip Transmission Test and the Modified Farnsworth D-15 Test.

AO H-R-R TEST

The test consists of a series of 24 color test plates that are used as

1. A simple screening test to separate subjects with defective color vision from those with normal color vision.
2. A qualitative diagnostic test to classify the type of defective color vision.
3. A quantitative diagnostic test to indicate the extent of the defective color vision.

The test is divided into four parts:

1. Four demonstration plates used to familiarize the subject with the test.
2. Six screening plates for the detection of defective red-green (protanopic or deuteranopic) or blue-yellow (tritanopic or tetratanopic) vision.
3. Ten diagnostic plates for the qualitative and quantitative analysis of red-green deficiencies.
4. Four diagnostic plates for the qualitative and quantitative analysis of the blue-yellow deficiencies.

Each test plate has a background pattern made up of small circular gray dots, varying both in size and brightness. The same background is used on each plate. All but one test plate contains colored dots that form simple geometric figures. The figures used are a circle, a cross, and a triangle. Since the subject is permitted to use his own name for these symbols, the test can be given without regard to the language used, provided the subject is consistent in naming the geometrical objects. A colored symbol may be located in any quadrant of the plate. These symbols do not cross or touch the background gray dots, and their gray values do not furnish any clues as to the shape of the symbol. Both the colored dots and gray dots vary in size and brightness. The hues of the symbols on the first three demonstration plates are readily visible to those with normal vision as well as those who have defective red-green or blue-yellow vision. The hues of the symbols on the screening plates were selected to separate subjects with normal vision from those with defective red-green or blue-yellow vision. The hues of the symbols on the diagnostic plates were critically selected to differentiate between the two types of defective red-green vision and the two types of defective blue-yellow vision. On the diagnostic plates, the hues of the symbols vary from plate to plate in a graded sequence of saturation (i.e., chroma or visual difference from gray). This permits the extent of a color defect to be determined.

Test Administration

The AO H-R-R Test, as well as the other color tests, was given in our RANDSIGHT laboratory where there is some control over the illumination. The room is shielded from outside light as well as from other sources of illumination that might have appreciably affected the results of the test.

The test plates were illuminated by a number of ceiling light fixtures, each housing daylight-type fluorescent tubes and covered by diffusers. This illumination was roughly equivalent to a CIE Standard Illuminant C.[1] The intensity of the illumination at desk level (i.e., on test plates) was between 100 and 150 footcandles.

The test was administered individually to each partially sighted subject. The subject was seated about 30 inches from the test plates, but was allowed to pick them up and move them as close to his eyes as he pleased. He was first shown the four demonstration plates. These indicated to him that there may be two, one, or no colored geometric symbols (0, X, Δ) on a plate, and that the symbols may appear in any of the four quadrants of the plate. The subject was told that the other plates might have similar designs in varying intensities of color and that only colored symbols were to be reported. He was then shown the remaining 20 plates, one at a time, and asked to name the color and/or the symbol(s) seen.

Observations

1. The testing procedure for the AO H-R-R Test states that the test is to be administered under illumination by a CIE Source C or a close approximation to such a source, and that the test plates be uniformly illuminated at an intensity of between 10 and 60 footcandles when held about 30 inches from the spectacle plane (eyes) and

[1] Source C is an approximate representation of average daylight and has a color temperature of about 6700 K

perpendicular to the visual axis of the subject's eyes. (Note that many partially sighted subjects cannot function under these conditions.)

2 Almost all the partially sighted subjects had to hold the test plates much closer to their eye(s) than 30 inches, and, as a consequence, their heads and other parts of their bodies tended to block out some of the light that was supposed to illuminate the test plates.

3. Subject response to the test plates did not improve even with illumination as great as 150 footcandles.

4. The subjects tended to tilt the test plates so that the light reflected from those plates was appreciably reduced.

5 The test does not measure color deficiencies alone, but rather the ability of a subject to detect colored geometrical objects that are embedded in a confused background. Although this may not cause any appreciable problem for the normally sighted, it plays havoc with many partially sighted people. We conjecture that it is one of the prime reasons that many of them fail to perform well with this test.

6 In this test and in all the other color tests, the examiner made sure that the subjects were not wearing any type of tinted glasses or contact lenses, as such lenses would have invalidated the test.

COLOR CHIP TRANSMISSION TEST

We searched the available color vision tests in order to find one that would allow us to rapidly screen the color discrimination of the partially sighted and demonstrate to those who had some color vision that they could see some colors even if they did not have perfect color vision. We were not able to find a ready-made test that fit our needs, and therefore members of the project staff decided to design and construct one of their own. The following criteria were used in designing the test:

1. It must be simple so that it can be administered rapidly and by nonprofessionals.
2. It must be rugged, portable, and inexpensive.
3. The test materials must be readily available from commercial sources.
4. The dye in the test materials must be relatively colorfast.
5. Spectrophotometric curves should be available or easily obtainable, and the quality control standards used in preparing the test materials must be available in print.
6. The illumination should be evenly distributed over the test area.

Test Description

The test we designed we call the Color Chip Transmission Test (CCTT). It consists of:

1. A mobile light source GE Model 11-FV-4-X-ray illuminator. The overall dimensions of this "light box" are approximately 14 inches wide, 20 inches high, and 7 inches deep. This plastic container houses two fluorescent tubes, and its front face is a piece of frosted glass about 16 inches wide by 18 inches high. A clip-type holder containing a micro-switch is located at the top and front of the plastic container.

When the test-holder (described below) is pushed into the clip, the light box is illuminated. and when it is removed, the illumination is turned off.

2. A test-holder—a piece of black, nonreflecting, thin art board (about 15 inches wide by 18 inches high) that completely covers the frosted glass. The test-holder has 12 holes, each one inch in diameter, arranged symmetrically and evenly spaced in 4 rows and 3 columns.

3. Color test targets—11 plexiglass transparent plastic color chips. Each chip is a 2-inch square, and each is taped to the back of the test-holder behind one of the 12 holes. The following 11 chips were selected for this test material (the names and numbers in parentheses are those of the manufacturer, Rohm & Haas): Amber (2422), Dark Blue (2424), Medium Blue (2069), Bronze (2370), Colorless (125), Gray (2064), Dark Green (2093), Medium Green (2404), Red (2423). and Yellow (2208).

One of the holes in the test-holder was not covered by a test target, because we wanted to use it to determine whether the color temperature of the illuminator was influencing the test results. Schematically, the array of colors seen by the subject has the following arrangement:

Blue	Green	Red
Blue, medium	Green, medium	Amber
Blank	Green, light	Yellow
Bronze	Colorless	Gray

4 Occluders—a series of black pieces of cardboard that cover one or more of the 12 holes in the test-holder. These allowed the examiner to choose selectively which color target(s) the observer viewed and/or how many he viewed at one time.

Test Administration

The CCTT test was administered individually to each partially sighted subject. The subject was seated before the color display and was allowed to move to any position in which he felt most comfortable. Depending on the subject's preference, the overhead room lights were left on or turned off. as this did not affect the color discrimination of the subject. The subject was asked to name the colors starting on the top line of the test-holder and going from left to right (the colors on the top line are the most highly saturated).

If the subject had trouble with any of the color targets, the occluders were used to determine whether his problem arose from the brightness of neighboring targets or from an inability to see the color of the target. Another technique used if the observer's responses were questionable was to rotate the test-holder 180 degrees and repeat the tests.

Unlike other color tests used in this research, the CCTT allowed the examiner to tell rapidly if the observer was having trouble seeing the test targets and to make changes in the testing technique that often corrected the difficulty. It was common for partially sighted subjects to complete this test in less than ten minutes.

Observations

1. In this test and in all other color tests the subjects were given encouragement and told how well they were doing. The emphasis was always on what colors they saw rather than on those they could not see.
2. If the subject had a color defect, an attempt was made to acquaint him with the colors that gave him difficulty.
3. The color targets could easily be removed for cleaning (or changing).
4. No attempt was made to match the color targets for equal brightness.
5. The target size was arbitrary.
6. All the exponents of this test are easily obtainable and relatively inexpensive
7. Although we used only one set of targets and one arrangement of targets for testing the partially sighted, it is simple and inexpensive to use other targets and to make many different types of test-holders (e.g., for elementary school children, a "look-alike" color test, a test of color targets of equal brightness, special tests for different color deficiencies, etc.).

THE STANDARD FARNSWORTH DICHOTOMOUS TEST FOR COLOR BLINDNESS, PANEL D-15

The Standard Farnsworth D-15 Test (also referred to here as the Std. D-15 Test) is designed to indicate severe color blindness clearly and quickly (i.e., to distinguish the functionally color blind from the moderately color defective and the normal). This test was chosen because it is easy to administer, gives reliable results, and is less dependent on the quality of illumination than many other tests of color vision.

There were three objections to its use:

1. The area of test color it presents to the partially sighted subject is too small.
2. The dye in the test material is very sensitive to the acid in a subject's hands.
3. The subject's head tended to obstruct the light falling on the test material.

Test Description

The Std. D-15 Test consists of 16 black Bakelite caps about ¾ inch in diameter. Each cap has a 7/16-inch circular depression in which a Munsell paper color fits. The 16 caps fit into a wooden rack about 2 inches wide, 11½ inches long, and 1¼ inches high. The rack is made of two hinged panels that are painted black on the inside. One of the panels serves as a test rack, and one color cap is fixed permanently at one end of the bottom of this panel, this fixed cap is called the "Reference Cap." The other 15 caps are numbered (on the bottom) 1 to 15, and when placed in the rack in proper order they form an incomplete color circle running from blue through blue-green, green, green-yellow, yellow, etc., up to purple. The numbers on the bottom of the caps form an increasing sequence from 1 to 15. Both the color (hue) and brightness (value) used in each cap have been carefully selected to make the test reasonably (but not unreasonably) difficult for the normally sighted subject.

The illumination on the color caps was the same as in the AO H-R-R Test, namely, between 100 and 150 footcandles.

Test Administration

The Std. D-15 Test was administered individually to each partially sighted subject. The subject was seated at a desk, covered by a black cloth, and the caps were removed from the rack, placed on the cloth with the color facing upward, and thoroughly mixed. The subject was told that he was not to turn the caps over at any time during the test. He was instructed to pick up the cap closest in color to the Reference Cap and place it in the rack next to that cap. He was then told to choose from the remaining 14 caps the one that was closest in color to the cap he had placed in the rack and to place the newly selected cap next to it. He repeated this process until he had placed all 15 caps in the rack. He could pick up the caps to compare them and/or rearrange them at any time during the test. He was advised not to touch the color paper in the caps and was told why this was important. The subject was also told that he was going to be timed and that he should inform the examiner when he was ready to start and when he had finished.

If the examiner saw that the partially sighted subject was not able to perform the test, he discontinued it, being careful not to jeopardize the subject's self-confidence.

After the subject finished the test, the examiner turned the caps over and, beginning with the cap next to the Reference Cap, he recorded the numbers on the bottom of the caps on a scoring sheet in the order in which they were arranged by the subject. He also recorded the time it took the subject to complete the test.

Observations

1. Normally sighted subjects usually complete this test in 60 seconds or less.
2. The color caps were all checked for equivalent brightness with the help of our pseudocolor system. This check showed that all 16 color caps were very close to having the same gray value and, hence, were of uniform brightness.
3. This test discriminates three types of anomalous color vision but does not measure the extent of deficiency. These three types are protan (commonly called red-blind), deutan (commonly called green-blind), and tritan (commonly called blue-blind).
4. This test and its modified form (described below) were the only tests where we recorded formal scoring and timing.

THE MODIFIED FARNSWORTH DICHOTOMOUS TEST FOR COLOR BLINDNESS, PANEL D-15

From our early observations of partially sighted subjects who were taking the Std. D-15 Test, we concluded that they might perform better, or at least with much less strain, if the color caps were larger and contained a larger circle of color. To test this conjecture, we made a set of 16 caps that have an outside diameter of 1⅞ inches and that contain a circle of color 1 inch in diameter. The colors used in these caps were the same as those used in the Std. D-15 Test. Since the Std. D-15 Test uses caps with a circle of color 7/16 inch in diameter, the Mod. D-15 Test provides the subject with circles of color that are more than five times as large in area as those provided by the Std. D-15 Test.

Test Description

Except for the increase in the size of the caps and the circle of color in these caps, the Mod. D-15 Test is not essentially different from the Std. D-15 Test.

Test Administration

The Mod. D-15 Test was administered in exactly the same way as the Std. D-15 Test. However, when both of these tests were administered (as was the case with most of the 19 subjects reported on below), the order in which the tests were administered to a subject was chosen by a random device (the flip of a coin).

RESULTS OF THE TESTS

Table 8 summarizes the test results obtained with the cooperation of 19 partially sighted subjects who were given the four color vision tests described above. Column 1 in the table contains the subject's identification code number. Column 2 contains the subject's major visual disorders; the following abbreviations are used in this column: ret. det. for retinal detachment, RP for retinitis pigmentosa, cong. cat for congenital cataracts, mac. deg. for macular degeneration, cat. surgery for cataract surgery, diab. retinopathy for diabetic retinopathy, RLF for retrolental fibroplasia, and path. myopia for pathological myopia. Column 3 contains the sex of the subject, col. 4 gives the age of the subject, and col. 5 indicates whether significant scotomas appeared to be obstructing portions of the subject's visual field. Columns 6 and 7 give, for the right and left eyes, respectively, the subject's distant visual acuity. Since we did not attempt to carry out a thorough refraction of the subject's vision, the acuities shown in these columns may not be the best distant visual acuities that the subject could achieve with the aid of spectacle lenses ground to his correct prescription.

Columns 8 through 13 give data concerning the subject's near visual acuity (VA). Column 8 gives the distance between the subject's right (OD) eye and the test reading card (the working distance WD) when he read the smallest print that he could on that card, and col. 9 gives the equivalent Snellen acuity of his right eye associated with that line on the test card. Columns 10 and 12 give data, similar to that given in col. 8, for the left eye (OS) and for both eyes (OU), respectively. Likewise, cols. 11 and 13 give similar data to that given in col. 9 for the left eye and both eyes, respectively. The symbols ϕ and LP used in cols. 6, 7, 9, 11, and 13 stand, respectively, for no vision at all and for light perception. Column 14 contains letters that identify the test card that was used in gathering the near vision data appearing to the left of the letter. L stands for the Lighthouse Near Acuity Test card, and R stands for the J. G. Rosenbaum Vision Screener card. The Lighthouse card calls for testing the subject with a 40-cm eye-to-card separation, and the Rosenbaum card

Table 8

Color Testing Data

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)
					Best Distance Acuity With or Without Rx		Near Acuity With or Without Rx							Std. D-15		Mod. D-15		Color Chip Transmission Test		
							OD		OS		OU									
Name Code	Visual Disorder	Sex	Age (yrs)	Scotomas	R	L	WD	VA	WD	VA	WD	VA	Test Chart	Results	Time (sec)	Results	Time (sec)	No Right	Colors Missed	AO H-R-R Test
1	Albino	M	26	No	20/200	20/100	4	20/70	8	20/30	—	—	R	Normal	72	Normal	40	12		—
2	Ret. det., glaucoma, RF	M	26	Yes	D	20/200	— —	D D	3½ 3½	20/30 20/40	— —	— —	R L	Tritan	320	Tritan Tritan	150 300	5	G, mG, 1G, mB, C, Gy, Bz	Could not do
3	Cong. cat.	M	36	Yes	20/200	20/160	—	—	3	20/20	—	—	R	Normal	45	Normal	29	10	1G, C	Normal
4	Cong. cat.	M	9	No	20/200	20/120	—	—	—	—	2	20/50	R	Normal	48	Normal	45	12		Normal
5	Mac. deg.	M	77	Yes	20/500	20/60	14	20/800	14	20/70	14	20/70	R	Marginal Marginal	90 90	Normal Normal	80 62	12 12		Could not do
6	Cat., scleromalacia perforans	F	63	Yes	LP	20/120	—	LP	2½	20/25	—	—	R	Inconclusive	105	Normal	90	12		—
7	Cong. cat., surgical complications	M	21	Yes	20/400	D	1½ 1½	20/100 20/80	— —	D D	— —	— —	R L	Marginal Normal Marginal Normal	65 90 82 90	Normal Normal Normal Normal	65 75 45 70	12		Could not do
8	Optic nerve atrophy	F	38	Yes	20/400	LP	4½	20/200	—	LP	4½	20/200	R	Deutan	155	Deutan	132	2	mB, G, mG, 1G, A, Y, Bk, C, Gy, Bz	Could not do
9	Cat. surgery, diab. retinopathy, glaucoma	M	50	Yes	20/800	20/80	—	—	7 7	20/70 20/80	— —	— —	R L	Normal	545	Normal	395	12		Could not do
10	RLF	F	20	Yes	20/400	20/800	4½ 2½	20/125 20/50	— 2½	— 20/100	2 2½	20/50 20/50	L R	Marginal	260	Normal	245	10	mG, 1G	Could not do
11	Optic nerve atrophy	M	48	Yes	20/700	20/600	— —	— —	1 1	20/30 20/25	1 1	20/30 20/25	R L	Deutan Deutan	90 30	Deutan Deutan	97 85	8	mB, mG, 1G, Bz	—
12	Path. myopia, ret. det.	F	18	Yes	20/30	20/300	2½	20/20	2½	20/60	—	—	R	Normal	75	Normal	50	12		Normal
13	RLF, cat., nystagmus	M	26	Yes	D	20/280	—	D	2	20/50	—	—	L	Normal	90	Normal	45	12		Normal
14	Cat., mac., deg.	M	59	Yes	20/160	20/200	— —	— —	— —	— —	12 13	20/400 20/400	R L	Deutan	60	Deutan Deutan	90 60	5	mB, G, mG, 1G, A, Gy, Bz	Could not do
15	Mac. deg.	M	82	Yes	20/700	20/240	—	—	—	—	6	20/125	R	Normal	248	Normal	97	9	G, 1G, mB	Could not do
16	Mac. deg.	M	79	Yes	20/120	D	7	20/80	—	D	—	—	L	Tritan	330	Tritan	180	4	B, mB, G, mG, 1G, A, Gy, Bz	Could not do
17	RLF, ret. det.	M	28	Yes	20/200	D	2 2	20/30 20/40	— —	D D	— —	— —	R L	Normal	220	Normal	235	12		Normal
18	Mac. deg.	F	84	Yes	20/400	20/200	—	—	—	—	12	20/200	L	Inconclusive	210	Marginal	230	8	G, mG, 1G, B	Could not do
19	Path. myopia	F	48	No	20/60	20/200	7	20/30	7	20/80	7	20/30	R	Normal	120	Normal	90	12		Normal

with a 14-inch separation. Since most partially sighted people do not normally read at these distances and thus would perform far below their capability, we permitted them to move the test cards as close to their eyes as was comfortable. In most cases, our subjects moved the cards closer to their eyes than was recommended for testing on the cards. Also, the distance between their eyes and the test cards tended to decrease dramatically as they progressed to smaller and smaller print.

Columns 15 and 16 give results obtained from the Standard Farnsworth D-15 Test. Column 15 gives the indicated state of the subject's color vision, and col. 16 gives the time in seconds that it took the subject to complete the test. Sometimes the test was repeated more than once, and the results for each trial are given in the table. The reader will recall that a deutan is one whose vision is deficient in the greens, and a tritan is one whose vision is deficient in the blues. The term "Marginal" indicates that the subject's color vision was normal but that the results appeared to be marginally normal. Columns 17 and 18 give results obtained from the Modified Farnsworth D-15 Test. The description of col. 17 is the same as that of col. 15, and the description of col. 18 is the same as that of col. 16.

Columns 19 and 20 contain results from the Color Chip Transmission Test. Column 19 indicates the number of test targets the subject identified correctly. Here 12 is a perfect score. Column 20 gives the test targets that the subject was not able to identify correctly. The following abbreviations were used: B for blue, G for green, mB for medium blue, mG for medium green, A for amber (orange), Bk for blank, lG for light green, Y for yellow, Bz for bronze (brown), C for colorless, and Gy for gray. It is interesting to note that all 19 subjects were able to recognize the red test target.

Column 21 contains the results from the American Optical Handy-Rand-Rittler Test. Here we indicate only whether the subject could not cope with the test or whether it indicated that he had normal vision. The experimenter found that none of the partially sighted who took this test and who by other tests appeared to have color deficiencies were able to cope with this test.

Only a few conclusions can be drawn from the results shown in Table 8. The average time for a total of 24 trials of the Std. D-15 Test was 149 seconds. The average time required for 26 trials of the Mod. D-15 Test was 119 seconds. In a clinical environment, the difference between 2 and 2.5 minutes to perform color screening may not be important enough to justify a change in procedure. However, the fact that in four cases the use of the Mod. D-15 Test allowed the examiner to make a definite decision rather than a marginal one is strong evidence in favor of the modified test and, if confirmed by further testing, may constitute sufficient evidence in favor of substituting the modified test for the standard test when testing partially sighted patients. The four cases referred to above are numbers 5, 6, 7, and 10.

There appears to be some correlation between the results from the Farnsworth tests and the transmission test in that for those subjects for whom a specific type of color deficiency was detected by the Farnsworth tests, at least the same color deficiencies were indicated by the results of the transparency test.

Appendix

CHROMATICITY ANALYSIS OF CONRAC MONITOR

by Roy H. Stratton

CONRAC COLOR TV MONITOR CHROMATICITIES

Given the following:

Red:	$x = .630,$	$y = .340,$
Green:	$x = .310,$	$y = .595,$
Blue:	$x = .155,$	$y = .070,$
White:	$x = .314,$	$y = .324$ (6500°K).[1]

Let R, G, and B be the relative amounts of the three primaries required to produce 6500°K white so that $R + G + B = 1.0000$. Then

$$.630R + .310G + .155B = .314,$$
$$.340R + .595G + .070B = .324,$$
$$R + G + B = 1.000.$$

Solving these three simultaneous equations yields

$$R = .2125,$$
$$G = .3745,$$
$$B = .4130.$$

Assume that we use the Weston meter whose spectral response is the same as the human eye. (This is not necessary for chromaticity determination but is necessary for relative luminosity determination.) Then by substitution of meter reading ratios in the above equation, the chromaticity becomes

$$x = \frac{.1339K_R + .1161K_G + .0640K_B}{.2125K_R + .3745K_G + .4130K_B},$$

$$y = \frac{.0723K_R + .2228K_G + .0289K_B}{.2125K_R + .3745K_G + .4130K_B}.$$

LUMINOSITY OF IMAGE

There is no way of calculating luminosities from chromaticities—we must either *know* the spectral energy distribution of the primaries or must *measure* the

[1] These data were supplied by The Conrac Corporation, Covina, California.

luminosity of the primaries with a meter whose response is the *same as the visual system.*

Let us assume the maximum luminosity of the 6500°K white point = 1.000 (with all knob settings at 15). Determine the normalization factor f such that

$$f = \frac{1}{M_{R_{15}} + M_{G_{15}} + M_{B_{15}}}$$

Then the luminosity L of any combination is

$$L = f(M_{R_n} + M_{G_n} + M_{B_n}).$$

Let M = meter readings for each of the three primaries at various knob positions with the other two primaries *completely off;* that is,

M_{R_7} = meter reading (footcandles) of the red primary at position 7.

Let R′, G′, and B′ be the amounts of primaries for a particular combination of knob settings.

Let K_R, K_B, and K_G be ratios of meter readings with any given primary at knob setting n (n = 0, 1, 2, . . ., 15) compared with knob setting 15 (maximum) or

$$K_i = \frac{M_{i_n}}{M_{i_{15}}}$$

where i = R, G, or B. Then

$$R' = RK_R = .2125K_R,$$
$$G' = GK_G = .3745K_G,$$
$$B' = BK_B = .4130K_B.$$

CHROMATICITY OF VARIOUS MIXTURES

$$.630R' + .310G' + .155B' = x(R' + G' + B'),$$
$$.340R' + .595G' + .070B' = y(R' + G' + B'),$$
$$x = \frac{.630R' + .310G' + .155B'}{R' + G' + B'},$$
$$y = \frac{.340R' + .595G' + .070B'}{R' + G' + B'}.$$